Module 07A
FOR B1 & B2 CERTIFICATION

MAINTENANCE PRACTICES

Aviation Maintenance Technician Certification Series

- Safety Precautions
- Workshop Practices
- Tools
- Avionic General Text Equipment
- Engineering Drawings, Diagrams and Standards
- Fits and Clearances
- Electrical Wiring Interconnection System (EWIS)
- Riveting
- Pipes and Hoses
- Springs
- Bearings
- Transmissions
- Control Cables
- Material Handling
- Welding, Brazing, Soldering and Bonding
- Aircraft Weight and Balance
- Aircraft Handling and Storage
- Disassembly, Inspection, Repair and Assembly Techniques
- Abnormal Events
- Maintenance Procedures

COMPLIANT WITH
EASA
European Aviation Safety Agency
EASA PART 66/147

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AIRCRAFT TECHNICAL BOOK COMPANY

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The publishers of this Aviation Maintenance Technician Certification Series welcome you to the world of aviation maintenance. As you move towards EASA certification, you are required to gain suitable knowledge and experience in your chosen area. Qualification on basic subjects for each aircraft maintenance license category or subcategory is accomplished in accordance with the following matrix. Where applicable, subjects are indicated by an "X" in the column below the license heading.

For other educational tools created to prepare candidates for licensure, contact Aircraft Technical Book Company.

We wish you good luck and success in your studies and in your aviation career!

EASA LICENSE CATEGORY CHART

Module number and title		A1 Airplane Turbine	B1.1 Airplane Turbine	B1.2 Airplane Piston	B1.3 Helicopter Turbine	B2 Avionics
1	Mathematics	X	X	X	X	X
2	Physics	X	X	X	X	X
3	Electrical Fundamentals	X	X	X	X	X
4	Electronic Fundamentals		X	X	X	X
5	Digital Techniques / Electronic Instrument Systems	X	X	X	X	X
6	Materials and Hardware	X	X	X	X	X
7A	Maintenance Practices	X	X	X	X	X
8	Basic Aerodynamics	X	X	X	X	X
9A	Human Factors	X	X	X	X	X
10	Aviation Legislation	X	X	X	X	X
11A	Turbine Aeroplane Aerodynamics, Structures and Systems	X	X			
11B	Piston Aeroplane Aerodynamics, Structures and Systems			X		
12	Helicopter Aerodynamics, Structures and Systems				X	
13	Aircraft Aerodynamics, Structures and Systems					X
14	Propulsion					X
15	Gas Turbine Engine	X	X		X	
16	Piston Engine			X		
17A	Propeller	X	X	X		

FORWARD

PART-66 and the Acceptable Means of Compliance (AMC) and Guidance Material (GM) of the European Aviation Safety Agency (EASA) Regulation (EC) No. 1321/2014, Appendix 1 to the Implementing Rules establishes the Basic Knowledge Requirements for those seeking an aircraft maintenance license. The information in this Module of the Aviation Maintenance Technical Certification Series published by the Aircraft Technical Book Company meets or exceeds the breadth and depth of knowledge subject matter referenced in Appendix 1 of the Implementing Rules. However, the order of the material presented is at the discretion of the editor in an effort to convey the required knowledge in the most sequential and comprehensible manner. Knowledge levels required for Category A1, B1, B2, and B3 aircraft maintenance licenses remain unchanged from those listed in Appendix 1 Basic Knowledge Requirements. Tables from Appendix 1 Basic Knowledge Requirements are reproduced at the beginning of each module in the series and again at the beginning of each Sub-Module.

How numbers are written in this book:
This book uses the International Civil Aviation Organization (ICAO) standard of writing numbers. This method displays large numbers by adding a space between each group of 3 digits. This is opposed to the American method which uses commas and the European method which uses periods. For example, the number one million is expressed as so:

ICAO Standard	1 000 000
European Standard	1.000.000
American Standard	1,000,000

SI Units:
The International System of Units (SI) developed and maintained by the General Conference of Weights and Measures (CGPM) shall be used as the standard system of units of measurement for all aspects of international civil aviation air and ground operations.

Prefixes:
The prefixes and symbols listed in the table below shall be used to form names and symbols of the decimal multiples and submultiples of International System of Units (SI) units.

MULTIPLICATION FACTOR		PREFIX	SYMBOL
1 000 000 000 000 000 000	$= 10^{18}$	exa	E
1 000 000 000 000 000	$= 10^{15}$	peta	P
1 000 000 000 000	$= 10^{12}$	tera	T
1 000 000 000	$= 10^{9}$	giga	G
1 000 000	$= 10^{6}$	mega	M
1 000	$= 10^{3}$	kilo	k
100	$= 10^{2}$	hecto	h
10	$= 10^{1}$	deca	da
0.1	$= 10^{-1}$	deci	d
0.01	$= 10^{-2}$	centi	c
0.001	$= 10^{-3}$	milli	m
0.000 001	$= 10^{-6}$	micro	μ
0.000 000 001	$= 10^{-9}$	nano	n
0.000 000 000 001	$= 10^{-12}$	pico	p
0.000 000 000 000 001	$= 10^{-15}$	femto	f
0.000 000 000 000 000 001	$= 10^{-18}$	atto	a

International System of Units (SI) Prefixes

PREFACE

This module includes an examination of many of the maintenance practices used by the EASA technician on a daily basis. In Module 06 - Hardware and Materials, an introduction to many of the materials and hardware used in aviation was given. Here in Module 07 - Maintenance Practices, rules, techniques and processes utilized when working with these materials and hardware are explained. Additionally, practices used for safe operation and handling of the entire aircraft during the performance of maintenance, operations and storage are also explained. Safety and quality workmanship are emphasized.

Module 07A Syllabus as outlined in PART-66, Appendix 1.

CERTIFICATION CATEGORY →	LEVELS B1	LEVELS B2
Sub-Module 01 - Safety Precautions - Aircraft and Workshop Aspects of safe working practices including precautions to take when working with electricity, gases (especially oxygen) oils and chemicals. Also, instruction in the remedial action to be taken in the event of a fire or another accident with one or more of these hazards including knowledge on extinguishing agents.	3	3
Sub-Module 02 - Workshop Practices Care of tools, control of tools, use of workshop materials; Dimensions, allowances and tolerances, standards of workmanship; Calibration of tools and equipment, calibration standards.	3	3
Sub-Module 03 - Tools Common hand tool types; Common power tool types; Operation and use of precision measuring tools; Lubrication equipment and methods. Operation, function and use of electrical general test equipment.	3	3
Sub-Module 04 - Avionic General Text Equipment Operation, function and use of avionic general test equipment.	2	3
Sub-Module 05 - Engineering Drawings, Diagrams and Standards Drawing types and diagrams, their symbols, dimensions, tolerances and projections; Identifying title block information; Microfilm, microfiche and computerized presentations; Specification 100 of the Air Transport Association (ATA) of America; Aeronautical and other applicable standards including ISO, AN, MS, NAS and MIL; Wiring diagrams and schematic diagrams.	2	2

CERTIFICATION CATEGORY →	LEVELS B1	B2
Sub-Module 06 - Fits and Clearances Drill sizes for bolt holes, classes of fits; Common system of fits and clearances; Schedule of fits and clearances for aircraft and engines; Limits for bow, twist and wear; Standard methods for checking shafts, bearings and other parts.	2	1
Sub-Module 07 - Electrical Wiring Interconnection System (EWIS) Continuity, insulation and bonding techniques and testing; Use of crimp tools: hand and hydraulic operated; Testing of crimp joints; Connector pin removal and insertion; Co-axial cables: testing and installation precautions; Identification of wire types, their inspection criteria and damage tolerance. Wiring protection techniques: Cable looming and loom support, cable clamps, protective sleeving techniques including heat shrink wrapping, shielding. EWIS installations, inspection, repair, maintenance and cleanliness standards.	3	3
Sub-Module 08 - Riveting Riveted joints, rivet spacing and pitch; Tools used for riveting and dimpling; Inspection of riveted joints.	2	-
Sub-Module 09 - Pipes and Hoses Bending and belling/flaring aircraft pipes; Inspection and testing of aircraft pipes and hoses; Installation and clamping of pipes.	2	-
Sub-Module 10 - Springs Inspection and testing of springs.	2	-
Sub-Module 11 - Bearings Testing, cleaning and inspection of bearings; Lubrication requirements of bearings; Defects in bearings and their causes.	2	-
Sub-Module 12 - Transmissions Inspection of gears, backlash; Inspection of belts and pulleys, chains and sprockets; Inspection of screw jacks, lever devices, push-pull rod systems.	2	-
Sub-Module 13 - Control Cables Swaging of end fittings; Inspection and testing of control cables; Bowden cables; aircraft flexible control systems.	2	-

CERTIFICATION CATEGORY →	LEVELS B1	B2
Sub-Module 14 - Material Handling		
Sub-Module 14.1- Sheet Metal		
Marking out and calculation of bend allowance; Sheet metal working, including bending and forming; Inspection of sheet metal work.	2	-
Sub-Module 14.2 - Composite and Non-metallic		
Bonding practices; Environmental conditions; Inspection methods.	2	-
Sub-Module 15 - Welding, Brazing, Soldering and Bonding		
(a) Soldering methods; inspection of soldered joints.	2	2
(b) Welding and brazing methods; Inspection of welded and brazed joints; Bonding methods and inspection of bonded joints.	2	-
Sub-Module 16 - Aircraft Weight and Balance		
(a) Centre of Gravity/Balance limits calculation: use of relevant documents;	2	2
(b) Preparation of aircraft for weighing; Aircraft weighing	2	-
Sub-Module 17 - Aircraft Handling and Storage		
Aircraft taxiing/towing and associated safety precautions; Aircraft jacking, chocking, securing and associated safety precautions; Aircraft storage methods; Refuelling/defuelling procedures; De-icing/anti-icing procedures; Electrical, hydraulic and pneumatic ground supplies. Effects of environmental conditions on aircraft handling and operation.	2	2
Sub-Module 18 - Disassembly, Inspection, Repair and Assembly Techniques		
(a) Types of defects and visual inspection techniques; Corrosion removal, assessment and reprotection;	3	3
(b) General repair methods, Structural Repair Manual; Ageing, fatigue and corrosion control programmes;	2	-
(c) Non destructive inspection techniques including, penetrant, radiographic, eddy current, ultrasonic and boroscope methods;	2	1
(d) Disassembly and re-assembly techniques;	2	2
(e) Trouble shooting techniques.	2	2

CERTIFICATION CATEGORY →	LEVELS B1	B2
Sub-Module 19 - Abnormal Events		
(a) Inspections following lightning strikes and HIRF penetration;	2	2
(b) Inspections following abnormal events such as heavy landings and flight through turbulence.	2	-
Sub-Module 20 - Maintenance Procedures Maintenance planning; Modification procedures; Stores procedures; Certification/release procedures; Interface with aircraft operation; Maintenance Inspection/Quality Control/Quality Assurance; Additional maintenance procedures; Control of life limited components.	2	2

REVISION LOG

VERSION	ISSUE DATE	DESCRIPTION OF CHANGE	MODIFICATION DATE
001	2016 01	Module Creation and Release	
002	2016 08	Module Revisions and Release	2016 09

MAINTENANCE PRACTICES

SUB-MODULE 01
SAFETY PRECAUTIONS - AIRCRAFT AND WORKSHOP

SUB-MODULE 02
WORKSHOP PRACTICES

SUB-MODULE 03
TOOLS

CONTENTS

SUB-MODULE 04
AVIONIC GENERAL TEXT EQUIPMENT

SUB-MODULE 05
ENGINEERING DRAWINGS, DIAGRAMS AND STANDARDS

CONTENTS

SUB-MODULE 06

FITS AND CLEARANCES

SUB-MODULE 07

ELECTRICAL WIRING INTERCONNECTION SYSTEM (EWIS)

SUB-MODULE 08
RIVETING

SUB-MODULE 09
PIPES AND HOSES

CONTENTS

SUB-MODULE 15
WELDING, BRAZING, SOLDERING AND BONDING

CONTENTS

SUB-MODULE 16
AIRCRAFT WEIGHT AND BALANCE

SUB-MODULE 17

AIRCRAFT HANDLING AND STORAGE

SUB-MODULE 18

DISASSEMBLY, INSPECTION, REPAIR, AND ASSEMBLY TECHNIQUES

CONTENTS

SUB-MODULE 19
ABNORMAL EVENTS

SUB-MODULE 20
MAINTENANCE PROCEDURES

SUB-MODULE 01

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 01 SAFETY PRECAUTIONS - AIRCRAFT AND WORKSHOP Knowledge Requirements		
7.1 - Safety Precautions - Aircraft and Workshop Aspects of safe working practices including precautions to take when working with electricity, gases (especially oxygen) oils and chemicals. Also, instruction in the remedial action to be taken in the event of a fire or another accident with one or more of these hazards including knowledge on extinguishing agents.	3	3

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

SAFETY PRECAUTIONS - AIRCRAFT AND WORKSHOP

Keeping hangars, shop, and the flight line orderly and clean is essential to safety and efficient maintenance. The highest standards of orderly work arrangements and cleanliness should be observed during the maintenance of aircraft. Safety lanes, pedestrian walkways, and fire lanes should be painted around the perimeter inside the hangars. This is a safety measure to prevent accidents and to keep pedestrian traffic out of work areas. Signs should be posted to indicate dangerous equipment or hazardous conditions. There should also be signs that provide the location of first aid and fire equipment.

Safety is everyone's business, and communication is key to ensuring everyone's safety. Technicians and supervisors should watch for their own safety and for the safety of others working around them. If other personnel are conducting their actions in an unsafe manner, communicate with them. Remind them of their safety and that of others around them.

Where continuous work shifts are established, the outgoing shift personal should remove and properly store personal tools and roll-a-way boxes. Work stands, maintenance stands, hoses, electrical cords, hoists, crates, and boxes that are still needed for the work to be accomplished may stay in the work area.

A face-to-face turnover of the progress made and the exact step in the procedure where the new technician must continue the operation should be mandatory. A review of the repair/maintenance documentation verifying all steps performed have been signed by the performing technician should also be done before or during turnover. This is of extreme importance because any work signed for is considered completely and satisfactorily accomplished by the incoming technician.

FLIGHT LINE SAFETY

HEARING PROTECTION

The flight line is a place of dangerous activity. Technicians who perform maintenance on the flight line must constantly be aware of what is going on around them. The noise on a flight line comes from many places. Aircraft are only one source of noise. There are auxiliary power units (APUs), fuel trucks, baggage handling equipment, and so forth. Each has its own frequency of sound. Combined all together, noises on the ramp or flight line can cause hearing loss.

There are many types of hearing protection available. Hearing protection can be external or internal. The external protection is the earmuff/headphone type. The internal type fit into the auditory canal. Both types will reduce the sound level reaching the eardrum and reduce the chances of hearing loss. Hearing protection should also be used when working with pneumatic drills, rivet guns, or other loud or noisy tools or machinery. Because of their high frequency, even short duration exposure to these sounds can cause a hearing loss. Continued exposure will cause permanent hearing loss.

FOREIGN OBJECT DAMAGE (FOD)

FOD is any damage caused by any loose object to aircraft, personnel, or equipment. These loose objects can be anything from broken runway concrete to shop towels to safety wire.

To control FOD, keep ramp and operation areas clean, have a tool control program, and provide convenient receptacles for trash, used hardware, shop towels, and other consumables.

The modern gas turbine engine will create a low pressure area in front of the engine that will cause any loose object to be drawn into the engine. The exhaust of these engines can propel loose objects great distances with enough force to damage anything that is hit. The importance of an FOD program cannot be overstressed when a technician considers the cost of engines, components, or the cost of a human life. Never leave tools or other items around the intake of a turbine engine.

SAFETY AROUND AIRPLANES

As with the previously mentioned items, it is important to be aware of propellers. Do not assume the pilot of a taxiing aircraft can see you. Technicians must stay where the pilot can see them while on the ramp area. Turbine engine intakes and exhaust can also be very hazardous areas. There should be no smoking or open flames anywhere near an aircraft in operation. Be aware of aircraft fluids that can be detrimental to skin. When operating support equipment around aircraft, be sure to allow space between it and the aircraft and secure it so it cannot roll into the aircraft. All items in the area of operating aircraft must be stowed properly.

SAFETY AROUND HELICOPTERS

Every type of helicopter has its own differences. These differences must be learned to avoid damage to the helicopter or injury to the technician. When approaching a helicopter while the blades are turning, observe the rotor head and blades to see if they are level. This will allow maximum clearance as you approach the helicopter. Observe the following:

- Approach the helicopter in view of the pilot.
- Never approach a helicopter carrying anything with a vertical height that blades could hit. This could cause blade damage and personal injury.
- Never approach a single masterhead helicopter from the rear. The tail rotor is invisible when operating.
- Never go from one side of the helicopter to the other by going around the tail. Always go around the nose of the helicopter.

When securing the rotor on helicopters with elastometric bearings, check the maintenance manual for the proper method. Using the wrong method could damage the bearings.

SAFETY PRECAUTIONS

ELECTRICAL

Working with electrical equipment poses certain physiological safety hazards. It is known that when electricity is applied to the human body, it can create severe burns in the area of entrance and at the point of exit from the body. In addition, the nervous system is affected and can be damaged or destroyed.

To safely deal with electricity, the technician must have a working knowledge of the principles of electricity, and a healthy respect for its capability to do both work and damage. Wear or use proper safety equipment to provide psychological assurance and physically protect one self. The use of rubber gloves, safety glasses, rubber or grounded safety mats, and other safety equipment contributes to the physiological safety of the technician working on or with electrical equipment.

Two factors that affect safety when dealing with electricity are fear and overconfidence. These two factors are major causes of accidents involving electricity. While both a certain amount of respect for electrical equipment is healthy and a certain level of confidence is necessary, extremes of either can be deadly.

Lack of respect is often due to lack of knowledge. Personnel who attempt to work with electrical equipment and have no knowledge of the principles of electricity lack the skills to deal with electrical equipment safely.

Overconfidence leads to risk taking. The technician who does not respect the capabilities of electricity can, sooner or later, become a victim of electricity's awesome power.

FIRE SAFETY

Any time current flows, whether during generation or transmission, a byproduct of that flow is heat. The greater the current flow, the greater the amount of heat created. When this heat becomes too great, protective coatings on wiring and other electrical devices can melt, causing shorting, which leads to more current flow and greater heat. This heat can become so great that metals can melt, liquids can vaporize, and flammable substances can ignite.

An important factor in preventing electrical fires is to keep the area around electrical work or electrical equipment clean, uncluttered, and free of all unnecessary flammable substances. Ensure that all power cords, wires, and lines are free of kinks and bends which can damage the wire. Never place wires or cords where they will be walked on or run over by other equipment. When several wires inside a power cord are broken, the current passing through the remaining wires increases. This generates more heat than the insulation coatings on the wire are designed to withstand and can lead to a fire. Closely monitor the condition of electrical equipment. Repair or replace damaged equipment before further use.

SAFETY AROUND COMPRESSED GASES

Compressed air, like electricity, is an excellent tool as long as it is under control. A typical nitrogen bottle set is shown in ***Figure 1-1.***

The following "do's and don'ts" apply when working with or around compressed gases:

- Inspect air hoses frequently for breaks and worn spots. Unsafe hoses should be replaced immediately.
- Keep all connections in a "no-leak condition."
- Maintain in-line oilers in operating condition, if installed.
- The system should have water sumps installed and should be drained at regular intervals.
- Air used for paint spraying should be filtered to remove oil and water.
- Never use compressed air to clean hands or clothing. Pressure can force debris into the flesh leading to infection.
- Never spray compressed air in the area of other personnel.
- Air hoses should be straightened, coiled, and properly stored when not in use.

Many accidents involving compressed gases occur during aircraft tire mounting. To prevent possible personal injury, use tire dollies and other appropriate lifting and mounting devices in mounting or removing heavy aircraft tires.

Figure 1-1. A typical nitrogen bottle.

When inflating tires on any type of aircraft wheels, always use tire cage guards. Because of possible personal injury, extreme caution is required to avoid over-inflation of high pressure tires. Use pressure regulators on high pressure air bottles to eliminate the possibility of over-inflation of tires. Tire cages need not be used when adjusting pressure in tires installed on aircraft.

OXYGEN SAFETY CONSIDERATIONS

Precautions must be observed when working with or around pure oxygen. It readily combines with other substances, some in a violent and explosive manner. It is extremely important to keep some distance between pure oxygen and petroleum products. When allowed to combine, an explosion can result. Additionally, there are a variety of inspection and maintenance practices that should be followed to ensure safety when working with oxygen and oxygen systems. Care should be used and, as much as possible, maintenance should be done outside.

When working on an oxygen system, it is essential that the warnings and precautions given in the aircraft maintenance manual be carefully observed. Before any work is attempted, an adequate fire extinguisher should be on hand. Cordon off the area and post "NO SMOKING" placards. Ensure that all tools and servicing equipment are clean and avoid power on checks and use of the aircraft electrical system.

When working around oxygen and oxygen systems, cleanliness enhances safety. Clean, grease-free hands, clothes, and tools are essential. A good practice is to use only tools dedicated for work on oxygen systems. There should be absolutely no smoking or open flames within a minimum of 50 feet of the work area. Always use protective caps and plugs when working with oxygen cylinders, system components, or plumbing. Do not use any kind of adhesive tape. Oxygen cylinders should be stored in a designated, cool, ventilated area in the hangar away from petroleum products or heat sources.

Oxygen system maintenance should not be accomplished until the valve on the oxygen supply cylinder is closed and pressure is released from the system. Fittings should be unscrewed slowly to allow any residual pressure to dissipate. All oxygen lines should be marked and should have at least 2 inches of clearance from moving parts, electrical wiring, and all fluid lines. Adequate clearance must also be provided from hot ducts and other sources that might heat the oxygen. A pressure and leak check must be performed each time the system is opened for maintenance. Do not use any lubricants, sealers, cleaners, etc., unless specifically approved for oxygen system use.

SAFETY AROUND HAZARDOUS MATERIALS

A material safety data sheet (MSDS or SDS) is a required document that contains information for the safe handling, use, storage and disposal of potentially hazardous chemicals. Manufacturers and distributors of these substances must supply users with a safety data sheet for each different chemical purchased. Employers are required to make this information available to their employees. Previously, each country's regulating agency had some type of similar required documentation and procedures for disseminating information on chemical substances. The United Nations created a Globally Harmonized System of Classification and Labeling of Chemicals (GHS) which was adopted by the European Union in EC 1272/2008. This standardizes worldwide the required documents that are to accompany and be kept on file for all potentially hazardous chemicals. The goal is to ensure the safety of all personnel that are involved in manufacturing, distributing, transporting and using these materials in their day-to-day operations by providing standardized information.

The GHS safety data sheet is a 16 section document that includes the following information:

1. Identification
2. Hazard(s) identification
3. Composition/ information on ingredients
4. First-aid measures
5. Fire-fighting measures
6. Accidental Release Measures
7. Handling and storage
8. Exposure control/personal protection
9. Physical and chemical properties
10. Stability and reactivity
11. Toxicological information
12. Ecological information
13. Disposal considerations
14. Transport information
15. Regulatory information
16. Other information.

The GHS safety data sheets are accompanied by standard labeling pictograms or symbols which categorize substances and can be easily seen by a transporter or user of a particular substance. There are pictograms for physical hazards, health hazards and environmental hazards as well as transportation class identification pictograms. Examples of various pictograms are shown in ***Figure 1-2***.

Many older national chemical safety organization SDS's may contain the pictogram label known as the risk diamond. This has been a staple of the Material Safety Data Sheet system utilized in the United States. It is a four color segmented diamond that represents Flammability (Red), Reactivity (Yellow), Health (Blue), and special Hazard (White). In the Flammability, Reactivity, and Health blocks, there should be a number from 0 to 4. Zero represents little or no hazard to the user; 4 means that the material is very hazardous. The special hazard segment contains a word or abbreviation to represent the special hazard. Some examples are: RAD for radiation, ALK for alkali materials, ACID for acidic materials, and CARC for carcinogenic materials. The letter W with a line through it stands for high reactivity to water. (***Figure 1-3***)

FIRE SAFETY

Performing maintenance on aircraft and their components requires the use of electrical tools which can produce sparks, along with heat-producing tools and equipment, flammable and explosive liquids, and gases. As a result, a high potential exists for fire to occur.

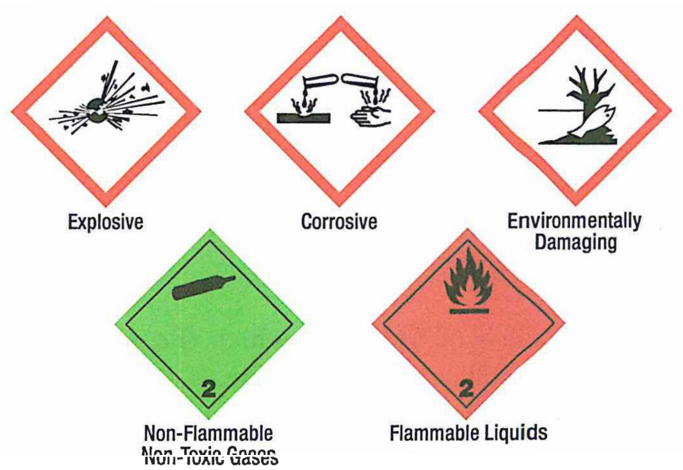


Figure 1-2. Examples of Globally Harmonized System of Classification and Labeling of Chemicals (GHS) pictograms.

Figure 1-3. A risk diamond.

Measures must be taken to prevent a fire from occurring and to also have a plan for extinguishing it. The key to fire safety is knowledge of what causes fire, how to prevent it, and how to put it out. This knowledge must be instilled in each technician and emphasized by their supervisors through sound safety programs, and occasionally practiced. Airport or other local fire departments can normally be called upon to assist in training personnel and helping to establish fire safety programs for the hangar, shops, and flight line.

FIRE PROTECTION

REQUIREMENTS FOR FIRE TO OCCUR

Three things are required for a fire:

1. Fuel — something that will, in the presence of heat, combine with oxygen, thereby releasing more heat and as a result reduces itself to other chemical compounds;
2. Heat — accelerates the combining of oxygen with fuel, in turn releasing more heat; and
3. Oxygen — the element which combines chemically with another substance through the process of oxidation. Rapid oxidation, accompanied by a noticeable release of heat and light, is called combustion or burning. (***Figure 1-4***) Remove any one of these things and the fire extinguishes.

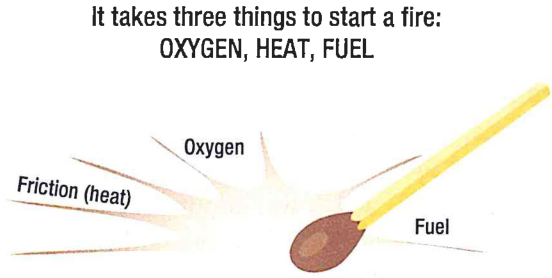


Figure 1-4. Three elements of fire.

CLASSIFICATION OF FIRES

For commercial purposes, the National Fire Protection Association (NFPA) has classified fires into three basic types: Class A, Class B, and Class C.

1. Class A fires occur in ordinary combustible materials, such as wood, cloth, paper, upholstery materials, and so forth.
2. Class B fires occur in flammable petroleum products of other flammable or combustible liquids, greases, solvents, paints, and so forth.
3. Class C fires involve energized electrical wiring and equipment.

A fourth class of fire, with which the technician should be familiar, the Class D fire, is defined as fire in flammable metal. Class D fires are not commercially considered by the National Fire Protection Association to be a basic type or category of fire since they are caused by a Class A, B, or C fire. Usually Class D fires involve magnesium in the shop or in aircraft wheels and brakes, or are the result of improper or poorly conducted welding operations.

Any one of these types of fires can occur during maintenance on or around, or operations involving, aircraft. There is a particular type extinguisher which is most effective for each type of fire.

FIRE EXTINGUISHERS

TYPES AND OPERATION

Water extinguishers are the best type to use on Class A fires. Water has two effects on fire: it deprives fire of oxygen and cools the material being burned.

Since most petroleum products float on water, water-type fire extinguishers are not recommended for Class B fires.

Extreme caution must be used when fighting electrical fires with water-type extinguishers. Not only must all electrical power be removed or shut off to the burning area, but residual electricity in capacitors, coils, and so forth must be considered to prevent severe injury and possibly death from electrical shock.

Never use water-type fire extinguishers on Class D fires. Because metals burn at extremely high temperatures, the cooling effect of water causes an explosive expansion of the metal. Water fire extinguishers are operated in a variety of ways. Some are hand pumped, while some are pressurized.

The pressurized types of extinguishers may have a gas charge stored in the container with the water, or it may contain a "soda-acid" container where acid is spilled into a container of soda inside the extinguisher. The chemical reaction of the soda and the acid causes pressure to build inside the fire extinguisher, forcing the water out.

Carbon dioxide (CO_2) extinguishers are used for Class A, B, and C fires, extinguishing the fire by depriving it of oxygen. (***Figure 1-5***) Additionally, like water-type extinguishers, CO_2 cools the burning material.

Figure 1-5. Carbon dioxide fire extinguisher.

Never use CO_2 on Class D fires. As with water extinguishers, the cooling effect of CO_2 on the hot metal can cause explosive expansion of the metal.

When using CO_2 fire extinguishers, all parts of the extinguisher can become extremely cold, and remain so for a short time after operation. Wear protective equipment or take other precautions to prevent cold injury (such as frostbite) from occurring.

Extreme caution must be used when operating CO_2 fire extinguishers in closed or confined areas. Not only can the fire be deprived of oxygen, but so too can the operator.

CO_2 fire extinguishers generally use the self-expelling method of operation. This means that the CO_2 has sufficient pressure at normal operating pressure to expel itself. This pressure is held inside the container by some type of seal or frangible disk, which is broken or punctured by a firing mechanism, usually a pin. This means that once the seal or disk is broken, pressure in the container is released, and the fire extinguisher is spent, requiring replacement. (***Figure 1-6***)

Halogenated hydrocarbon extinguishers are most effective on Class B and C fires. They can be used on Class A and D fires but they are less effective. Halogenated hydrocarbon, (commonly called Freon™ by the industry), are numbered according to chemical formulas with Halon™ numbers.

Carbon tetrachloride (Halon 104), chemical formula CCl4, has an Underwriters Laboratory (UL) toxicity rating of 3. As such, it is extremely toxic. (***Figure 1-7***)

Hydrochloric acid vapor, chlorine and phosgene gas are produced whenever carbon tetrachloride is used on ordinary fires. The amount of phosgene gas is increased whenever carbon tetrachloride is brought in direct contact with hot metal, certain chemicals, or continuing electrical arcs. It is not approved for any fire extinguishing use. Old containers of Halon 104 found in or around shops or hangars should be disposed of in accordance with Environmental Protection Agency (EPA) regulations and local laws and ordinances.

Methyl bromide (Halon 1001), chemical formula CH3Br, is a liquefied gas with a UL toxicity rating of 2. This chemical is very toxic, it is corrosive to aluminum alloys, magnesium, and zinc. Halon 1001 is not recommended for aircraft use.

Extinguishing Materials	Class of Fire A	B	C	D	Self-Generating	Self-Expelling	Cartridge of N_2 Cylinder	Stored Pressure	Pump	Hand
Water and Anti-Freeze	X						X	X	X	X
Soda-Acid (water)	X				X					
Wetting Agent	X						X			
Foam	X	X			X					
Loaded Stream	X	X+					X	X		
Multipurpose Dry Chemical	X+	X	X				X	X		
Carbon Dioxide		X+	X			X				
Dry Chemical		X	X				X	X		
Bromotrifluoromethane—Halon 1301		X	X			X				
Bromochlorodifluoromethane—Halon 1211		X	X					X		
Dry Powder (Metal Fires)				X			X			X

+ Smaller sizes of these extinguishers are not recognized for use on these classes of fires.

Figure 1-6. Extinguisher operation and methods of expelling.

Group	Definition	Examples
6 (Least toxic)	Gases or vapors which in concentrations up to 20% by volume for durations of exposure of up to approximately 2 hours do not appear to produce injury.	Bromotrifluoromethane (Halon 1301)
5a	Gases or vapors much less toxic than Group 4 but more toxic than Group 6.	Carbon Dioxide
4	Gases or vapors which in concentrations of the order of 2 to 2½% for durations of exposure of up to approximately 2 hours are lethal or produce serious injury.	Dibromodifluormethane (Halon 1202)
3	Gases or vapors which in concentrations of the order of 2 to 2½% for durations of exposure of the order of 1 hour are lethal or produce serious injury.	Bromochloromethane (Halon 1011) Carbon Tetrachloride (Halon 104)
2	Gases or vapors which in concentrations of approximately ½ to 1% for durations of exposure of up to approximately ½ hour are lethal or produce serious injury.	Methyl Bromide (Halon 1001)

Figure 1-7. Toxicity table.

Chlorobromomethane (Halon 1011), chemical formula CH2ClBr, is a liquefied gas with a UL toxicity rating of 3. Like methyl bromide, Halon 1011 is not recommended for aircraft use.

Dibromodifluoromethane (Halon 1202), chemical formula CBr2F2, has a UL toxicity rating of 4. Halon 1202 is not recommended for aircraft use.

Bromochlorodifluoromethane (Halon 1211), chemical formula $CBrClF_2$, is a liquefied gas with a UL toxicity rating of 5. It is colorless, noncorrosive and evaporates rapidly, leaving no residue. It does not freeze or cause cold burns, and will not harm fabrics, metals or other materials it contacts. It acts rapidly on fires by producing a heavy blanketing mist that eliminates oxygen from the fire source. But more importantly, it interferes chemically with the combustion process of the fire. It has outstanding properties in preventing reflash after the fire has been extinguished.

Bromotrifluoromethane (Halon 1301), chemical formula CF_3Br, is also a liquefied gas with a UL toxicity rating of 6. It has all the characteristics of Halon 1211. A significant difference between the two is that Halon 1211 forms a spray similar to CO_2, while Halon 1301 has a vapor spray that is more difficult to direct.

Note: The U.S. Environmental Protection Agency (EPA) has restricted Halon to its 1986 production level due to its effect on the ozone layer.

Dry powder extinguishers, while effective on Class B and C fires, are the best for use on Class D fires.

The method of operation of dry powder fire extinguishers varies from gas cartridge charges, or stored pressure within the container which forces the powder charge out of the container, to tossing the powder on the fire by hand, by scooping pails or buckets of the powder from large containers or barrels.

Dry powder is not recommended for aircraft use (except on metal fires as a fire extinguisher) because the leftover chemical residues and dust often make cleanup difficult, and can damage electronic or other delicate equipment.

INSPECTION OF FIRE EXTINGUISHERS

Fire extinguishers should be checked periodically utilizing a checklist. If a checklist is unavailable, check the following as a minimum:

- Proper location of appropriate extinguisher
- Safety seals unbroken
- All external dirt and rust removed
- Gauge or indicator in operable range
- Proper weight
- No nozzle obstruction
- No obvious damage

Airport or other local fire departments can usually help in preparing and often can provide extinguisher checklists. In addition, these fire departments can be helpful in answering questions and assisting in obtaining repairs to or replacement of fire extinguishers.

IDENTIFYING FIRE EXTINGUISHERS

Fire extinguishers should be marked to indicate suitability for a particular class of fire. The markings on ***Figure 1-8*** should be placed on the fire extinguisher and in a conspicuous place in the vicinity of the fire extinguisher. When the location is marked, however extreme care must be taken to ensure that the fire extinguisher kept at that location is in fact the type

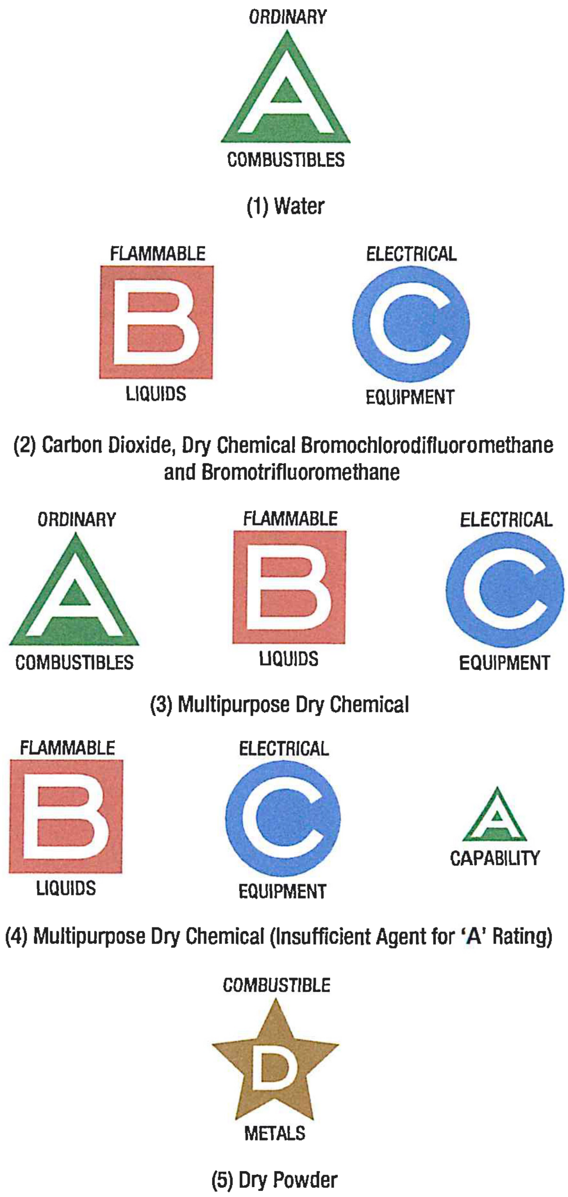


Figure 1-8. Typical extinguisher markings.

depicted by the marking. In other words, if a location is marked for a Class B fire extinguisher, ensure that the fire extinguisher in that location is in fact suitable for Class B fires. Markings should be applied by decalcomanias (decals), painting, or similar methods. They should be legible and as durable as necessary for the location. For example, markings used outside need to be more durable than those in the hangar or office spaces.

Where markings are applied to the extinguisher, they should be located on the front of the shell (if one is installed) above or below the extinguisher nameplate. Markings should be large enough and in a form that is easily seen and identifiable by the average person with average eyesight at a distance of at least 3 feet.

Where markings are applied to wall panels, and so forth, in the vicinity of extinguishers, they should be large enough and in a form that is easily seen and identifiable by the average person with average eyesight, at a distance of at least 25 feet. (***Figure 1-9***)

USING FIRE EXTINGUISHERS

When using a fire extinguisher, make sure you have the correct type for the fire. Most extinguishers have a pin to pull that will allow the handle to activate the agent. Stand back and aim at the base of the fire or flames. Squeeze the lever and sweep side to side until the fire is extinguished.

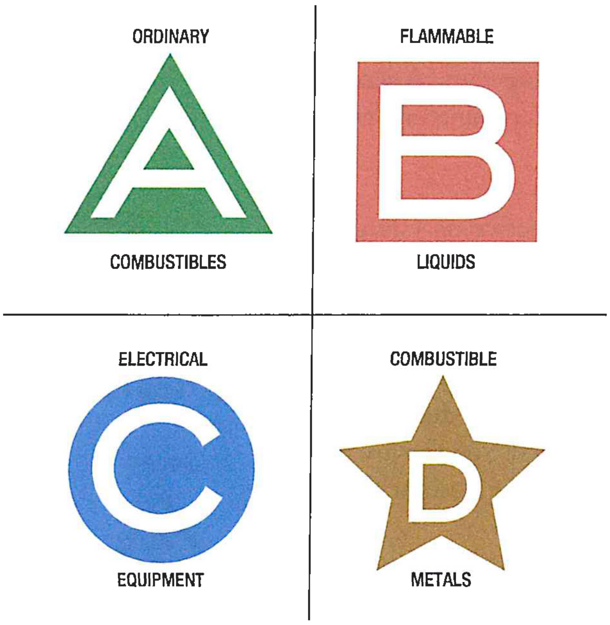


Figure 1-9. Identification of fire extinguisher type location.

Question: 1-1
Fire extinguishers should be ________________ to indicate suitability for a particular class of fire.

Question: 1-2
________________ readily combines with other substances, some in a violent and explosive manner.

Question: 1-3
What fire extinguishing agent is used on class A, B, and C fires and extinguishes the fire by depriving it of oxygen?

Question: 1-4
Fire extinguishers should be ________________ to indicate suitability for a particular class of fire.

ANSWERS

Answer: 1-1
FOD (foreign object damage).

Answer: 1-2
oxygen.

Answer: 1-3
Carbon dioxide (CO_2).

Answer: 1-4
marked.

MAINTENANCE PRACTICES

WORKSHOP PRACTICES

SUB-MODULE 02

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 02 WORKSHOP PRACTICES Knowledge Requirements		
7.2 - Workshop Practices Care of tools, control of tools, use of workshop materials; Dimensions, allowances and tolerances, standards of workmanship; Calibration of tools and equipment, calibration standards.	3	3

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

WORKSHOP PRACTICES

The aviation maintenance engineer engages in activities where the use of tools is featured. Many common and special tools are used on a daily basis. Proper care and control of tools is integral to proper maintenance. Workshop practices as they relate to tools may be slightly different from organization to organization. In this sub-module an examination of standard practices with tools and tooling is made.

CARE OF TOOLS

Each engineer is responsible for the acquisition and maintenance of his or her own common hand tool set. Wrenches, spanners, socket sets, hammers, screwdrivers, pliers and the like are normally owned by the engineer while the maintenance organization owns and provide special tools required to maintain the aircraft and power plants. The user of any tool has the responsibility to ensure the tool is in good working condition.

Tools must be kept clean. A light coating of oil wiped on the tool after use helps prevent corrosion of steel tools. Tools with moving parts should be kept clean and lubricated if necessary to perform as designed. Engineers typically store their tools in sturdy tool boxes when not in use. Special tools, especially precision instruments, are often stored in each tool's own custom made storage container. A quick, visual inspection before use is needed. Complicated or precision tools should be inspected, zeroed or calibrated, and operated in accordance with instructions that accompany the tool. If ever in doubt about how to use a tool, the technician should seek assistance from an experienced colleague or the manufacturer of the tool.

CONTROL OF TOOLS

One of the most important responsibilities of the engineer is the control of tools. A misplaced tool can have catastrophic effects resulting in significant expense and the possible loss of life. Effort must be made to control all tools in a manner such that the whereabouts of any tool is never in doubt.

Each engineer is responsible for the control of his or her own tools and any special tools borrowed from the company to perform a job. Organizing one's tool storage so that all tools can be accounted for is a good practice. Wrench and socket holders are helpful in that each tool occupies a specific location in the holder and it is easy to see when a tool is missing. A shadow board type concept for storage of pliers, screw drivers, ratchets, hammers and other tools have the same effect. In other words, tool box tool storage should be executed in such a way that every tool is kept in a specific place and the engineer can quickly see when a tool is missing. (***Figure 2-1***)

Special tools and company owned tools must be accounted for as well. A tool room or tool crib is a common feature at large, organized aviation maintenance facilities. All special tools are inventoried and kept in an organized storage location in the tool room or crib. The tools are frequently labeled with an identification number or have a bar code label attached directly to the tool for identification. When a tool is "checked out" for use by a technician, the name of the engineer receiving the tool is recorded and the inventory record is noted. Sometimes a tag or a worker ID is exchanged.

At the end of a work shift, the administrator of the tool room seeks to have every tool returned and inventory restored. Missing tools are located. If still being used on a job, the out-going engineer may transfer responsibility of control of the tool to the incoming technician who

Figure 2-1. Foam draw liner where every tool has its place.

becomes the registered responsible party for the tool's whereabouts. The tool rooms records reflect the change. Many maintenance operations will have shops or bays where certain jobs are performed exclusively in those locations and tools needed for these jobs are kept in an organized fashion strictly in these locations.

No matter where tools are being used, it is the responsibility of each technician to keep track of ALL of the tools used during a particular task. The most important check of all is the final, 'End of Work' tool check, when all tools must be collected and checked off against personal and tool room inventories. The aircraft should not be released for service until every tool is accounted for.

USE OF WORKSHOP MATERIALS

For safety, management and economy issues, many workshop materials are issued in a controlled fashion. Toxic materials may cause health risks which can be controlled by controlling the handling and storage of this type of substance. Highly corrosive materials pose a similar issue where close control is required to prevent material damage. Control of other materials may just be due to a desire to manage accurate inventory control so that quantities are known and available when needed.

Still other materials are easily wasted or stolen unless controlled through disciplined administration. Abrasive papers, solder and brazing materials, wire wool, tire powder, oil spill powder and so on, all require control of issue and use, though they may not, normally, require stringent safety precautions. A huge range of liquids can be used in the workshop situation, some of which are harmless and some of which are extremely toxic. It is vital that the work-force is aware of the risks involved when dealing with any materials, and especially when working within enclosed areas. Some materials are flammable and must, therefore, be stored outdoors or in specially designed cabinets.

These include oils, greases, some adhesives, sealing and glazing compounds in addition to many paints, enamels and epoxy surface finishes. When stored, the materials and storage cabinets are kept out of direct sunlight in a workshop or hangar.

When handling materials that give off fumes, it is necessary to have the area well ventilated and/or have the operator wearing a mask or some form of remote breathing apparatus. The finished work may also give off fumes for some time afterwards, so care must be taken to keep it ventilated if necessary.

All liquids must only be used for the purpose for which they are designed and never mixed together, unless the two materials are designed to be mixed, such as with two part epoxy adhesives and sealants. Many liquids used in workshops and in the hangar have a fixed 'life'. The expiration date is printed on the container and must be checked before use. Many materials are unsafe if used beyond their expiry date.

The disposal of liquids is a critical operation, and must only be carried out in accordance with company, local, national, and international regulations. Liquids must never be disposed of by pouring them into spare or unidentified containers and they must not be allowed to enter the 'domestic' drains systems. Most large companies have a department dedicated to the proper disposal of materials.

Another area of hazardous workshop materials is that of gases stored in high pressure containers such as nitrogen and oxygen. Safety precautions for individual high pressure gases are discussed in dedicated sections throughout this module series. In general, follow operator shop and hangar safety practices when working with these gases.

TOOL CALIBRATION

Requirements within the relevant airworthiness codes of one's national aviation authority and EASA as well as a company's air operation certificate prescribe that, where necessary, tools, equipment and test equipment are all calibrated to acceptable standards. Large companies keep inventory control over tools that need periodic calibration and may have a calibration shop in-house. They may also send tools out to independent agencies that perform the calibration. An engineer who owns a tool that requires periodic calibration must ensure that it is performed or the tool is not suitable for use in maintenance work on an aircraft.

The key factor is the need to establish confidence in the accuracy of the equipment when it is required for use. The required calibration frequency for any particular piece of test equipment is that which is considered sufficient to ensure it is in condition to perform its intended use. Annual calibration is common on tools that hold calibration well. Sensitive instruments, especially electrical instruments, are calibrated by the user before each use. They may also require periodic calibration.

Calibration takes place per the standard specified by the equipment manufacturer/design organization and/or the appropriate National/International Standards. Appropriate standards are used to achieve consistency between measurements made in different locations, possibly using alternate measuring techniques.

The calibration of test equipment is best achieved by the operation of a methodical system of control.

This system should be traceable by an unbroken chain of comparisons, through measurement standards of successively better accuracy up to the appropriate standard. Where recommendations for calibration standards are not published, or where they are not specified, calibration should be carried out per standards set by the national standards organization approved by the country NAA or EASA. In all instances, it is the responsibility of the user to be satisfied that the unbroken traceability chain is in place.

A written record is kept for all tools that require calibration, detailing when last done, when next due, and the requirements of the calibration. A sticker is attached to the tool detailing the due date of the next calibration. This should always be checked before use, and no tool should be used if it out of calibration. Calibration records or certificates should contain the following information:

- Identification of equipment
- Standard used
- Results obtained
- Uncertainty of measurement
- Assigned calibration interval
- Limits of permissible error
- The authority under which the release document was issued
- Any limitation in the use of the equipment
- Date on which each calibration was conducted

Any appliance whose serviceability is in doubt, should be removed from service, and labeled accordingly. Such equipment shall not be returned to service until the reasons for the unserviceability have been eliminated and its continued calibration is revalidated.

DIMENSIONS, ALLOWANCES, TOLERANCES

The aircraft maintenance engineer works with consideration for dimensions, allowances and tolerances. A dimension is a measurable extent of some kind, such as length, width, or height. Aircraft components including hardware have dimensions that physically describe the item from a size prospective. A limit dimension is the maximum or minimum dimension of a machined part. When referring to the size of an item, nominal size is an approximate dimension that is used for the purpose of general identification. The basic size is the theoretical size from which limits of size are derived by applying allowances and tolerances. The actual size of a part is the measured size. A tolerance is the total amount by which a given dimension is alloyed to vary. Thus, if a basic size is known and the tolerance is known, one can measure the actual size of a part and know whether it is within tolerance.

For Example, the diameter of a piston is 4.0 inches. This is its basic size. The tolerance established by the engine manufacturer is .005 inch. This means that if the piston is measured, its actual size must be between 3.995 inches and 4.005 inches to be within tolerance. If it is not, the piston is rejected for use in the engine.

Most tolerances are given as bilateral tolerances, meaning that the tolerance can be added to or subtracted from the basic size. However, there are parts where a unilateral tolerance is given by the manufacturer. This means that the basic size only has tolerance in one direction. For example, consider a piston again. Too large of a piston can cause it to seize in the cylinder during operation. A piston negligibly smaller than the basic size of the piston will perform adequately. So the manufacturer may state the basic size and give a unilateral tolerance of -.005. If the actual measured size of the piston is the basic size or within .005 inch smaller than the basic size, the piston is within tolerance.
Any measurement of the piston that is greater than the basic size would be cause for rejection because there is no tolerance in that direction.

Tolerance can be used when examining the dimension of a single part or it can be used when comparing the dimensional relationship between two parts, which is known as fit. When examining fit, clearance is the space between mating parts. There are different types of fits which reflect variations in the clearance between parts. Generally, one can refer to a loose fit or a tight fit, etc. But in machining, terms assigned to describe fit have specific meanings. A clearance fit is a fit that allows for sliding or rotating between mating parts. An interference fit is one in which the dimensions of two parts over lap - such as when a pin diameter is slightly larger than the hole in which it is to be inserted.

An allowance is the minimum clearance space intended between two parts. The intentional difference between the maximum material dimensional limits of mating parts creates the allowance. A limit is the maximum or minimum dimension formed when maximum or minimum tolerance is considered.

Note that the fit of two items may be slightly different depending on which standard is being used. Standards for hardware such as AN and MS have basically the same fits and clearances but there may be small differences in tolerance. Fits and clearances will be discussed further in *Sub-Module 06* of this Module.

STANDARDS OF WORKMANSHIP

In aviation, the highest standards of workmanship are practiced. An error for any reason could result in the loss of human life. Therefore, it is the aspiration of all engineers to meet or exceed the requirements of any maintenance function.

Manufacturer's instructions are designed procedures used by the engineer as mandatory guidance to bring about the best results in aircraft maintenance and repair. Deviation from these procedures requires approval.

Maintenance instructions typically specify measurable values and tolerances for acceptable actions. Maintenance actions that do not achieve these values within tolerances cause the aircraft to remain unairworthy and it must not be released for service.

Question: 2-1
A ________________ is a common feature at large, organized aviation maintenance facilities for controlling and accounting for tools.

Question: 2-2
A ________________ means that the tolerance can be added to or subtracted from the basic size.

Question: 2-3
________________ are designed procedures used by the engineer as mandatory guidance to bring about the best results in aircraft maintenance and repair.

ANSWERS

Answer: 2-1
tool room or tool crib.

Answer: 2-2
bilateral tolerance.

Answer: 2-3
Manufacturer's instructions.

MAINTENANCE PRACTICES

TOOLS

SUB-MODULE 03

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 03 TOOLS Knowledge Requirements		
7.3 - Tools Common hand tool types; Common power tool types; Operation and use of precision measuring tools; Lubrication equipment and methods. Operation, function and use of electrical general test equipment.	3	3

TOOLS

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
- (a) The applicant should know the theory of the subject and interrelationships with other subjects.
- (b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- (c) The applicant should understand and be able to use mathematical formula related to the subject.
- (d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- (e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
- (f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

TOOLS

The aviation maintenance technician spends a major portion of each day using a wide variety of hand tools to accomplish maintenance tasks. This chapter contains an overview of some of the hand tools the aircraft maintenance professional can expect to use. A technician encounters many special tools as their experience widens; large transport category aircraft have different maintenance tasks from those of a light airplane, and special hand tools are often required when working on complex aircraft.

This chapter outlines the basic knowledge required in using the most common hand tools and measuring instruments used in aircraft repair work. This information, however, cannot replace sound judgment on the part of the individual, nor additional training as the need arises. There are many times when ingenuity and resourcefulness can supplement the basic rules. Sound knowledge is required of these basic rules and of the situations in which they apply. The use of tools may vary, but good practices for safety, care, and storage of tools remain the same.

LAYOUT AND MEASURING TOOLS

Due to wise and experienced advise suggesting that you "measure twice before cutting once," we have placed this tool section first in this sub-module.

Layout and measuring devices are precision tools. They are carefully machined, accurately marked and, in many cases, are made up of delicate parts. When using these tools, be careful not to drop, bend, or scratch them.

The finished product will be no more accurate than the measurements or the layout; therefore, it is very important to understand how to read, use, and care for these tools.

RULES

Rules (also called rulers or line gauges) are made of steel and are either rigid or flexible. The flexible steel rule will bend, but it should not be bent intentionally as it may be broken rather easily. In aircraft work, the unit of measure most commonly used is the inch. The inch may be divided into smaller parts by means of either common or decimal fraction divisions.

The fractional divisions for an inch are found by dividing the inch into equal parts: halves (½), quarters (¼), eighths (⅛), sixteenths (1⁄16), thirty-seconds (1⁄32), and sixty-fourths (1⁄64).

The fractions of an inch may be expressed in decimals, called decimal equivalents of an inch; for example, ⅛ inch is expressed as 0.125 (one hundred twenty-five thousandths of an inch).

Rules are manufactured in two basic styles — those divided or marked in common fractions and those divided or marked in decimals or divisions of one one-hundredth of an inch. A rule may be used either as a measuring tool or as a straightedge. The imperial rule is a bit harder to read than a metric rule. (***Figure 3-1***)

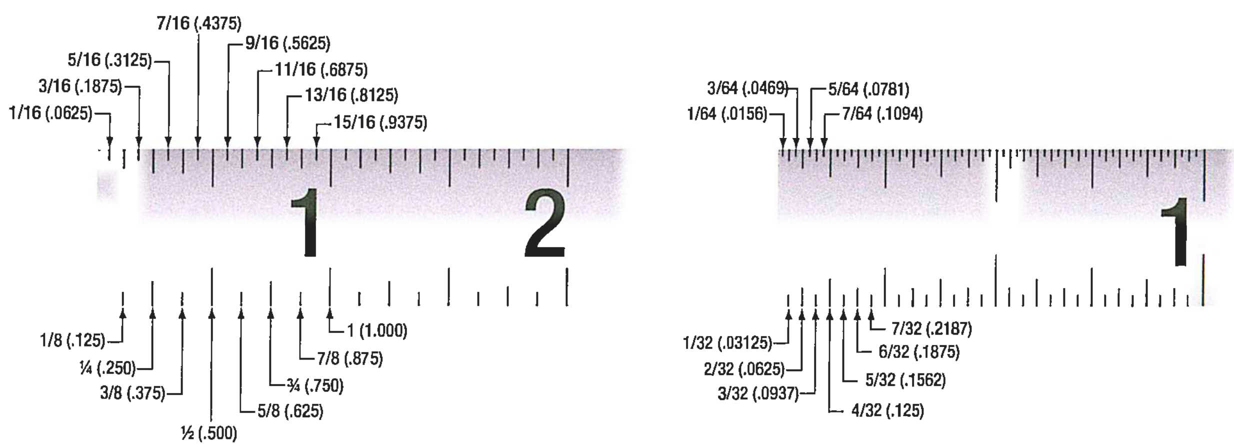


Figure 3-1. Rules.

COMBINATION SETS

The combination set, as its name implies, is a tool that has several uses. It can be used for the same purposes as an ordinary tri-square, but it differs from the tri-square in that the head slides along the blade and can be clamped at any desired place. Combined with the square or stock head are a level and scriber. The head slides in a central groove on the blade or scale, which can be used separately as a rule. (***Figure 3-2***)

The spirit level in the stock head makes it convenient to square a piece of material with a surface and at the same time tell whether one or the other is plumb or level. The head can be used alone as a simple level.

The combination of square head and blade can also be used as a marking gauge to scribe lines at a 45° angle, as a depth gauge, or as a height gauge. A convenient scriber is held frictionally in the head by a small brass bushing. The protractor head can be used to check angles and also may be set at any desired angle to draw lines.

SCRIBER

The scriber is designed to serve the aviation mechanic in the same way a pencil or pen serves a writer. In general, it is used to scribe or mark lines on metal surfaces. The scriber is made of tool steel, 4 to 12 inches long, and has two needle pointed ends. One end is bent at a 90° angle for reaching and marking through holes. (***Figure 3-3***)

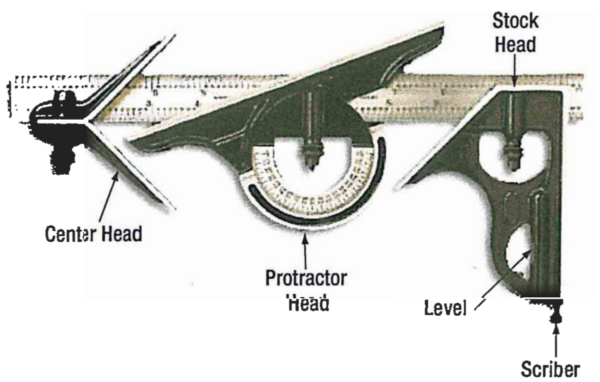


Figure 3-2. Combination set.

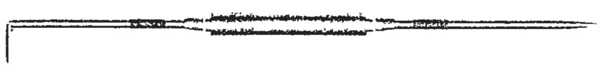


Figure 3-3. Scriber.

Before using a scriber, always inspect the points for sharpness. Be sure the straightedge is flat on the metal and in position for scribing. Tilt the scriber slightly in the direction toward which it will be moved, holding it like a pencil. Keep the scriber's point close to the guiding edge of the straightedge. The scribed line should be heavy enough to be visible, but no deeper than necessary to serve its purpose.

DIVIDERS AND PENCIL COMPASSES

Dividers and pencil compasses have two legs joined at the top by a pivot. They are used to scribe circles and arcs and for transferring measurements from the rule to the work. Pencil compasses have one leg tapered to a needle point; the other leg has a pencil or pencil lead inserted. Dividers have both legs tapered to needle points.

When using pencil compasses or dividers, the following procedures are suggested:

1. Inspect the points to make sure they are sharp.
2. To set the dividers or compasses, hold them with the point of one leg in the graduations on the rule. Turn the adjustment nut with the thumb and forefinger; adjust the dividers or compasses until the point of the other leg rests on the graduation of the rule that gives the required measurement.
3. To draw an arc or circle with either the pencil compasses or dividers, hold the thumb attachment on the top with the thumb and forefinger. With pressure exerted on both legs, swing the compass in a clockwise direction and draw the desired arc or circle.
4. The tendency for the legs to slip is avoided by inclining the compasses or dividers in the direction in which they are being rotated. In working on metals, the dividers are used only to scribe arcs or circles that will later be removed by cutting. All other arcs or circles are drawn with pencil compasses to avoid scratching the material.
5. On paper layouts, the pencil compasses are used for describing arcs and circles. Dividers should be used to transfer critical measurements because they are more accurate than a pencil compass.

CALIPERS

Calipers are used for measuring diameters and distances or for comparing distances and sizes. The three common types of calipers are inside, outside, and hermaphrodite calipers. (*Figure 3-4*)

Outside calipers are used for measuring outside dimensions — for example, the diameter of a piece of round stock. Inside calipers have outward curved legs for measuring inside diameters, such as diameters of holes, the distance between two surfaces, the width of slots, and other similar jobs. A hermaphrodite caliper is generally used as a marking gauge in layout work. It should not be used for precision measurement.

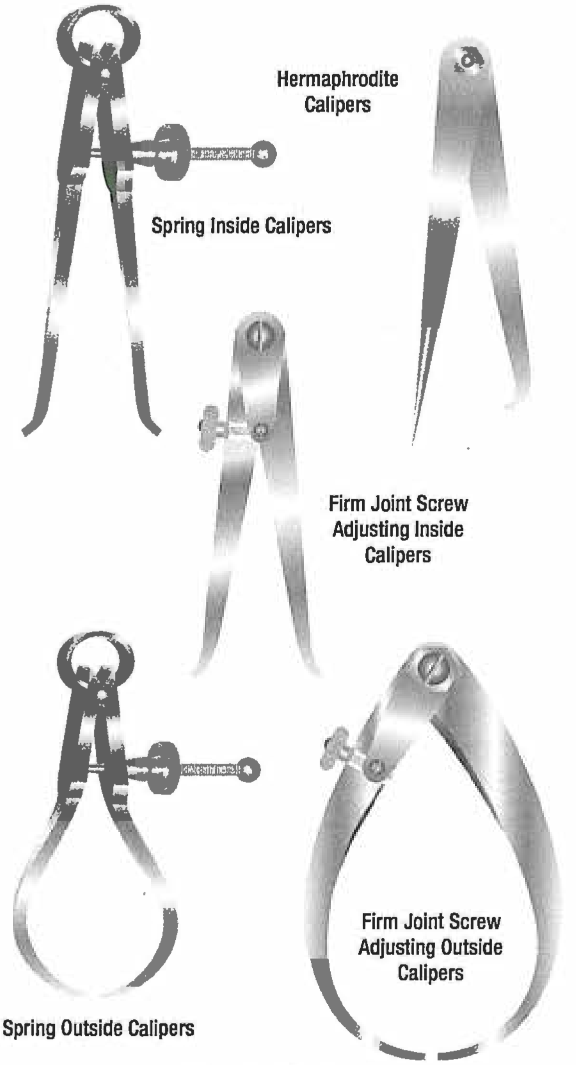


Figure 3-4. Calipers.

MICROMETER CALIPERS

There are four types of micrometer calipers, each designed for a specific use: outside micrometer, inside micrometer, depth micrometer, and thread micrometer. Micrometers are available in a variety of sizes, either 0 to ½ inch, 0 to 1 inch, 1 to 2 inch, 2 to 3 inch, 3 to 4 inch, 4 to 5 inch, or 5 to 6 inch sizes. In addition to the micrometer inscribed with the measurement markings, micrometers equipped with electronic digital liquid crystal display (LCD) readouts are also in common use.

The AMT will use the outside micrometer more often than any other type. It may be used to measure the outside dimensions of shafts, thickness of sheet metal stock, the diameter of drills, and for many other applications. (*Figure 3-5*)

The smallest measurement which can be made with the use of the steel rule is one sixty-fourth of an inch in common fractions, and one one-hundredth of an inch in decimal fractions.

To measure more closely than this (in thousandths and ten-thousandths of an inch), a micrometer is used. If a dimension given in a common fraction is to be measured with the micrometer, the fraction must be converted to its decimal equivalent.

All four types of micrometers are read in the same way. The method of reading an outside micrometer is discussed later in this chapter.

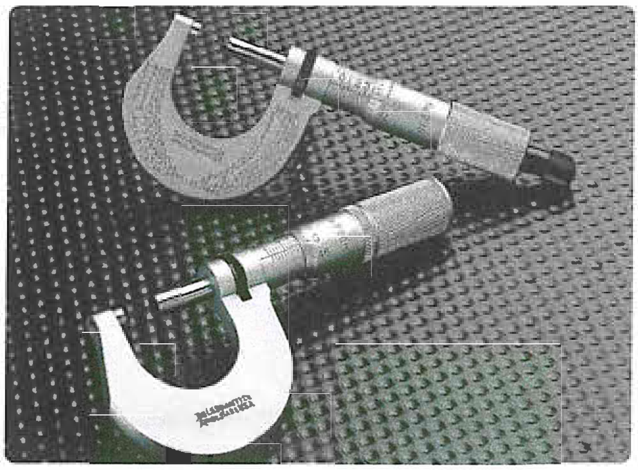


Figure 3-5. Outside micrometers.

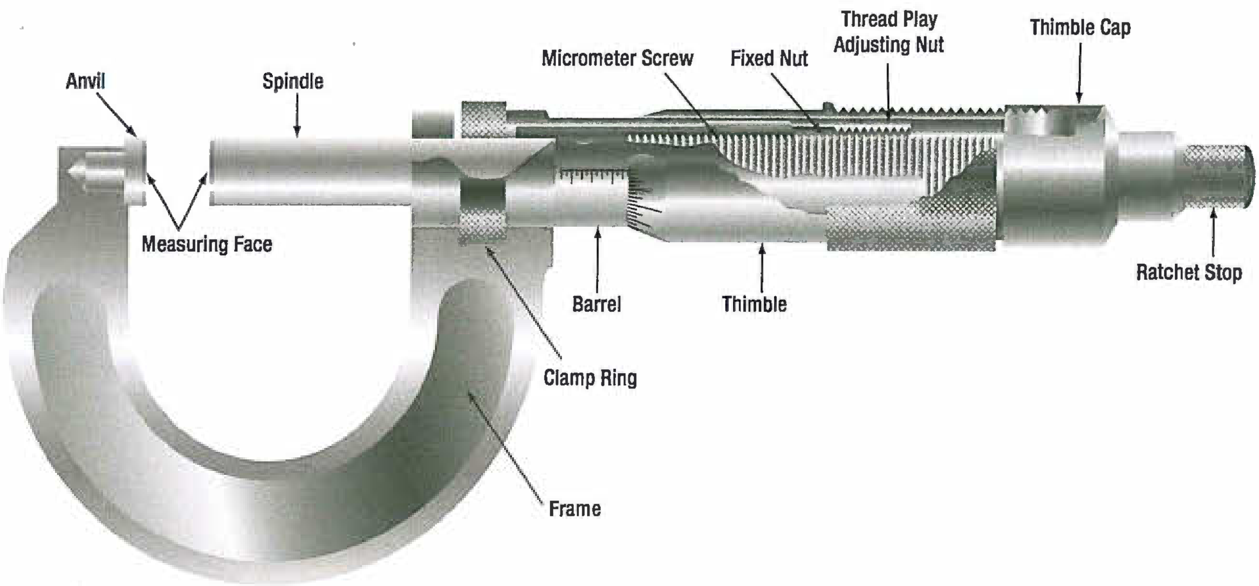


Figure 3-6. Outside micrometer parts.

Micrometer Parts

The fixed parts of a micrometer are the frame, barrel, and anvil. The movable parts of a micrometer are the thimble and spindle. The thimble rotates the spindle which moves in the threaded portion inside the barrel. Turning the thimble provides an opening between the anvil and the end of the spindle where the work is measured. The size of the work is indicated by the graduations on the barrel and thimble. (***Figure 3-6***)

Reading A Micrometer

The lines on the barrel marked 1, 2, 3, 4, and so forth, indicate measurements of tenths, or 0.100 inch, 0.200 inch, 0.300 inch, 0.400 inch, respectively. (***Figure 3-7***)

Each of the sections between the tenths divisions (between 1, 2, 3, 4, and so forth) is divided into four parts of 0.025 inch each. One complete revolution of the thimble (from zero on the thimble around to the same zero) moves it one of these divisions (0.025 inch) along the barrel.

The bevel edge of the thimble is divided into 25 equal parts. Each of these parts represents one twenty-fifth of the distance the thimble travels along the barrel in moving from one of the 0.025 inch divisions to another. Thus, each division on the thimble represents one one-thousandth (0.001) of an inch.

These divisions are marked for convenience at every five spaces by 0, 5, 10, 15, and 20. When 25 of these graduations have passed the horizontal line on the barrel, the spindle (having made one revolution) has moved 0.025 inch.

The micrometer is read by first noting the last visible figure on the horizontal line of the barrel representing tenths of an inch. Add to this the length of barrel between the thimble and the previously noted number. (This is found by multiplying the number of graduations by 0.025 inch.) Add to this the number of divisions on the bevel edge of the thimble that coincides with the line of the graduation. The total of the three figures equals the measurement. ***Figure 3-8*** shows several sample readings.

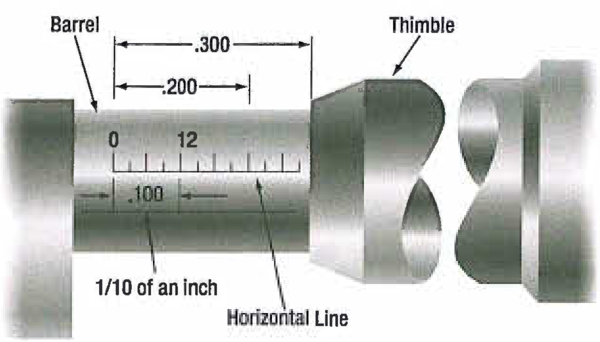


Figure 3-7. Micrometer measurements.

Vernier Scale

Some micrometers are equipped with a vernier scale that makes it possible to directly read the fraction of a division that is indicated on the thimble scale. Typical examples of the vernier scale as it applies to the micrometer are shown in ***Figure 3-9***.

All three scales on a micrometer are not fully visible without turning the micrometer, but the examples shown in ***Figure 3-8*** are drawn as though the barrel and thimble of the micrometer were laid out flat so that all three scales can be seen at the same time. The barrel scale is the lower horizontal scale, the thimble scale is vertical on the right, and the long horizontal lines (0 through 9 and 0) make up the vernier scale.

In reading a micrometer, an excellent way to remember the relative scale values is to remember that the 0.025 inch barrel scale graduations are established by the lead screw (40 threads per inch). Next, the thimble graduations divide the 0.025 inch into 25 parts, each equal to 0.001 inch. Then, the vernier graduations divide the 0.001 inch into 10 equal parts, each equal to 0.0001 inch. Remembering the values of the various scale graduations, the barrel scale reading is noted. The thimble scale reading is added to it; then the vernier scale reading is added to get the final reading. The vernier scale line to be read is always the one aligned exactly with any thimble graduation.

In the first example in ***Figure 3-9***, the barrel reads 0.275 inch and the thimble reads more than 0.019 inch. The number 1 graduation on the thimble is aligned exactly with the number 4 graduation on the vernier scale. Thus, the final reading is 0.2944 inch. In the second example in ***Figure 3-9***, the barrel reads 0.275 inch, and the thimble reads more than 0.019 inch and less than 0.020 inch. On the vernier scale, the number 7 graduation coincides with a line on the thimble. This means that the thimble reading would be 0.0197 inch. Adding this to the barrel reading of 0.275 inch gives a total measurement of 0.2947 inch.

The third and fourth examples in ***Figure 3-9*** are additional readings that would require use of the vernier scale for accurate readings to ten-thousandths of an inch.

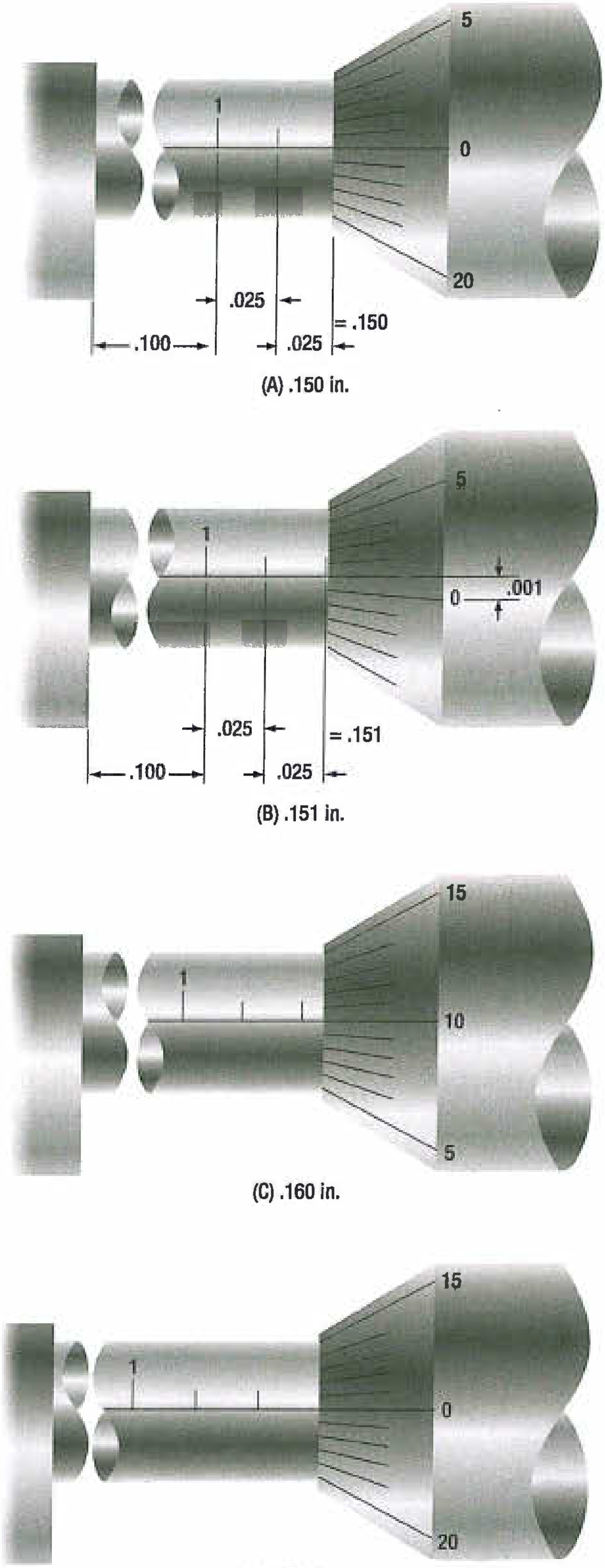


Figure 3-8. Reading a micrometer.

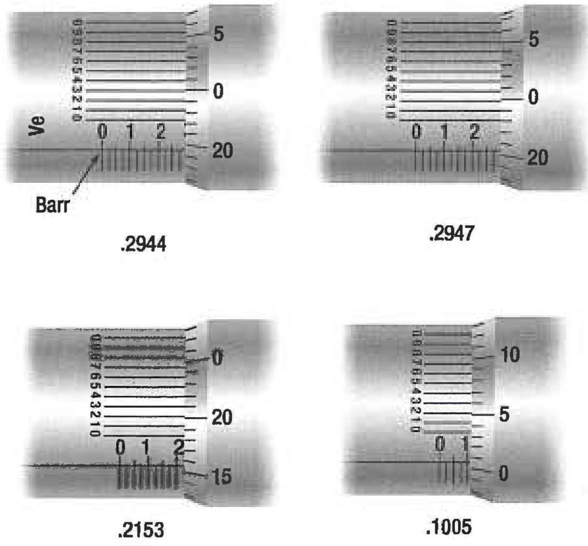


Figure 3-9. Vernier scale readings.

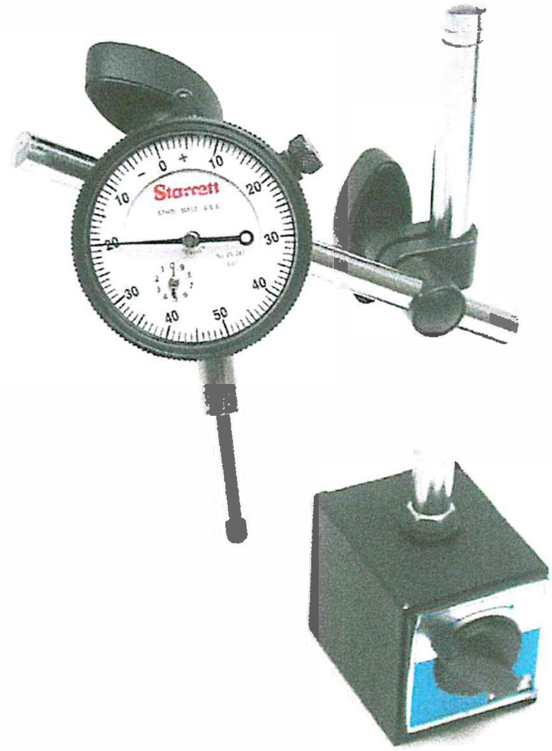


Figure 3-10. Dial indicator.

Using A Micrometer

The micrometer must be handled carefully. If it is dropped, its accuracy may be permanently affected. Continually sliding work between the anvil and spindle may wear the surfaces. If the spindle is tightened too much, the frame may be sprung permanently and inaccurate readings will result.

To measure a piece of work with the micrometer, hold the frame of the micrometer in the palm of the hand with the little finger or third finger, whichever is more convenient. This allows the thumb and forefinger to be free to turn the thimble for adjustment.

DIAL INDICATOR

A variation of the micrometer is the dial indicator, which measures variations in a surface by using an accurately machined probe mechanically linked to a circular hand whose movement indicates thousandths of an inch, or is displayed on a liquid crystal display (LCD) screen. (***Figure 3-10***)

A typical example would be using a dial indicator to measure the amount of runout, or bend, in a shaft. If a bend is suspected, the part can be rotated while resting between a pair of machined V-blocks. A dial indicator is then clamped to a machine table stand, and the probe of the indicator is positioned so it lightly contacts the surface. The outer portion of the dial is then rotated until the needle is pointed at zero. The part is then rotated, and the amount of bend is displayed on the dial as the needle fluctuates. The total amount of the fluctuation is the runout.

Another common use for the dial indicator is to check for a warp in a rotating component such as a brake disc. In some cases, this can be done with the brake disc installed on the airplane, with the base clamped to a stationary portion of the structure. In either case, it is imperative that the dial indicator be securely fastened so that the movement of the indicator itself induces no errors in measurement.

SLIDE CALIPERS

Often used to measure the length of an object, the slide caliper provides greater accuracy than the ruler. It can, by virtue of its specially formed jaws, measure both inside and outside dimensions. As the tool's name implies, the slide caliper jaw is slid along a graduated scale, and its jaws then contact the inside or outside of the object to be measured. The measurement is then read on the scale located on the body of the caliper, or on the LCD screen. (***Figure 3-11***)

Some slide calipers also contain a depth gauge for measuring the depth of blind holes.

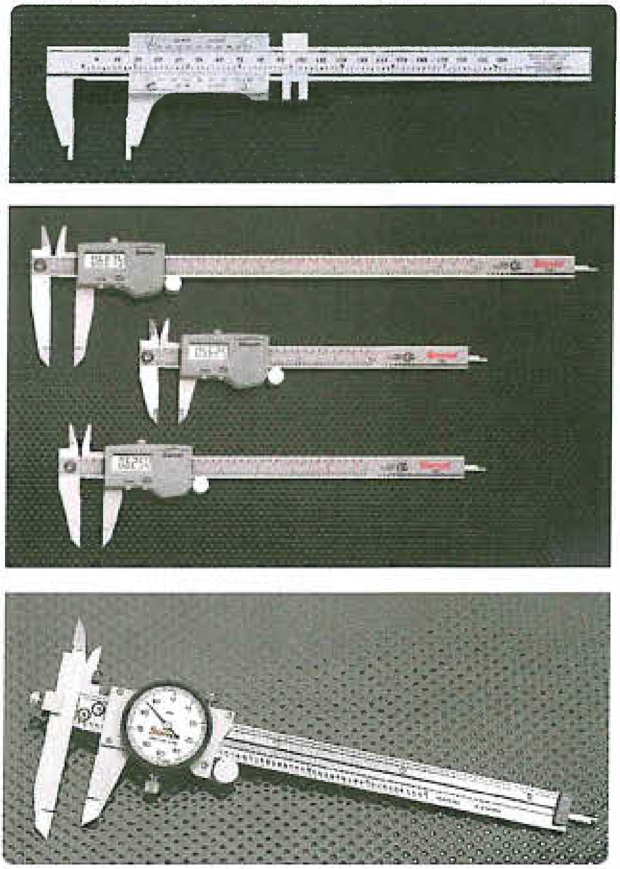


Figure 3-11. Various types of slide calipers.

GENERAL PURPOSE TOOLS

SCREWDRIVERS

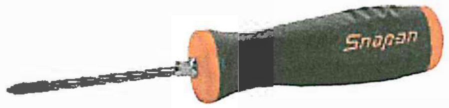
The screwdriver can be classified by its shape, type of blade, and blade length. It is made for only one purpose, i.e., for loosening or tightening screws or screw head bolts. ***Figure 3-12*** shows several different types of screwdrivers. When using the common screwdriver, select the largest screwdriver whose blade will make a good fit in the screw that is to be turned.

A common screwdriver must fill at least 75 percent of the screw slot. If the screwdriver is the wrong size, it cuts and burrs the screw slot, making it worthless. The damage may be so severe that the use of screw extractor may be required. A screwdriver with the wrong size blade may slip and damage adjacent parts of the structure. The common screwdriver is used only where slotted head screws or fasteners are found on aircraft. An example of a fastener that requires the use of a common screwdriver is the cam-lock style fastener that is used to secure the cowling on some aircraft.

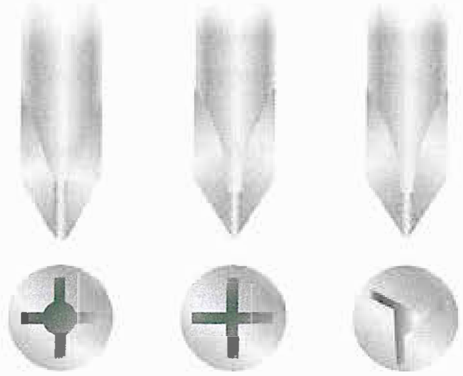
The two types of recessed head screws in common use are the Phillips and the Reed & Prince.

Both the Phillips and Reed & Prince recessed heads are optional on several types of screws. As shown in ***Figure 3-12***, the Reed & Prince recessed head forms a perfect cross. The screwdriver used with this screw is pointed on the end. Since the Phillips screw has a slightly larger center in the cross, the Phillips screwdriver is blunt on the end. The Phillips screwdriver is not interchangeable with the Reed & Prince. The use of the wrong type screwdriver results in mutilation of the screwdriver and the screw head. When turning a recessed head screw, use only the proper recessed head screwdriver of the correct size. The most common crosspoint screwdrivers are the Number 1 and Number 2 Phillips.

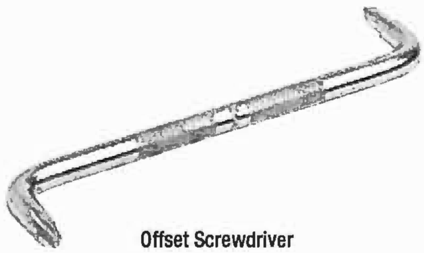
An offset screwdriver may be used when vertical space is limited. Offset screwdrivers are constructed with both ends bent 90° to the shank handle. By using alternate ends, most screws can be seated or loosened even when the swinging space is limited.



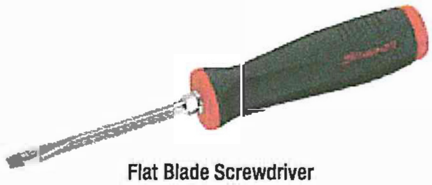
Phillips Screwdriver



Phillips Reed & Prince Tri-Wing



Offset Screwdriver



Flat Blade Screwdriver

Figure 3-12. Typical screwdrivers.

Offset screwdrivers are made for both standard and recessed head screws. Ratcheting right angle screwdrivers are also available, and often prove to be indispensable when working in close quarters.

A screwdriver should not be used for chiseling or prying. Do not use a screwdriver to check an electric circuit since an electric arc will burn the tip and make it useless. In some cases, an electric arc may fuse the blade to the unit being checked, creating a short circuit.

When using a screwdriver on a small part, always hold the part in the vise or rest it on a workbench. Do not hold the part in the hand, as the screwdriver may slip and cause serious personal injury.

Replaceable tip screwdrivers, sometimes referred to as "10 in 1" screwdrivers, allow for the quick changing of a screwdriver tip, and economical replacement of the tip when it becomes worn. A wide variety of screwdriver tips, including flat, crosspoint (Phillips and Reed & Prince), Torx and square drive tips are available for use with the handles. (***Figure 3-13***)

The cordless hand-held power screwdriver has replaced most automatic or spiral screwdrivers for the removal of multiple screws from an airframe. Care must be exercised when using a power screwdriver; if the slip clutch is set for too high a setting when installing a screw, the screwdriver tip will slip and rotate on top of the screw head, damaging it. The screw should be started by hand, to avoid driving the screw into the nut or nut plate in a cross-threaded manner. To avoid damaging the slot or receptacle in the head of the screw, the use of cordless power drills fitted with a removable tip driver to remove or install screws is not recommended, as the drill does not have a slip-clutch installed.

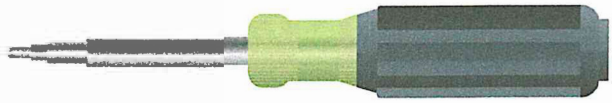


Figure 3-13. Replaceable tip screwdriver.

PLIERS AND PLIER-TYPE CUTTING TOOLS

As shown in ***Figure 3-14***, the pliers used most frequently in aircraft repair work are the diagonal, needlenose, and duckbill. The size of pliers indicates their overall length, usually ranging from 5 to 12 inches.

Roundnose pliers are used to crimp metal. They are not made for heavy work because too much pressure will spring the jaws, which are often wrapped to prevent scarring the metal.

Needlenose pliers have half round jaws of varying lengths. They are used to hold objects and make adjustments in tight places.

Duckbill pliers resemble a "duck's bill" in that the jaws are thin, flat, and shaped like a duck's bill. They are used exclusively for twisting safety wire.

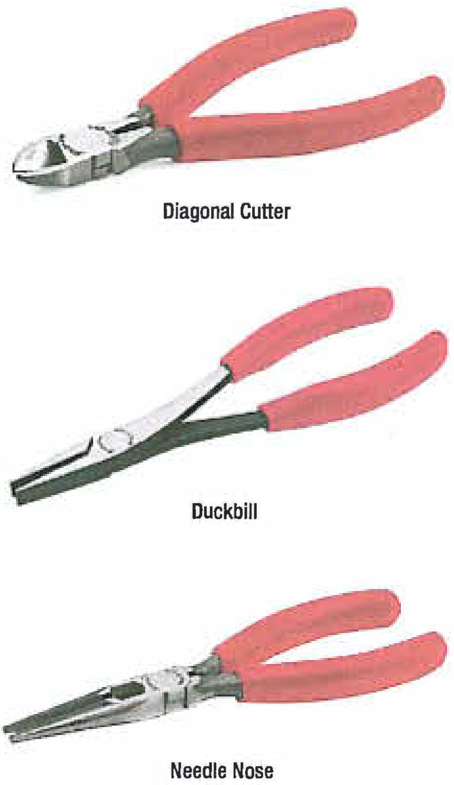


Figure 3-14. Pliers.

Diagonal pliers are usually referred to as diagonals or "dikes." The diagonal is a short-jawed cutter with a blade set at a slight angle on each jaw. This tool can be used to cut wire, rivets, small screws, and cotter pins, besides being practically indispensable in removing or installing safety wire. The duckbill pliers and the diagonal cutting pliers are used extensively in aviation for the job of safety wiring.

Two important rules for using pliers are:

1. Do not make pliers work beyond their capacity. The long-nosed variety is especially delicate. It is easy to spring or break them, or nick the edges. If this occurs, they are practically useless.
2. Do not use pliers to turn nuts. In just a few seconds, a pair of pliers can damage a nut more than years of service.

CLAMPS AND VISES

In order to work with sheet metal during the fabrication process, the aviation technician uses a variety of holding devices, such as clamps, vises, and fasteners (see sub-module 8 for more on fasteners) to hold the work together. The type of operation being performed and the type of metal being used determine what type of the holding device is needed.

Clamps and vises hold materials in place when it is not possible to handle a tool and the workpiece at the same time. A clamp is a fastening device with movable jaws that has opposing, often adjustable, sides or parts. An essential fastening device, it holds objects tightly together to prevent movement or separation.

Clamps can be either temporary or permanent. A clamp is a fastening device with movable jaws that has opposing, often adjustable, sides or parts. An essential fastening device, it holds objects tightly together to prevent movement or separation. Temporary clamps, such as the carriage clamp (commonly called the C-clamp), are used to position components while fixing them together.

C-CLAMPS

The C-clamp is shaped like a large C and has three main parts: threaded screw, jaw, and swivel head. (***Figure 3-15***) The swivel plate or flat end of the screw prevents the end from turning directly against the material being clamped. C-clamp size is measured by the dimension of the largest object the frame can accommodate with the screw fully extended. The distance from the center line of the screw to the inside edge of the frame or the depth of throat is also an important consideration when using this clamp. C-clamps vary in size from one inch upward. C-clamps can leave marks on aluminum, protect the aircraft covering with masking tape at the places where the C-clamp is used.

Figure 3-15. C-clamps.

VISES

Vises are another clamping device that hold the workpiece in place and allow work to be done on it with tools such as saws and drills.

The vise consists of two fixed or adjustable jaws that are opened or closed by a screw or a lever. The size of a vise is measured by both the jaw width and the capacity of the vise when the jaws are fully open. Vises also depend on a screw to apply pressure, and their textured jaws enhance gripping ability beyond that of a clamp.

Two of the most commonly used vises are the machinist's vise and the utility vise. The machinist's vise has flat jaws and usually a swivel base, whereas the utility bench vise has scored, removable jaws and an anvil-faced back jaw. This vise holds heavier material than the machinist's vise and also grips pipe or rod firmly. The back jaw can be used as an anvil if the work being done is light. To avoid marring metal in the vise jaws, add some type of padding, such as a ready-made rubber jaw pad. (***Figure 3-16***)

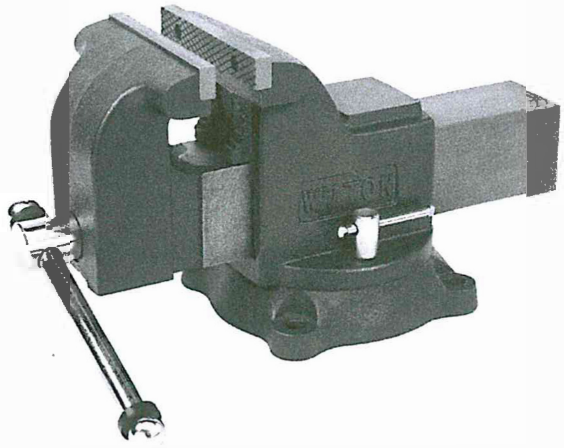


Figure 3-16. Utility vise with swivel base and anvil.

HAMMERS AND MALLETS

Figure 3-17 shows some of the hammers that the aviation mechanic may be required to use. Metal head hammers are usually sized according to the weight of the head without the handle.

Occasionally it is necessary to use a soft-faced hammer, which has a striking surface made of wood, brass, lead, rawhide, hard rubber, or plastic. These hammers are intended for use in forming soft metals and striking surfaces that are easily damaged. Soft-faced hammers should not be used for striking punch heads, bolts, or nails, as using one in this fashion will quickly ruin this type of hammer. A mallet is a hammer-like tool with a head made of hickory, rawhide, or rubber. It is handy for shaping thin metal parts without causing creases or dents with abrupt corners. Always use a wooden mallet when pounding a wood chisel or a gouge.

When using a hammer or mallet, choose the one best suited for the job. Ensure that the handle is tight. When striking a blow with the hammer, use the forearm as an extension of the handle. Swing the hammer by bending the elbow, not the wrist. Always strike the work squarely with the full face of the hammer. When striking a metal tool with a metal hammer, the use of safety glasses or goggles is strongly encouraged. Always keep the faces of hammers and mallets smooth and free from dents, chips, or gouges to prevent marring the work.

PUNCHES

Punches are used to locate centers for drawing circles, to start holes for drilling, to punch holes in sheet metal, to transfer location of holes in patterns, and to remove damaged rivets, pins or bolts. Solid or hollow punches are the two types generally used. Solid punches are classified according to the shape of their points. ***Figure 3-18*** shows several types of punches.

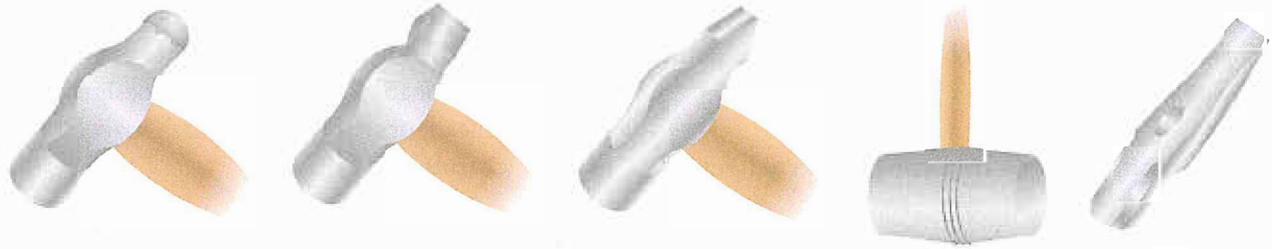


Figure 3-17. Hammers.

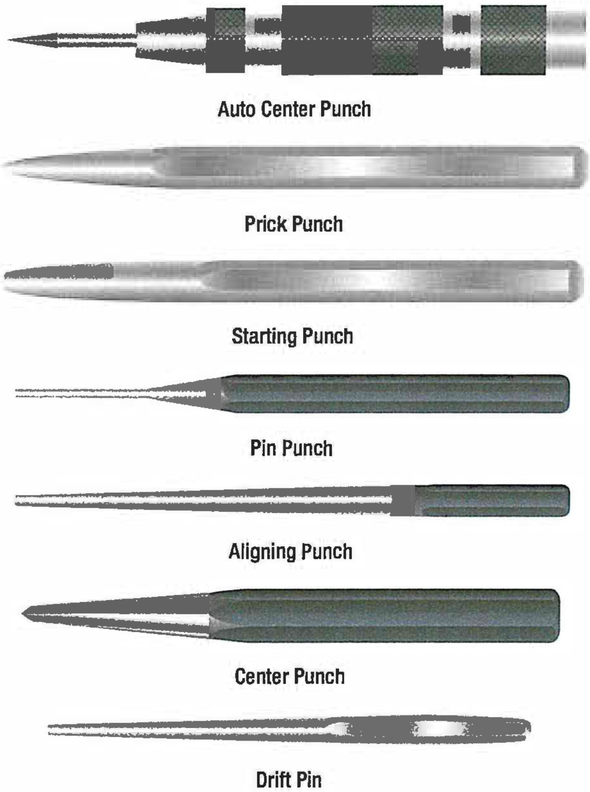


Figure 3-18. Punches.

Prick punches are used to place reference marks on metal. This punch is often used to transfer dimensions from a paper pattern directly on the metal. To do this, first place the paper pattern directly on the metal. Then go over the outline of the pattern with the prick punch, tapping it lightly with a small hammer and making slight indentations on the metal at the major points on the drawing. These indentations can then be used as reference marks for cutting the metal. A prick punch should never be struck a heavy blow with a hammer because it may bend the punch or cause excessive damage to the material being worked.

Large indentations in metal, which are necessary to start a twist drill, are made with a center punch. It should never be struck with enough force to dimple the material around the indentation or to cause the metal to protrude through the other side of the sheet. A center punch has a heavier body than a prick punch and is ground to a point with an angle of about 60°.

The drive punch, which is often called a tapered punch, is used for driving out damaged rivets, pins, and bolts that sometimes bind in holes. The drive punch is therefore made with a flat face instead of a point. The size of the punch is determined by the width of the face, which is usually ⅛ inch to ¼ inch. Pin punches, often called drift punches, are similar to drive punches and are used for the same purposes. The difference between the two is that the sides of a drive punch taper all the way to the face while the pin punch has a straight shank. Pin punches are sized by the diameter of the face, in thirty-seconds of an inch, and range from 1/16 to ⅜ inch in diameter. In general practice, a pin or bolt which is to be driven out is usually started and driven with a drive punch until the sides of the punch touch the side of the hole. A pin punch is then used to drive the pin or bolt the rest of the way out of the hole. Stubborn pins may be started by placing a thin piece of scrap copper, brass, or aluminum directly against the pin and then striking it with a hammer until the pin begins to move.

Never use a prick punch or center punch to remove objects from holes because the point of the punch will spread the object and cause it to bind even more.

The transfer punch is usually about 4 inches long. It has a point that tapers, and then turns straight for a short distance in order to fit a drill locating hole in a template. The tip has a point similar to that of a prick punch. As its name implies, the transfer punch is used to transfer the location of holes through the template or pattern to the material.

WRENCHES

The wrenches most often used in aircraft maintenance are classified as open-end, box-end, socket, adjustable, ratcheting and special wrenches. The Allen wrench, is required on one special type of recessed screw. One of the most widely used metals for making wrenches is chrome-vanadium steel. Wrenches made of this metal are almost unbreakable.

OPEN-END WRENCHES

Solid, nonadjustable wrenches with open parallel jaws on one or on both ends are known as open-end wrenches. Open-end wrenches may have their jaws parallel to the handle or at an angle of up to 90°; most are set at an angle of 15°. The wrenches are designed to fit on a nut, bolt head, or other object, which makes it possible to exert a turning action.

BOX-END WRENCHES

Box-end wrenches are popular tools because of their usefulness in close quarters. They are called box wrenches since they box, or completely surround, the nut or bolt head. Practically all well-manufactured box-end wrenches are made with 12 points so they can be used in places having as little as 15° swing. In ***Figure 3-19***, point A on the illustrated double broached hexagon wrench is nearer the centerline of the head and the wrench handle than point B, and also the centerline of nut C. If the wrench is inverted and installed on nut C, point A will be centered over side "Y" instead of side "X." The centerline of the handle will now be in the dotted line position. It is by reversing (turning the wrench over) the position of the wrench that a 15° arc may be made with the wrench handle.

Although box-end wrenches are ideal to break loose tight nuts or pull tight nuts tighter, time is lost turning the nut off the bolt once the nut is broken loose. Only when there is sufficient clearance to rotate the wrench in a complete circle can this tedious process be avoided.

After a tight nut is broken loose, it can be completely backed off or unscrewed more quickly with an open than with a box-end wrench. In this case, a combination wrench can be used; it has a box end on one end and an open-end wrench of the same size on the other. Another option for removing a nut from a bolt is the ratcheting box-end wrench, which can be swung back and forth to remove the nut or bolt. The box-end, combination, and ratcheting wrenches are shown in ***Figure 3-20***.

SOCKET WRENCHES

Sockets with detachable handles usually come in sets and fit several types of handles, such as the T, ratchet, screwdriver grip, and speed handle. Socket wrench handles have a square lug on one end that fits into a square recess in the socket head. The two parts are held together by a light spring-loaded poppet. Two types of sockets, a set of handles, and an extension bar are shown in ***Figure 3-21***.

ADJUSTABLE WRENCHES

The adjustable wrench is a handy utility tool that has smooth jaws and is designed as an open-end wrench. One jaw is fixed, but the other may be moved by a thumbscrew or spiral screwworm adjustment in the handle. The width of the jaws may be varied from 0 to ½ inch or more. The angle of the opening to the handle is 22½ degrees on an adjustable wrench. One adjustable wrench does the work of several open-end wrenches. Although versatile, they are not intended to replace the standard open-end, box-end, or socket wrenches. When using any adjustable wrench, always exert the pull on the side of the handle attached to the fixed jaw of the wrench. To minimize the possibility or rounding off the fastener, use care to fit the wrench to the bolt or nut to be turned.

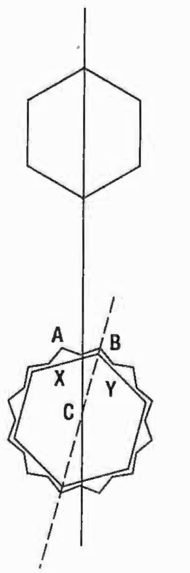


Figure 3-19. Box-end wrench use.

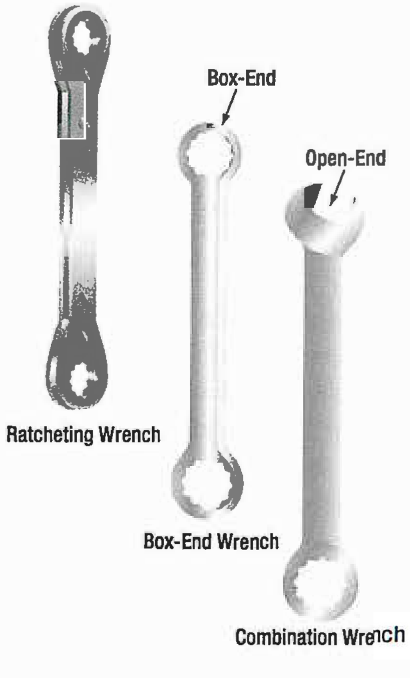


Figure 3-20. Box-end wrench use.

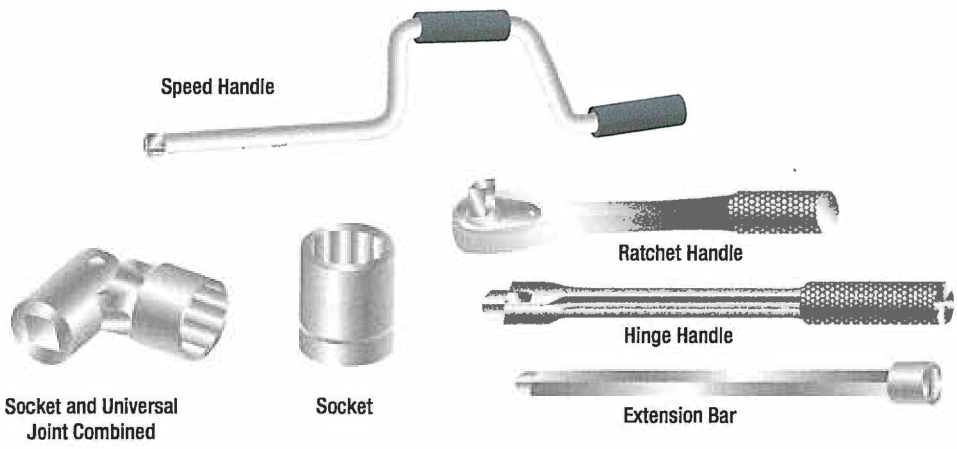


Figure 3-21. Socket wrench set.

SPECIAL WRENCHES

The category of special wrenches includes the crowfoot, flare nut, spanner, torque, and Allen wrenches. (*Figures 3-22)*

The crowfoot wrench is normally used when accessing nuts that must be removed from studs or bolts that cannot be accessed using other tools.

The flare nut wrench has the appearance of a box-end wrench that has been cut open on one end. This opening allows the wrench to be used on the B-nut of a fuel, hydraulic, or oxygen line. Since it mounts using the standard square adapter, like the crowfoot wrench, it can be used in conjunction with a torque wrench.

The hook spanner is for a round nut with a series of notches cut in the outer edge. This wrench has a curved arm with a hook on the end that fits into one of the notches on the nut. The hook is placed in one of these notches with the handle pointing in the direction the nut is to be turned.

Some hook spanner wrenches are adjustable and will fit nuts of various diameters. U-shaped hook spanners have two lugs on the face of the wrench to fit notches cut in the face of the nut or screw plug. End spanners resemble a socket wrench, but have a series of lugs that fit into corresponding notches in a nut or plug. Pin spanners have a pin in place of a lug, and the pin fits into a round hole in the edge of a nut. Face pin spanners are similar to the U-shaped hook spanners except that they have pins instead of lugs.

Most headless setscrews are the hex-head Allen type and must be installed and removed with an Allen wrench. Allen wrenches are six-sided bars in the shape of an L, or they can be hex-shaped bars mounted in adapters for use with hand ratchets. They range in size from 3⁄64 to ½ inch and fit into a hexagonal recess in the setscrew.

STRAP WRENCHES

The strap wrench can prove to be an invaluable tool for the AMT. By their very nature, aircraft components such as tubing, pipes, small fittings, and round or irregularly shaped components are built to be as light as possible, while still retaining enough strength to function properly. The misuse of pliers or other gripping tools can quickly damage these parts. If it is necessary to grip a part to hold it in place, or to rotate it to facilitate removal, consider using a strap wrench that uses a plastic covered fabric strap to grip the part. (***Figure 3-23***)

IMPACT DRIVERS

Although not typically used on aircraft, except with extreme care on some heavy structures, an impact driver may be required. Struck with a mallet, the impact driver uses cam action to impart a high amount of torque in a sharp impact to break loose a stubborn fastener. The drive portion of the impact driver can accept a number of different bits and sockets. The use of special bits and sockets specifically manufactured for use with an impact driver is required. (***Figure 3-24***)

TORQUE WRENCHES

There are times when a specific pressure must be applied to a nut or bolt as it is installed. In such cases a calibrated torque wrench must be used. A calibrated torque wrench

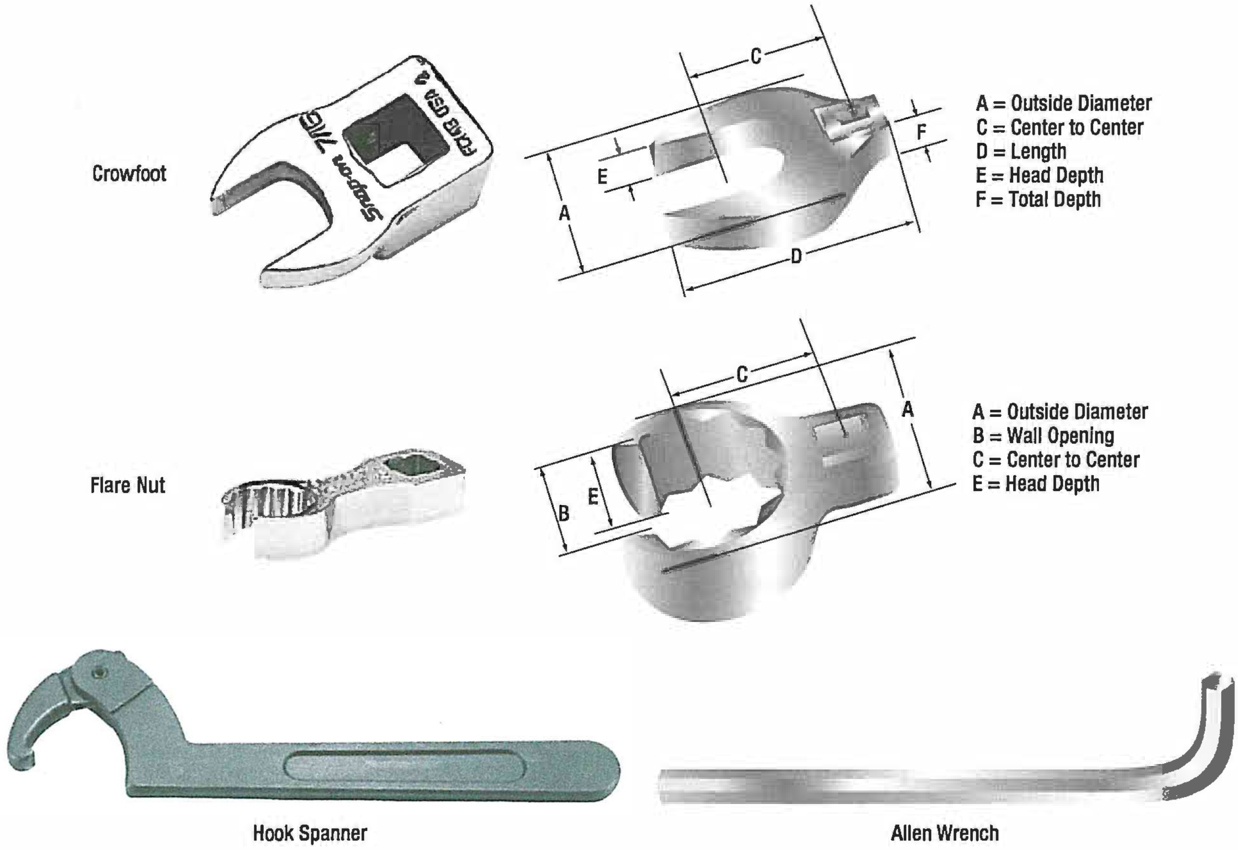


Figure 3-22. Special wrenches.

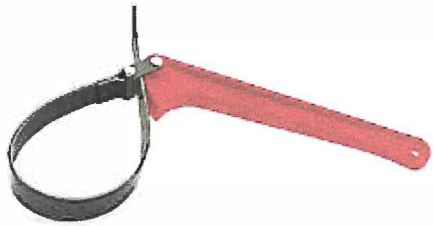


Figure 3-23. Strap wrench.

Figure 3-24. Impact driver.

is a precision tool consisting of a torque indicating handle and appropriate adapter or attachments. It measures the amount of turning or twisting force applied to a nut, bolt, or screw. Commonly used torque wrenches include the deflecting beam, dial indicating, micrometer, and electronic setting types. ***(Figure 3-25)***

When using the deflecting beam and dial indicating torque wrenches, the torque is read visually on a dial or scale mounted on the handle of the wrench. The micrometer setting torque wrench is preset to the desired value. When this torque is reached, the operator notices a sharp impulse or breakaway "click"

Under controlled conditions, the amount of force required to turn a fastener is directly related to the tensile strength of the fastener. The amount of torque, measured in inch-pounds or foot-pounds, is the product of the force required to turn the fastener multiplied by the distance between the center of the fastener and the point at which the force is applied. For example, a torque wrench has a length permanently established between the center of the drive hub and a pivot in the handle.

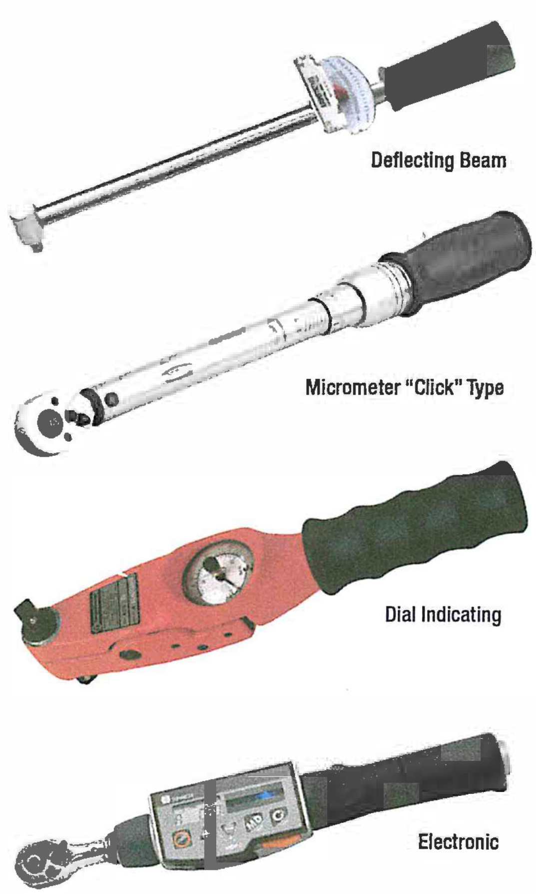


Figure 3-25. Torque wrenches.

The force is measured by the amount the beam deflects or by the tension set by a calibrated spring inside the wrench handle. Hooke's Law states that the amount a beam deflects is directly related to the force applied. Therefore, if the lever is exactly 12 inches long, and a force of 30 pounds is applied to the handle, a torque of 360 inch-pounds is produced on the fastener.

$$12 \text{ inches} \times 30 \text{ lbs} = 360 \text{ inch-pounds}$$

For additional information on the installation of fasteners requiring the use of a torque wrench, refer to "Installation of Nuts, Washers, and Bolts" located in *Module 06, SubModule 05.*

Before each use, the torque wrench should be visually inspected for damage. If a bent pointer, cracked glass, or signs of rough handling are found, the wrench must be tested or recalibrated to ensure accuracy. In addition, all torque wrenches should be professionally recalibrated by a metrology lab at least once per year. ***Figure 3-26*** shows a professional calibration device.

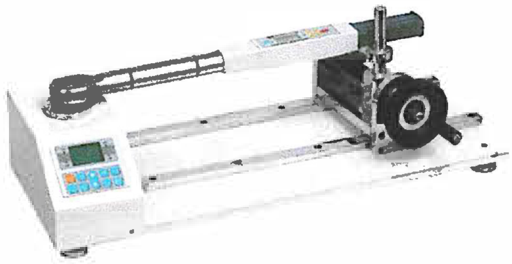


Figure 3-26. Torque wrench calibration tool.

When an extension ***(Figure 3-27)*** is needed to reach a particular fastener, the length of the torque wrench changes and so the indication of torque needs to be recalculated to find the actual torque being applied.

Figure 3-27. A typical torque wrench extension in the straight position.

For example, if the length from the drive head to the handle is 20 inches and a 5-inch extension is added, a reading of 120 inch-pounds results in 150 inch-pounds of torque actually applied. To find the torque applied to a fastener when using an extension, use this formula: ***(Figure 3-28)***

$$T_A = \frac{T_W (L + E)}{L}$$

T_A = desired torque
T_W = indicated torque
L = length of torque wrench without extension
E = added or subtracted length of extension from hub of wrench

By shifting the variables, this similar formula can be used to determine what a torque wrench will indicate for a given torque on a fastener.

$$T_W = \frac{T_A \times L}{(L + E)}$$

Using the figures above, we find that in order to apply 150 inch-pounds on a fastener with a straight 5 inch extension, the torque indicator needs to read 120 inch-pounds.

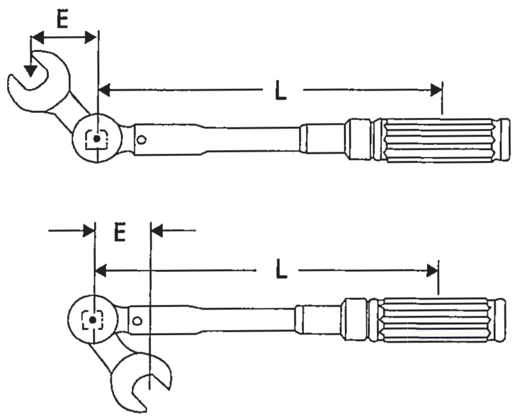


Figure 3-28. Variables for torque formula.

CUTTING TOOLS-HAND AND POWER

Powered and non-powered metal cutting tools available to the aviation technician include various types of saws, nibblers, shears, sanders, notchers, and grinders. Both hand-held power tools and larger shop-based power tools are used during aviation maintenance. They tend to accomplish a job faster than non-powered tools and may even perform tasks not possible with non-powered hand tools. Extreme caution must be exercised when using any power tool. An incorrectly used power tool can cause injury and even death. Always seek instruction on how to use a tool that is unfamiliar.

In general, power tools are either electrically powered or pneumatically powered. Large shop tools are typically electrically powered. The fact that they are stationary and located a long distance from the aircraft permits the advantages of electric power without too much concern of fire danger. Powered hand tools are electric or pneumatic. Pneumatic tools are preferred in the hangar and on the ramp since they are spark free and pose little threat of fire compared to electric tools. A large, remotely located air compressor with a manifold of rigid tubing throughout the hangar or shop can usually supply enough pneumatic power for an entire operation. The technician simply connects one end of a flexible hose into the manifold and the other end to the pneumatic tool for power.

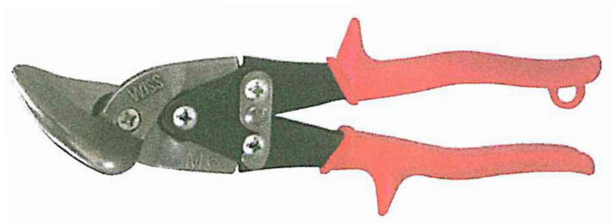
Due to the dominance of aluminum in aircraft construction, many of the power tools used in aviation are metal working tools. Of these, cutting tools, drilling tools and forming tools are common.

Also due to size, weight, and/or power source, shop tools are usually in a fixed location, and the airframe part to be constructed or repaired is brought to the tool.

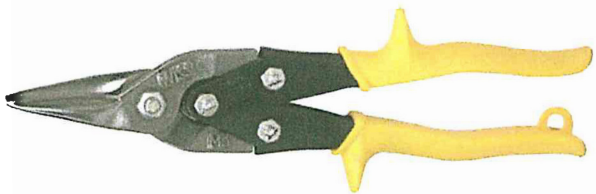
SNIPS

HAND SNIPS

There are several kinds of hand snips, each of which serves a different purpose. Straight, curved, hawksbill, and aviation snips are in common use. Straight snips are used for cutting straight lines when the distance is not great enough to use a squaring shear and for cutting the outside of a curve. The other types are used for cutting the inside of curves or radii. Snips should never be used to cut heavy sheet metal. (***Figure 3-29***)



Left Cut Snips



Straight Snips

Figure 3-29. Typical snips.

Aviation snips are designed especially for cutting heat treated aluminum alloy and stainless steel. They are also adaptable for enlarging small holes. The blades have small teeth on the cutting edges and are shaped for cutting very small circles and irregular outlines. The handles are the compound leverage type, making it possible to cut material as thick as 0.051 inch. Aviation snips are available in two types, those which cut from right to left and those which cut from left to right.

Unlike the hacksaw, snips do not remove any material when the cut is made, but minute fractures often occur along the cut. Therefore, cuts should be made about $\frac{1}{32}$ inch from the layout line and finished by hand filing down to the line.

STRAIGHT SNIPS

Straight snips, or sheet metal shears, have straight blades with cutting edges sharpened to an 85° angle. (***Figure 3-30***) Available in sizes ranging from 6 to 14 inches, they cut aluminum up to $\frac{1}{16}$ of an inch. Straight snips can be used for straight cutting and large curves, but aviation snips are better for cutting circles or arcs.

AVIATION SNIPS

Aviation snips are used to cut holes, curved parts, round patches, and doublers (a piece of metal placed under a part to make it stiffer) in sheet metal. Aviation snips have colored handles to identify the direction of the cuts: yellow aviation snips cut straight, green aviation snips curve right, and red aviation snips curve left. (***Figure 3-31***)

HACKSAWS

The common hacksaw has a blade, a frame, and a handle. The handle can be obtained in two styles: pistol grip and straight. (***Figure 3-32***)

Hacksaw blades have holes in both ends; they are mounted on pins attached to the frame. When installing a blade in a hacksaw frame, mount the blade with the teeth pointing forward, away from the handle.

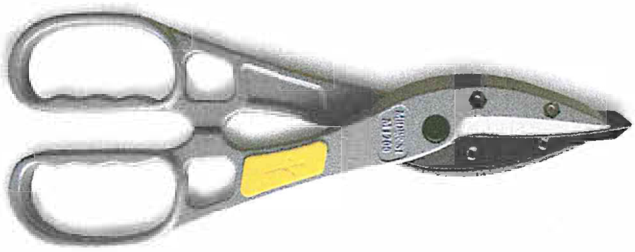


Figure 3-30. Straight snips.

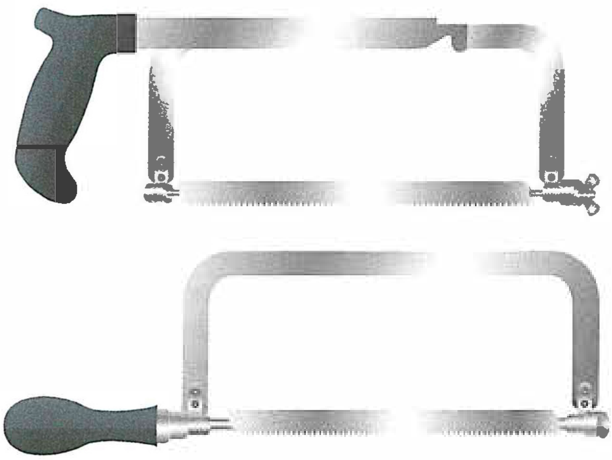


Figure 3-32. Typical hacksaws.

Figure 3-31. Aviation snips.

Blades are made of high-grade tool steel or tungsten steel and are available in sizes from 6 to 16 inches in length. The 10-inch blade is most commonly used. There are two types, the all-hard blade and the flexible blade. In flexible blades, only the teeth are hardened.

Selection of the best blade for the job involves finding the right type and pitch. An all-hard blade is best for sawing brass, tool steel, cast iron, and heavy cross-section materials. A flexible blade is often best for sawing hollow shapes and metals having a thin cross section.

The pitch of a blade indicates the number of teeth per inch. Pitches of 14, 18, 24, and 32 teeth per inch are available. A blade with 14 teeth per inch is preferred when cutting machine steel, cold rolled steel, or structural steel. A blade with 18 teeth per inch is preferred for solid stock aluminum, bearing metal, tool steel, and cast iron. Use a blade with 24 teeth per inch when cutting thick-walled tubing, pipe, brass, copper, channel, and angle iron. Use the 32 teeth per inch blade for cutting thin-walled tubing and sheet metal.

When using a hacksaw, observe the following procedures:

1. Select an appropriate saw blade for the job.
2. Assemble the blade in the frame so the cutting edge of the teeth points away from the handle.
3. Adjust tension of the blade in the frame to prevent the saw from buckling and drifting.
4. Clamp the work in the vise in such a way that will provide as much bearing surface as possible and will engage the greatest number of teeth.
5. Indicate the starting point by nicking the surface with the edge of a file to break any sharp corner that might strip the teeth. This mark will also aid in starting the saw at the proper place.
6. Hold the saw at an angle that will keep at least two teeth in contact with the work at all times. Start the cut with a light, steady, forward stroke just outside the cutting line. At the end of the stroke, relieve the pressure and draw the blade back. (The cut is made on the forward stroke.)
7. After the first few strokes, make each stroke as long as the hacksaw frame will allow. This will prevent the blade from overheating. Apply just enough pressure on the forward stroke to cause each tooth to remove a small amount of metal. The strokes should be long and steady with a speed not more than 40 to 50 strokes per minute.
8. After completing the cut, remove chips from the blade, loosen tension on the blade, and return the hacksaw to its proper place.

CHISELS

A chisel is a hard steel cutting tool that can be used for cutting and chipping any metal softer than the chisel itself. It can be used in restricted areas and for such work as shearing rivets, or splitting seized or damaged nuts from bolts. (***Figure 3-33***)

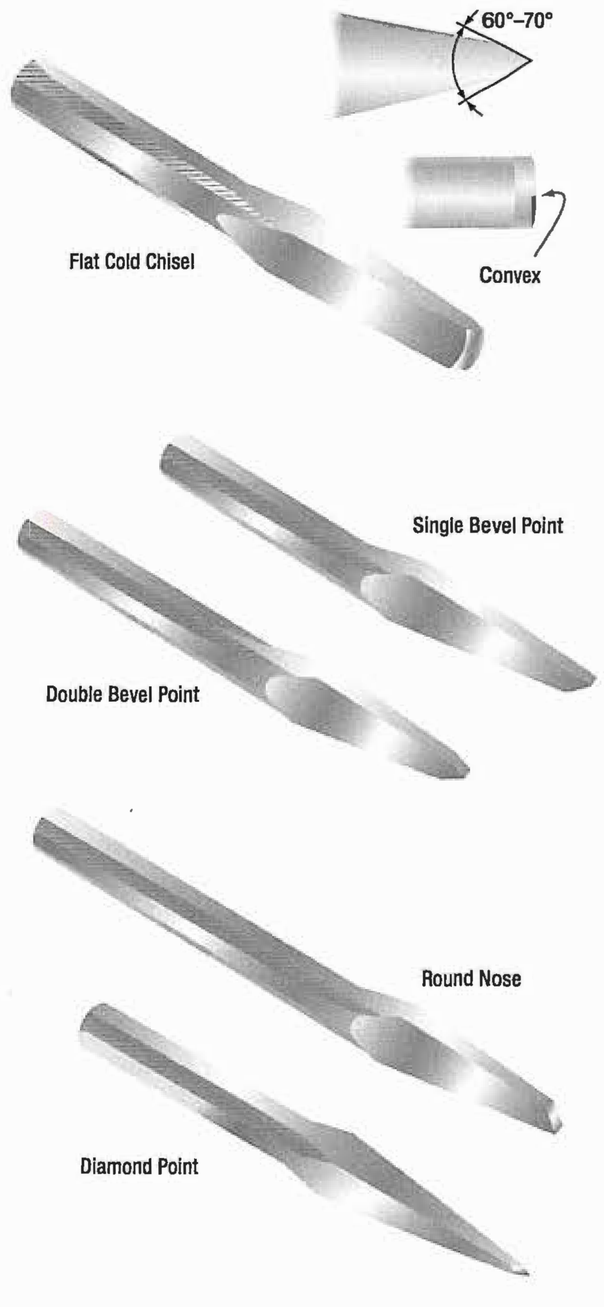


Figure 3-33. Chisels.

The size of a flat cold chisel is determined by the width of the cutting edge. Lengths will vary, but chisels are seldom under 5 inches or over 8 inches long.

Chisels are usually made of eight-sided tool steel bar stock, carefully hardened and tempered. Since the cutting edge is slightly convex, the center portion receives the greatest shock when cutting, and the weaker corners are protected. The cutting angle should be 60° to 70° for general use, such as for cutting wire, strap iron, or small bars and rods.

When using a chisel, hold it firmly in one hand. With the other hand, strike the chisel head squarely with a ball peen hammer.

When cutting square corners or slots, a special cold chisel called a cape chisel should be used. It is like a flat chisel except the cutting edge is very narrow. It has the same cutting angle and is held and used in the same manner as any other chisel.

Rounded or semicircular grooves and corners that have fillets should be cut with a roundnose chisel. This chisel is also used to re-center a drill that has moved away from its intended center.

The diamond point chisel is tapered to a square at the cutting end, and then ground at an angle to provide the sharp diamond point. It is used for cutting B-grooves and inside sharp angles.

FILES

The file is an important but often overlooked tool used to shape metal by cutting and abrasion. Files have five distinct properties: length, contour, the form in cross section, the kind of teeth, and the fineness of the teeth. Many different types of files are available and the sizes range from 3 to 18 inches. (***Figure 3-34***)

The portion of the file on which the teeth are cut is called the face. The tapered end that fits into the handle is called the tang. The part of the file where the tang begins is the heel. The length of a file is the distance from the point or tip to the heel and does not include the tang. The teeth of the file do the cutting. These teeth are set at an angle across the face of the file. A file with a single row of parallel teeth is called a single-cut file. The teeth are cut at an angle of 65°–85° to the centerline,

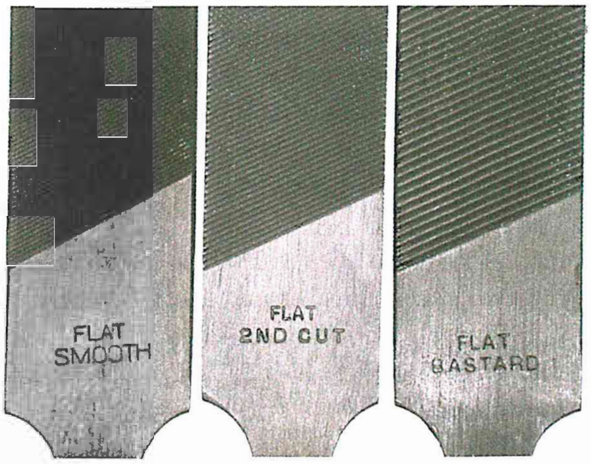


Figure 3-34. Files.

depending on the intended use of the file. Files that have one row of teeth crossing another row in a crisscross pattern are called double-cut files. The angle of the first set usually is 40°–50° and that of the crossing teeth 70°–80°. Crisscrossing produces a surface that has a very large number of little teeth that slant toward the tip of the file. Each little tooth looks like an end of a diamond point cold chisel.

Files are graded according to the tooth spacing; a coarse file has a small number of large teeth, and a smooth file has a large number of fine teeth. The coarser the teeth, the more metal is removed on each stroke of the file. The terms used to indicate the coarseness or fineness of a file are rough, coarse, bastard, second cut, smooth, and dead smooth, and the file may be either single cut or double cut. Files are further classified according to their shape. Some of the more common types are: flat, triangle, square, half round, and round. There are several filing techniques. The most common is to remove rough edges and slivers from the finished part before it is installed. Crossfiling is a method used for filing the edges of metal parts that must fit tightly together.

Crossfiling involves clamping the metal between two strips of wood and filing the edge of the metal down to a preset line. Draw filing is used when larger surfaces need to be smoothed and squared. It is done by drawing the file over the entire surface of the work.

To protect the teeth of a file, files should be stored separately in a plastic wrap or hung by their handles. Files kept in a toolbox should be wrapped in waxed paper to prevent rust from forming on the teeth. File teeth can be cleaned with a file card.

Most files are made of high-grade tool steels that are hardened and tempered. Files are manufactured in a variety of shapes and sizes. They are known either by the cross section, the general shape, or by their particular use. The cuts of files must be considered when selecting them for various types of work and materials. Files are used to square ends, file rounded corners, remove burrs and slivers from metal, straighten uneven edges, file holes and slots, and smooth rough edges.

Files have three distinguishing features: (1) their length, measured exclusive of the tang (***Figure 3-35***); (2) their kind or name, which has reference to the relative coarseness of the teeth; and (3) their cut.

Files are usually made in two types of cuts: single cut and double cut. The single cut file has a single row of teeth extending across the face at an angle of 65° to 85° with the length of the file. The size of the cuts depends on the coarseness of the file. The double cut file has two rows of teeth that cross each other. For general work, the angle of the first row is 40° to 45°. The first row is generally referred to as "overcut," and the second row as "upcut;" the upcut is somewhat finer and not as deep as the overcut.

FILES-TYPES AND USE

Files and rasps are cataloged in three ways:

- Length. Measuring from the tip to the heel of the file. The tang is never included in the length.
- Shape. Refers to the physical configuration of the file (circular, rectangular, or triangular or a variation thereof).
- Cut. Refers to both the character of the teeth or the coarseness — rough, coarse, and bastard for use on heavier classes of work and second cut, smooth and dead smooth for finishing work.

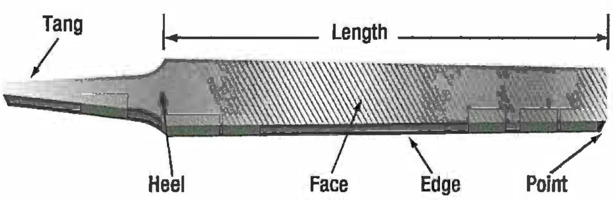


Figure 3-35. Hand file.

Most Commonly Used Files: (***Figure 3-36***)

- Hand files—These are parallel in width and tapered in thickness. They have one safe edge (smooth edge) which permits filing in corners, and on other work where a safe edge is required. Hand files are double cut and used principally for finishing flat surfaces and similar work.
- Flat files—These files are slightly tapered toward the point in both width and thickness. They cut on both edges as well as on the sides. They are the most common files in use. Flat files are double cut on both sides and single cut on both edges.
- Mill files—These are usually tapered slightly in thickness and in width for about one-third of their length. The teeth are ordinarily single cut. These files are used for draw filing and to some extent for filing soft metals.

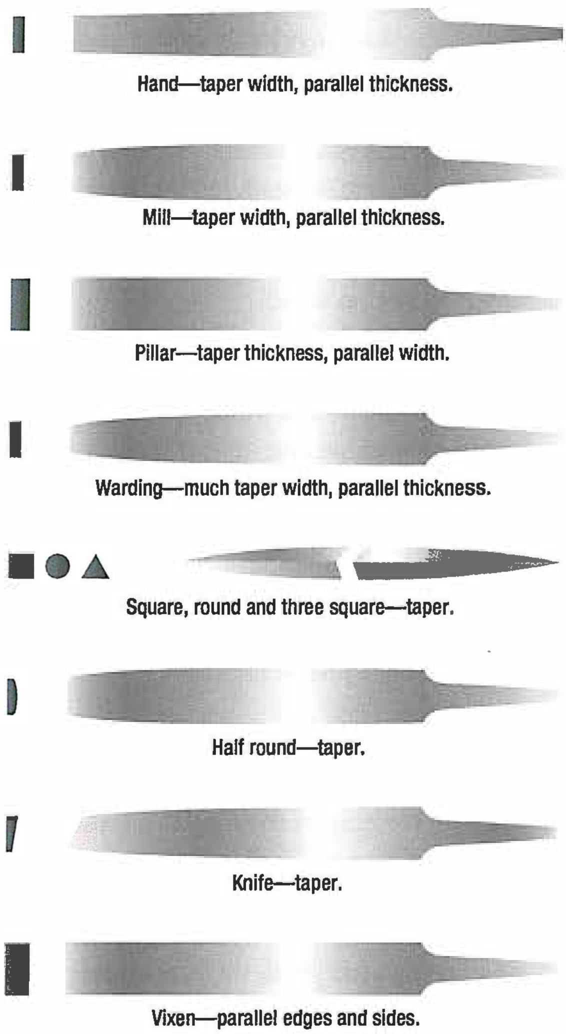


Figure 3-36. Types of files.

- Square files—These files may be tapered or blunt and are double cut. They are used principally for filing slots and key seats, and for surface filing.
- Round or rattail files—These are circular in cross section and may be either tapered or blunt and single or double cut. They are used principally for filing circular openings or concave surfaces.
- Triangular and three square files—These files are triangular in cross section. Triangular files are single cut and are used for filing the gullet between saw teeth. Three square files, which are double cut, may be used for filing internal angles, clearing out corners, and filing taps and cutters.
- Half-round files—These files cut on both the flat and round sides. They may be single or double cut. Their shape permits them to be used where other files would be unsatisfactory.
- Lead float files—These are especially designed for use on soft metals. They are single cut and are made in various lengths.
- Warding file—Rectangular in section and tapers to narrow point in width. This file is used for narrow space filing where other files cannot be used.
- Knife file—Knife blade section. This file is used by tool and die makers on work having acute angles.
- Wood file—Same section as flat and half-round files. This file has coarser teeth and is especially adaptable for use on wood.
- Vixen (curved-tooth files)—Curved-tooth files are especially designed for rapid filing and smooth finish on soft metals and wood. The regular cut is adapted to work on cast iron, soft steel, copper, brass, aluminum, wood, slate, marble, fiber, rubber, and so forth. The fine cut gives excellent results on steel, cast iron, phosphor bronze, white brass, and all hard metals. The smooth cut is used where the amount of material to be removed is very slight, but where a superior finish is desired.

The following methods are recommended for using files:

1. Crossfiling. Before attempting to use a file, place a handle on the tang of the file. This is essential for proper guiding and safe use. In moving the file endwise across the work (commonly known as crossfiling), grasp the handle so that its end fits into and against the fleshy part of the palm with the thumb lying along the top of the handle in a lengthwise direction. Grasp the end of the file between the thumb and first two fingers. To prevent undue wear of the file, relieve the pressure during the return stroke.
2. Drawfiling. A file is sometimes used by grasping it at each end, crosswise to the work, then moving it lengthwise with the work. When done properly, work may be finished somewhat finer than when crossfiling with the same file. In drawfiling, the teeth of the file produce a shearing effect. To accomplish this shearing effect, the angle at which the file is held with respect to its line of movement varies with different files, depending on the angle at which the teeth are cut. Pressure should be relieved during the backstroke.
3. Rounding corners. The method used in filing a rounded surface depends upon its width and the radius of the rounded surface. If the surface is narrow or only a portion of a surface is to be rounded, start the forward stroke of the file with the point of the file inclined downward at approximately a 45° angle. Using a rocking chair motion, finish the stroke with the heel of the file near the curved surface. This method allows use of the full length of the file.
4. Removing burred or slivered edges. Practically every cutting operation on sheet metal produces burrs or slivers. These must be removed to avoid personal injury and to prevent scratching and marring of parts to be assembled. Burrs and slivers will prevent parts from fitting properly and should always be removed from the work.

Lathe filing requires that the file be held against the work revolving in the lathe. The file should not be held rigid or stationary but should be stroked constantly with a slight gliding or lateral motion along the work. A standard mill file may be used for this operation, but the long angle lathe file provides a much cleaner shearing and self-clearing action. Use a file with "safe" edges to protect work with shoulders from being marred. There are several precautions that any good craftsman will take in caring for files.

CARE OF FILES

1. Choose the right file for the material and work to be performed.
2. Keep all files racked and separated so they do not, wear against each other.
3. Keep the files in a dry place—rust will corrode the teeth points, dulling the file.

4. Keep files clean. Tap the end of the file against the bench after every few strokes, to loosen and clear the filings. Use the file card to keep files clean; a dirty file is a dull file. A dirty file can also contaminate different metals when the same file is used on multiple metal surfaces.

Particles of metal collect between the teeth of a file and may make deep scratches in the material being filed. When these particles of metal are lodged too firmly between the teeth and cannot be removed by tapping the edge of the file, remove them with a file card or wire brush. Draw the brush across the file so that the bristles pass down the gullet between the teeth. (***Figure 3-37***)

CIRCULAR-CUTTING SAWS

The circular cutting saw cuts with a toothed, steel disk that rotates at high speed. Handheld or table mounted and powered by compressed air, this power saw cuts metal or wood. To prevent the saw from grabbing the metal, keep a firm grip on the saw handle at all times. Check the blade carefully for cracks prior to installation because a cracked blade can fly apart during use, possibly causing serious injury.

KETT SAW

The Kett saw is an electrically operated, portable circular cutting saw that uses blades of various diameters. (***Figure 3-38***) Since the head of this saw can be turned to any desired angle, it is useful for removing damaged sections on a stringer.

The advantages of a Kett saw include:

1. Can cut metal up to $\frac{3}{16}$-inch in thickness.
2. No starting hole is required.
3. A cut can be started anywhere on a sheet of metal.
4. Can cut an inside or outside radius.

PNEUMATIC CIRCULAR-CUTTING SAW

The pneumatic circular cutting saw, useful for cutting out damage, is similar to the Kett saw. (***Figure 3-39***)

RECIPROCATING SAW

The versatile reciprocating saw achieves cutting action through a push and pull (reciprocating) motion of the blade. This saw can be used right side up or upside down, a feature that makes it handier than the circular saw for working in tight or awkward spots. A variety of blade types are available for reciprocating saws; blades with finer teeth are used for cutting through metal. The portable, air-powered reciprocating saw uses a standard hacksaw blade and can cut a 360° circle or a square or rectangular hole.

Unsuited for fine precision work, this saw is more difficult to control than the pneumatic circular cutting saw. A reciprocating saw should be used in such a way that at least two teeth of the saw blade are cutting at all times. Avoid applying too much downward pressure on the saw handle because the blade may break. (***Figure 3-40***)

Figure 3-38. Kett saw.

Figure 3-37. File card.

Figure 3-39. Pneumatic circular saw.

Figure 3-40. Reciprocating saw.

DIE GRINDER

A die grinder is a handheld tool that turns a mounted cutoff wheel, rotary file, or sanding disk at high speed. (***Figure 3-41***) Usually powered by compressed air, electric die grinders are also used. Pneumatic die grinders run at 12 000 to 20 000 revolutions per minute (rpm) with the rotational speed controlled by the operator who uses a hand or foot-operated throttle to vary the volume of compressed air. Available in straight, 45°, and 90° models, the die grinder is excellent for weld breaking, smoothing sharp edges, deburring, porting, and general high-speed polishing, grinding, and cutting.

CUT-OFF WHEEL

A cut-off wheel is a thin abrasive disc driven by a high-speed pneumatic die-grinder and used to cut out damage on aircraft skin and stringers. The wheels come in different thicknesses and sizes. (***Figure 3-42***)

Figure 3-41. Die grinders.

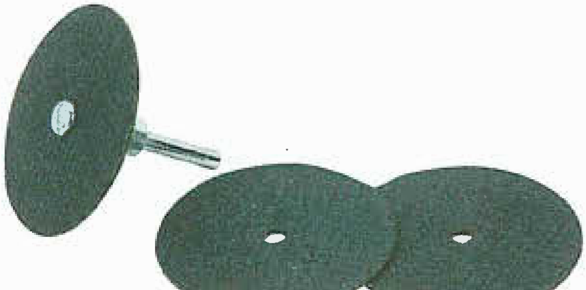


Figure 3-42. Cut-off wheels.

BURRING TOOL

This type of tool is used to remove a burr from an edge of a sheet or to deburr a hole. (***Figure 3-43***)

NIBBLERS

Usually powered by compressed air, the nibbler is another tool for cutting sheet metal. Portable nibblers utilize a high speed blanking action (the lower die moves up and down and meets the upper stationary die) to cut the metal. (***Figure 3-44***)

The shape of the lower die cuts out small pieces of metal approximately 1⁄16-inch wide. The cutting speed of the nibbler is controlled by the thickness of the metal being cut. Nibblers satisfactorily cut through sheets of metal with a maximum thickness of 1⁄16-inch. Too much force applied to the metal during the cutting operation clogs the dies (shaped metal), causing them to fail or the motor to overheat. Both electric and hand nibblers are available.

NOTCHER

The notcher is used to cut out metal parts, with some machines capable of shearing, squaring, and trimming metal. The notcher consists of a top and bottom die and most often cuts at a 90° angle, although some machines can cut metal into angles up to 180°. Notchers are available in manual and pneumatic models able to cut various thicknesses of mild steel and aluminum. This is an excellent tool for quickly removing corners from sheet metal parts. (***Figure 3-45***)

BAND SAW

A band saw consists of a toothed metal band coupled to, and continuously driven around, the circumferences of two wheels. It is used to cut aluminum, steel, and composite parts.(***Figure 3-46***) The speed of the band saw and the type and style of the blade depends on the material to be cut. Band saws are often designated to cut one type of material, and if a different material is to be cut, the blade is changed. The speed is controllable and the cutting platform can be tilted to cut angled pieces.

Figure 3-43. Burring tools.

Figure 3-44. Nibbler.

Figure 3-45. Notcher.

THROATLESS SHEAR

Airframe technicians use the throatless shear to cut aluminum sheets up to 0.063 inches. This shear takes its name from the fact that metal can be freely moved around the cutting blade during cutting because the shear lacks a "throat" down which metal must be fed. (***Figure 3-47***) This feature allows great flexibility in what shapes can be cut because the metal can be turned to any angle for straight, curved, and irregular cuts. Also, a sheet of any length can be cut.

A hand lever operates the cutting blade which is the top blade. Throatless shears made by the Beverly Shear Manufacturing Corporation, called Beverly™ shears, are often used.

SCROLL SHEARS

Scroll shears are used for cutting irregular lines on the inside of a sheet without cutting through to the edge. (***Figure 3-48***) The upper cutting blade is stationary while the lower blade is movable. A handle connected to the lower blade operates the machine.

ROTARY PUNCH PRESS

Used in the airframe repair shop to punch holes in metal parts, the rotary punch can cut radii in corners, make washers, and perform many other jobs where holes are required. (***Figure 3-49***)

The machine is composed of two cylindrical turrets, one mounted over the other and supported by the frame, with both turrets synchronized to rotate together. Index

Figure 3-46. Horizontal Band Saw.

Figure 3-47. Throatless shears.

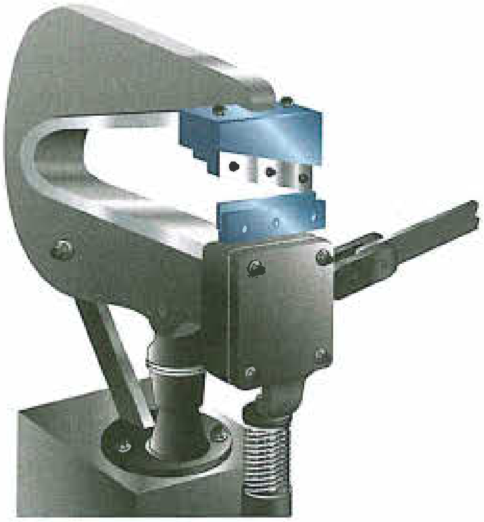


Figure 3-48. Scroll shears.

Figure 3-50. Foot-operated squaring shear.

Figure 3-49. Rotary punch press.

Figure 3-51. Power squaring shear.

pins, which ensure correct alignment at all times, may be released from their locking position by rotating a lever on the right side of the machine. This action withdraws the index pins from the tapered holes and allows an operator to turn the turrets to any size punch desired.

FOOT-OPERATED SHEAR

Foot-operated shears have a maximum metal cutting capacity of 0.063 inch of aluminum alloy. Use powered squaring shears for cutting thicker metals. (***Figure 3-50***)

SQUARING SHEAR

The squaring shear provides the airframe technician with a convenient means of cutting and squaring sheet metal. Available as a manual, hydraulic, or pneumatic model, this shear consists of a stationary lower blade attached to a bed and a movable upper blade attached to a crosshead. (***Figure 3-51***)

Two squaring fences, consisting of thick strips of metal used for squaring metal sheets, are placed on the bed. One squaring fence is placed on the right side and one on the left to form a 90° angle with the blades. A scale graduated in fractions of an inch is scribed on the bed for ease in placement.

To make a cut with a foot shear, move the upper blade down by placing the foot on the treadle and pushing downward. Once the metal is cut and foot pressure removed, a spring raises the blade and treadle. Hydraulic or pneumatic models utilize remote foot pedals to ensure operator safety. The squaring shear performs three distinctly different operations:

1. Cutting to a line
2. Squaring
3. Multiple cutting to a specific size

When cutting to a line, place the sheet on the bed of the shears in front of the cutting blade with the cutting line even with the cutting edge of the bed. To cut the sheet with a foot shear, step on the treadle while holding the sheet securely in place.

Squaring requires several steps. First, one end of the sheet is squared with an edge (the squaring fence is usually used on the edge). Then, the remaining edges are squared by holding one squared end of the sheet against the squaring fence and making the cut, one edge at a time, until all edges have been squared.

When several pieces must be cut to the same dimensions, use the backstop, located on the back of the cutting edge on most squaring shears. The supporting rods are graduated in fractions of an inch and the gauge bar may be set at any point on the rods. Set the gauge bar the desired distance from the cutting blade of the shears and push each piece to be cut against the gauge bar. All the pieces can then be cut to the same dimensions without measuring and marking each one separately.

Figure 3-52. Disk Sander.

DISK SANDER

Disk sanders have a powered abrasive-covered disk or belt and are used for smoothing or polishing surfaces. The sander unit uses abrasive paper of different grits to trim metal parts. (*Figure 3-52*)

It is much quicker to use a disk sander than to file a part to the correct dimension. The combination disk and belt sander has a vertical belt sander coupled with a disk sander and is often used in a metal shop.

Figure 3-53. Belt sander.

BELT SANDER

The belt sander uses an endless abrasive belt driven by an electric motor to sand down metal parts much like the disk sander unit. The abrasive paper used on the belt comes in different degrees of grit or coarseness. The belt sander is available as a vertical or horizontal unit. The tension and tracking of the abrasive belt can be adjusted so the belt remains centered on its rollers. (*Figure 3-53*)

WET OR DRY GRINDER

Grinding machines come in a variety of types and sizes, depending upon the class of work for which they are to be used. Dry and/or wet grinders are found in airframe repair shops. Grinders can be bench or pedestal mounted. A dry grinder usually has a grinding wheel on each end of a shaft that runs through an electric motor or a pulley operated by a belt. The wet grinder has a pump to supply a flow of water on a single grinding wheel. The water acts as a lubricant for faster grinding while it continuously cools the edge of the metal, reducing the heat produced by material being ground against the wheel.

It also washes away any bits of metal or abrasive removed during the grinding operation. The water returns to a tank and can be re-used.

Grinders are used to sharpen knives, tools, and blades as well as grinding steel, metal objects, drill bits, and tools. ***Figure 3-54***, illustrates a common type bench grinder found in most airframe repair shops. It can be used

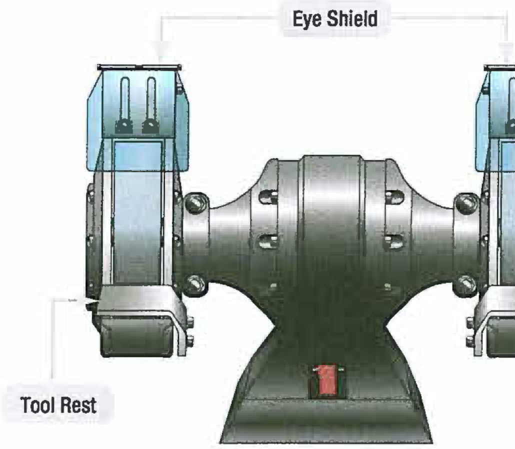


Figure 3-54. Bench Grinder.

to dress mushroomed heads on chisels and points on chisels, screwdrivers, and drills, as well as for removing excess metal from work and smoothing metal surfaces.

The bench grinder is generally equipped with one medium grit and one fine-grit abrasive wheel. The medium-grit wheel is usually used for rough grinding where a considerable quantity of material is to be removed or where a smooth finish is unimportant. The fine-grit wheel is used for sharpening tools and grinding to close limits. It removes metal more slowly, gives the work a smooth finish, and does not generate enough heat to anneal the edges of cutting tools. Before using any type of grinder, ensure that the abrasive wheels are firmly held on the spindles by the flange nuts. An abrasive wheel that comes off or becomes loose could seriously injure the operator in addition to ruining the grinder. A loose tool rest could cause the tool or piece of work to be "grabbed" by the abrasive wheel and cause the operator's hand to come in contact with the wheel, possibly resulting in severe wounds.

Always wear goggles when using a grinder, even if eye shields are attached to the grinder. Goggles should fit firmly against the face and nose. This is the only way to protect the eyes from the fine pieces of steel. Goggles that do not fit properly should be exchanged for ones that do fit. Be sure to check the abrasive wheel for cracks before using the grinder. A cracked abrasive wheel is likely to fly apart when turning at high speeds. Never use a grinder unless it is equipped with wheel guards that are firmly in place.

GRINDING WHEELS

A grinding wheel is made of a bonded abrasive and provides an efficient way to cut, shape, and finish metals. Available in a wide variety of sizes and numerous shapes, grinding wheels are also used to sharpen knives, drill bits, and many other tools, or to clean and prepare surfaces for painting or plating.

Grinding wheels are removable and a polishing or buffing wheel can be substituted for the abrasive wheel. Silicon carbide and aluminum oxide are the kinds of abrasives used in most grinding wheels. Silicon carbide is the cutting agent for grinding hard, brittle material, such as cast iron. It is also used in grinding aluminum, brass, bronze, and copper. Aluminum oxide is the cutting agent for grinding steel and other metals of high tensile strength.

DRILLING

Drilling holes is a common operation in the airframe repair shop. Once the fundamentals of drills and their uses are learned, drilling holes for rivets and bolts on light metal is not difficult. While a small portable power drill is usually the most practical tool for this common operation in airframe metalwork, sometimes a drill press may prove to be the better piece of equipment for the job.

PORTABLE POWER DRILLS

Portable power drills operate by electricity or compressed air. Pneumatic drill motors are recommended for use on repairs around flammable materials where potential sparks from an electric drill motor might become a fire hazard. Because of this, most power drills used in aviation maintenance work are pneumatic.

When using the portable power drill, hold it firmly with both hands. Before drilling, be sure to place a backup block of wood under the hole to be drilled to add support to the metal structure. The drill bit should be inserted in the chuck and tested for trueness or vibration. This may be visibly checked by running the motor freely. A drill bit that wobbles or is slightly bent should not be used since such a condition causes enlarged holes. The drill should always be held at right angles to the work regardless of the position or curvatures.

Tilting the drill at any time when drilling into or withdrawing from the material may cause elongation (egg shape) of the hole. When drilling through sheet metal, small burrs are formed around the edge of the hole. Burrs must be removed to allow rivets or bolts to fit snugly and to prevent scratching. Burrs may be removed with a bearing scraper, a countersink, or a drill bit larger than the hole. If a drill bit or countersink is used, it should be rotated by hand. Always wear safety goggles while drilling.

PNEUMATIC DRILL MOTORS

Pneumatic drill motors are the most common type of drill motor for aircraft repair work. They are light weight and have sufficient power and good speed control. Drill motors are available in many different sizes and models. Most drill motors used for aircraft sheet metal work are rated at 3 000 rpm, but if drilling deep holes or drilling in hard materials, such as corrosion resistant steel or titanium, a drill motor with more torque and lower rpm should be selected to prevent damage to tools and materials. (***Figure 3-55***)

RIGHT ANGLE AND 45° DRILL MOTORS

Right angle and 45° drill motors are used for positions that are not accessible with a pistol grip drill motor. Most right angle drill motors use threaded drill bits that are available in several lengths. Heavy-duty right angle drills are equipped with a chuck similar to the pistol grip drill motor.

TWO-HOLE DRILL MOTORS

Special drill motors that drill two holes at the same time are used for the installation of nutplates. By drilling two holes at the same time, the distance between the holes is fixed and the holes line up perfectly with the holes in the nutplate. (***Figure 3-56***)

Figure 3-55. A 90 degree pneumatic drill motor.

Figure 3-56. Two hole nutplate drill.

DRILL EXTENSIONS AND ADAPTERS

When access to a place where drilling is difficult or impossible with a straight drill motor, various types of drill extensions and adapters are used.

EXTENSION DRILL BITS

Extension drill bits are widely used for drilling holes in locations that require reaching through small openings or past projections. These drill bits, which come in 6 to 12-inch lengths, are high speed with spring-tempered shanks. Extension drill bits are ground to a special notched point, which reduces end thrust to a minimum.

When using extension drill bits always:

1. Select the shortest drill bit that will do the job. It is easier to control.
2. Check the drill bit for straightness. A bent drill bit makes an oversized hole and may whip, making it difficult to control.
3. Keep the drill bit under control. Extension drills smaller than ¼-inch must be supported by a drill guard made from a piece of tubing or spring to prevent whipping.

STRAIGHT EXTENSION

A straight extension for a drill can be made from an ordinary piece of drill rod. The drill bit is attached to the drill rod by shrink fitting, brazing, or silver soldering.

ANGLE ADAPTERS

Angle adapters can be attached to an electric or pneumatic drill when the location of the hole is inaccessible to a straight drill. Angle adapters have an extended shank fastened to the chuck of the drill. The drill is held in one hand and the adapter in the other to prevent the adapter from spinning around the drill chuck.

SNAKE ATTACHMENT

The snake attachment is a flexible extension used for drilling in places inaccessible to ordinary drills. Available for electric and pneumatic drill motors, its flexibility permits drilling around obstructions with minimum effort. (*Figure 3-57*)

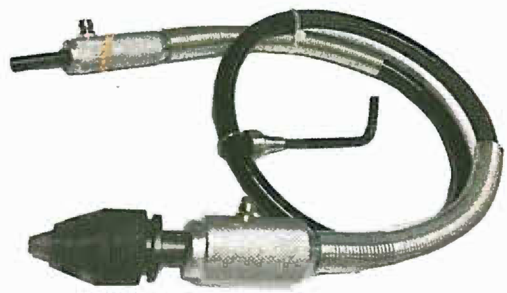


Figure 3-57. A Snake attachment.

DRILL PRESS

The drill press is a precision machine used for drilling holes that require a high degree of accuracy. It serves as an accurate means of locating and maintaining the direction of a hole that is to be drilled and provides the operator with a feed lever that makes the task of feeding the drill into the work easier. The upright drill press is the most common of the variety of drill presses available. (*Figure 3-58*)

Figure 3-58. Drill press.

When using a drill press, the height of the drill press table is adjusted to accommodate the height of the part to be drilled. When the height of the part is greater than the distance between the drill and the table, the table is lowered. When the height of the part is less than the distance between the drill and the table, the table is raised.

After the table is properly adjusted, the part is placed on the table and the drill is brought down to aid in positioning the metal so that the hole to be drilled is directly beneath the point of the drill. The part is then clamped to the drill press table to prevent it from slipping during the drilling operation.

Parts not properly clamped may bind on the drill and start spinning, causing serious cuts on the operator's arms or body, or loss of fingers or hands. Always make sure the part to be drilled is properly clamped to the drill press table before starting the drilling operation.

The degree of accuracy that it is possible to attain when using the drill press depends to a certain extent on the condition of the spindle hole, sleeves, and drill shank. Therefore, special care must be exercised to keep these parts clean and free from nicks, dents, and warping. Always be sure that the sleeve is securely pressed into the spindle hole. Never insert a broken drill in a sleeve or spindle hole. Be careful never to use the sleeve-clamping vise to remove a drill since this may cause the sleeve to warp.

The drill speed on a drill press is adjustable. Always select the optimum drill speed for the material to be drilled. Technically, the speed of a drill bit means its speed at the circumference, in surface feet per minute (sfm). The recommended speed for drilling aluminum alloy is from 200 to 300 sfm, and for mild steel is 30 to 50 sfm. In practice, this must be converted into rpm for each size drill. Machinist and mechanic handbooks include drill rpm charts or drill rpm may be computed by use of the formula:

$$\frac{CS \times 4}{D} = rpm$$

Where:
CS = The recommended cutting speed in sfm
D = The diameter of the drill bit in inches

Example: At what rpm should a $^1/_8$-inch drill turn to drill aluminum at 300 sfm? (Answer 9 600 rpm)

TYPES OF DRILL BITS

A wide variety of drill bits including specialty bits for specific jobs are available. High Speed Steel (HSS) drill bits come in short shank or standard length, sometimes called jobbers length. HSS drill bits can withstand temperatures nearing the critical range of 1 400 °F (dark cherry red) without losing their hardness. The industry standard for drilling metal (aluminum, steel, etc.), these drill bits stay sharper longer.

STEP DRILL BITS

Typically, the procedure for drilling holes larger than 3⁄16 inch in sheet metal is to drill a pilot hole with a No. 40 or No. 30 drill bit and then to oversize with a larger drill bit to the correct size. The step drill combines these two functions into one step. The step drill bit consists of a smaller pilot drill point that drills the initial small hole. When the drill bit is advanced further into the material, the second step of the drill bit enlarges the hole to the desired size. Step drill bits are designed to drill round holes in most metals, plastic, and wood. Commonly used in general construction and plumbing, they work best on softer materials, such as plywood, but can be used on very thin sheet metal. Step drill bits can also be used to deburr holes left by other bits.

COBALT ALLOY DRILL BITS

Cobalt alloy drill bits are designed for hard, tough metals like corrosion-resistant steel and titanium. It is important for the aircraft technician to note the difference between HSS and cobalt.

HSS drill bits wear out quickly when drilling titanium or stainless. Cobalt drill bits are excellent for drilling titanium or stainless steel, but do not produce a quality hole in aluminum alloys. Cobalt drill bits can be recognized by thicker webs and a taper at the end of the drill shank.

TWIST DRILL BITS

Easily the most popular drill bit type, the twist drill bit has spiral grooves or flutes running along its working length. (*Figure 3-59*)

This drill bit comes in a single-fluted, two-fluted, three-fluted, and four-fluted styles. Single-fluted and two-fluted drill bits (most commonly available) are used for originating holes. Three-fluted and four-fluted drill bits are used interchangeably to enlarge existing holes.

Figure 3-59. Twist drill bits.

Twist drill bits are available in a wide choice of tooling materials and lengths with the variations targeting specific projects.

The standard twist drill bits used for drilling aluminum are made from HSS and have a 135° split point. Drill bits for titanium are made from cobalt vanadium for increased wear resistance.

DRILL BIT SIZES

Drill diameters are grouped by three size standards: number, letter, and fractional. The decimal equivalents of standard drill are shown in ***Figure 3-60.***

DRILLS

There are generally three types of portable drills used in aviation for holding and turning twist drills. Holes ¼ inch in diameter and under can be drilled using a hand drill. This drill is sometimes called an "egg beater."

Electric and pneumatic power drills, often called drill motors, are available in various shapes and sizes to satisfy almost any requirement. Pneumatic powered drills are preferred for use around flammable materials and, therefore, around aircraft. Sparks from an electric drill are a fire and explosion hazard.

TWIST DRILLS

A twist drill, or drill bit, is a pointed tool that is rotated to cut holes in material. It is made of a cylindrical hardened steel bar having spiral flutes (grooves) running the length of the body, and a conical point with cutting edges formed by the ends of the flutes. Twist drills are made of

Drill Size	Decimal (Inches)	Drill Size	Decimal (Inches)	Drill Size	Decimal (Inches)	Drill Size	Decimal (Inches)	Drill Size	Decimal (Inches)
80	.0135	50	.0700	22	.1570	G	.2610	31/64	.4844
79	.0145	49	.0730	21	.1590	17/64	.2656	1/2	.5000
1/54	.0156	48	.0760	20	.1610	H	.2660	33/64	.5156
78	.0160	5/64	.0781	19	.1660	I	.2720	17/32	.5312
77	.0180	47	.0785	18	.1695	J	.2770	35/64	.5469
76	.0200	46	.0810	11/64	.1718	K	.2810	9/16	.5625
75	.0210	45	.0820	17	.1730	9/32	.2812	37/64	.5781
74	.0225	44	.0860	16	.1770	L	.2900	19/32	.5937
73	.0240	43	.0890	15	.1800	M	.2950	39/84	.6094
72	.0250	42	.0935	14	.1820	19/64	.2968	5/8	.6250
71	.0260	3/32	.0937	13	.1850	N	.3020	41/64	.6406
70	.0280	41	.0960	3/16	.1875	5/16	.3125	21/32	.6562
69	.0293	40	.0980	12	.1890	0	.3160	43/64	.6719
68	.0310	39	.0995	11	.1910	P	.3230	11/16	.6875
1/32	.0312	38	.1015	10	.1935	21/64	.3281	45/64	.7031
67	.0320	37	.1040	9	.1960	Q	.3320	23/32	.7187
66	.0330	36	.1065	8	.1990	R	.3390	47/64	.7344
65	.0350	7/64	.1093	7	.2010	11/32	.3437	3/4	.7500
64	.0360	35	.1100	13/64	.2031	S	.3480	49/64	.7656
63	.0370	34	.1110	6	.2040	T	.3580	25/32	.7812
62	.0380	33	.1130	5	.2055	23/64	.3593	51/64	.7969
61	.0390	32	.1160	4	.2090	U	.3680	13/16	.8125
60	.0400	31	.1200	3	.2130	3/8	.3750	53/64	.8281
59	.0410	1/8	.1250	7/32	.2187	V	.3770	27/32	.8437
58	.0420	30	.1285	2	.2210	W	.3860	55/64	.8594
57	.0430	29	.1360	1	.2280	25/64	.3906	7/8	.8750
56	.0465	28	.1405	A	.2340	X	.3970	57/64	.8906
3/64	.0468	9/64	.1406	15/64	.2343	Y	.4040	29/32	.9062
55	.0520	27	.1440	B	.2380	13/32	.4062	59/64	.9219
54	.0550	26	.1470	C	.2420	Z	.4130	15/16	.9375
53	.0595	25	.1495	D	.2460	27/64	.4219	61/64	.9531
1/16	.0625	24	.1520	1/4	.2500	7/16	.4375	31/32	.9687
52	.0635	23	.1540	E	.2500	29/64	.4531	63/64	.9844
51	.0670	5/32	.1562	F	.2570	15/32	.4687	1	1.0000

Figure 3-60. Drill sizes and decimal equivalents.

carbon steel or high-speed alloy steel. Carbon steel twist drills are satisfactory for general work and are relatively inexpensive. The more expensive high-speed twist drills are used for the tough materials such as stainless steels. Twist drills have from one to four spiral flutes. Drills with two flutes are used for most drilling; those with three or four are used principally to follow smaller drills or to enlarge holes. The principal parts of a twist drill are the shank, the body, and the heel. (***Figure 3-61***)

The drill shank is the end that fits into the chuck of a hand or power drill. The two shank shapes most commonly used in hand drills are the straight shank and the square or bit stock shank. The straight shank generally is used in hand, breast, and portable electric or pneumatic drills; the square shank is made to fit into a carpenter's brace. Tapered shanks generally are used in machine shop drill presses. (***Figure 3-62***)

The metal column forming the core of the drill is the body. The body clearance area lies just back of the margin; it is slightly smaller in diameter than the margin, to reduce the friction between the drill and the sides of the hole. The angle at which the drill point is ground is the lip clearance angle. On standard drills used to cut steel and cast iron, the angle should be 59°

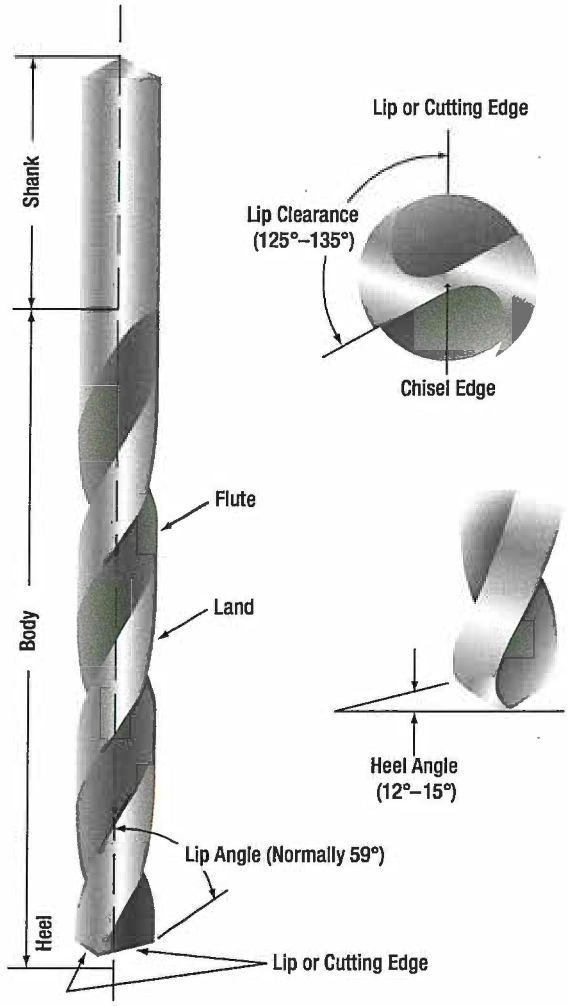


Figure 3-61. Twist drill.

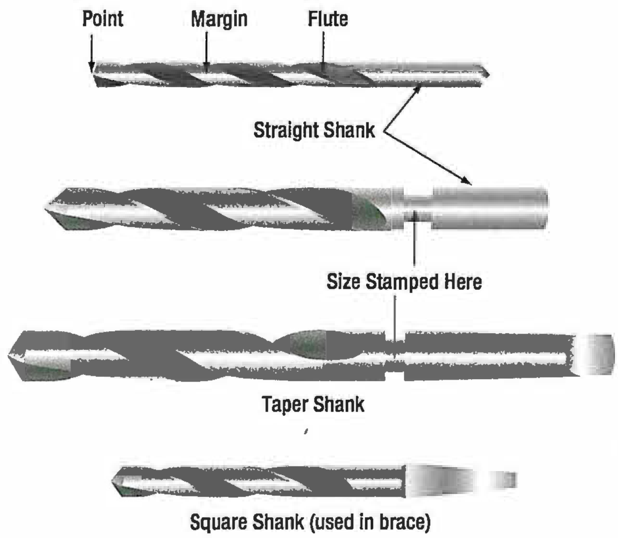


Figure 3-62. Drill types.

from the axis of the drill. For faster drilling of soft materials, sharper angles are used.

The diameter of a twist drill may be given in one of three ways: (1) by fractions, (2) letters, or (3) numbers. Fractionally, they are classified by sixteenths of an inch (from 1⁄16 to 3½ inch), by thirty-seconds (from 1⁄32 to 2½ inch), or by sixty-fourths (from 1⁄64 to 1¼ inch). For a more exact measurement, a letter system is used with decimal equivalents: A (0.234 inch) to Z (0.413 inch). The numbering system of classification is the most accurate: No. 80 (0.0314 inch) to No. 1 (0.228 inch). Drill sizes and their decimal equivalents are shown in ***Figure 3-63.***

The twist drill should be sharpened at the first sign of dullness. For most drilling, a twist drill with a cutting angle of 118° (59° on either side of center) will be sufficient; however, when drilling soft metals, a cutting angle of 90° may be more efficient. Typical procedures for sharpening drills are as follows: (***Figure 3-64***)

A. Adjust the grinder tool rest to a height for resting the back of the hand while grinding.
B. Hold the drill between the thumb and index finger of the right or left hand. Grasp the body of the drill near the shank with the other hand.
C. Place the hand on the tool rest with the centerline of the drill making a 59° angle with the cutting face of the grinding wheel. Lower the shank end of the drill slightly.
D. Slowly place the cutting edge of the drill against the grinding wheel. Gradually lower the shank of the drill as you twist the drill in a clockwise direction. Maintain pressure against the grinding surface only until you reach the heel of the drill.
E. Check the results of grinding with a gauge to determine whether or not the lips are the same length and at a 59° angle.

Alternatively, there are commercially available twist drill grinders available, as well as attachments for bench grinders which will ensure consistent, even sharpening of twist drills.

Millimeter	Decimal Equivalent	Fractional	Number	Millimeter	Decimal Equivalent	Fractional	Number	Millimeter	Decimal Equivalent	Fractional	Number	Millimeter	Decimal Equivalent	Fractional	Number
.1	.0039			—	.0410		59	2.2	.0866			—	.1470		26
.15	.0059			1.05	.0413			2.25	.0885			3.75	.1476		
.2	.0079			—	.0420		58	—	.0890		43	—	.1495		25
.25	.0098			—	.0430		57	2.3	.0905			3.8	.1496		
.3	.0118			1.1	.0433			2.35	.0925			—	.1520		24
—	.0135		80	1.15	.0452			—	.0935		42	3.9	.1535		
.35	.0138			—	.0465		56	2.38	.0937	3/32	—	—	.1540		23
—	.0145		79	1.19	.0469	3/64	—	2.4	.0945			3.97	.1562	5/32	—
.39	.0156	1/64	—	1.2	.0472			—	.0960		41	—	.1570		22
.4	.0157			1.25	.0492			2.45	.0964			4.0	.1575		
—	.0160		78	1.3	.0512			—	.0980		40	—	.1590		21
.45	.0177			—	.0520		55	2.5	.0984			—	.1610		20
—	.0180		77	1.35	.0531			—	.0995		39	4.1	.1614		
.5	.0197			—	.0550		54	—	.1015		38	4.2	.1654		
—	.0200		76	1.4	.0551			2.6	.1024			—	.1660		19
—	.0210		75	1.45	.0570			—	.1040		37	4.25	.1673		
.55	.0217			1.5	.0591			2.7	.1063			4.3	.1693		
—	.0225		74	—	.0595		53	—	.1065		36	—	.1695		18
.6	.0236			1.55	.0610			2.75	.1082			4.37	.1719	11/64	—
—	.0240		73	1.59	.0625	1/16	—	2.78	.1094	7/64	—	—	.1730		17
—	.0250		72	1.6	.0629			-	.1100		35	4.4	.1732		
.65	.0256			—	.0635		52	2.8	.1102			—	.1770		16
—	.0260		71	1.65	.0649			—	.1110		34	4.5	.1771		
—	.0280		70	1.7	.0669			—	.1130		33	—	.1800		15
.7	.0276			—	.0670		51	2.9	.1141			4.6	.1811		
—	.0292		69	1.75	.0689			—	.1160		32	—	.1820		14
.75	.0295			—	0.700		50	3.0	.1181			4.7	.1850		13
—	.0310		68	1.8	.0709			—	.1200		31	4.75	.1870		
.79	.0312	1/32	—	1.85	.0728			3.1	.1220			4.76	.1875	3/16	—
.8	.0315			—	.0730		49	3.18	.1250	1/8	—	4.8	.1890		12
—	.0320		67	1.9	.0748			3.2	.1260			—	1910		11
—	.0330		66	—	.0760		48	3.25	.1279			4.9	.1929		
.85	.0335			1.95	.0767			—	.1285		30	—	.1935		10
—	.0350		65	1.98	.0781	5/64	—	3.3	.1299			—	.1960		9
.9	.0354			—	.0785		47	3.4	.1338			5.0	.1968		
—	.0360		64	2.0	.0787			—	.1360		29	—	.1990		8
—	.0370		63	2.05	.0807			3.5	.1378			5.1	.2008		
.95	.0374			—	.0810		46	—	.1405		28	—	.2010		7
—	.0380		62	—	.0820		45	3.57	.1406	9/64		5.16	.2031	13/64	—
—	.0390		61	2.1	.0827			3.6	.1417			—	.2040		6
1.0	.0394			2.15	.0846			—	.1440		27	5.2	.2047		
—	.0400		60	—	.0860		44	3.7	.1457		—	—	.2055		5

Figure 3-63. Drill sizes.

Millimeter	Decimal Equivalent	Fractional	Number
5.25	.2067		
5.3	.2086		
—	.2090		4
5.4	.2126		
—	.2130		
5.5	.2165		
5.56	.2187	1/32	—
5.6	.2205		
—	.2210		2
5.7	.2244		
5.75	.2263		
—	.2280		1
5.8	.2283		
5.9	.2323		
—	.2340		A
5.95	.2344	15/64	—
6.0	.2362		
—	.2380		B
6.1	.2401		
—	.2420		C
6.2	.2441		
6.25	.2460		D
6.3	.2480		
6.35	.2500	1/4	E
6.4	.2520		
6.5	.2559		
—	.2570		F
6.6	.2598		
—	.2610		G
6.7	.2638		
6.75	.2657	17/64	—
6.75	.2657		
—	.2660		H
6.8	.2677		
6.9	.2716		
—	.2720		I
7.0	.2756		
—	.2770		J
7.1	.2795		
—	.2811		K
7.14	.2812	9/32	—
7.2	.2835		

Millimeter	Decimal Equivalent	Fractional	Number
7.25	.2854		
7.3	.2874		
—	2900		L
7.4	.2913		
—	.2950		M
7.5	.2953		
7.54	.2968	19/64	—
7.6	.2992		
—	.3020		N
7.7	.3031		
7.75	.3051		
7.8	.3071		
7.9	.3110		
7.94	.3125	5/16	—
8.0	.3150		
—	.3160		O
8.1	.3189		
8.2	.3228		
—	.3230		P
8.25	.3248		
8.3	.3268		
8.33	.3281	21/64	—
8.4	.3307		
—	.3320		Q
8.5	.3346		
8.6	.3386		
—	.3390		R
8.7	.3425		
8.73	.3437	11/32	—
8.75	.3445		
8.8	.3465		
—	.3480		S
8.9	.3504		
9.0	.3543		
—	.3580		T
9.1	.3583		
9.13	.3594	23/64	—
9.2	.3622		
9.25	.3641		
9.3	.3661		
—	.3680		U
9.4	.3701		

Millimeter	Decimal Equivalent	Fractional	Number
9.5	.3740		
9.53	.3750	3/8	—
—	.3770		V
9.6	.3780		
9.7	.3819		
9.75	.3838		
9.8	.3858		
—	.3860		W
9.9	.3898		
9.92	.3906	25/64	—
10.0	.3937		
	.3970		X
—	.4040		Y
10.32	.4062	13/32	—
—	.4130		Z
10.5	.4134		
10.72	.4219	27/64	
11.0	.4330		
11.11	.4375	7/16	
11.5	.4528		
11.51	.4531	29/64	
11.91	.4687	15/32	
12.0	.4724		
12.30	.4843	31/64	
12.5	.4921		
12.7	.5000	1/2	
13.0	.5118		
13.10	.5156	33/64	
13.49	.5312	17/32	
13.5	.5315		
13.89	.5469	35/64	
14.0	.5512		
14.29	.5625	9/16	
14.5	.5709		
14.68	.5781	37/64	
15.0	.5906		
15.08	.5937	19/32	
15.48	.6094	39/32	
15.5	.6102		
15.88	.6250	5/8	
16.0	.6299		
16.27	.6406	41/64	

Millimeter	Decimal Equivalent	Fractional	Number
16.5	.6496		
16.67	.6562	21/32	
17.0	.6693		
17.06	.6719	43/64	
17.46	.6875	11/16	
17.5	.6890		
17.86	.7031	45/64	
18.0	7087		
18.26	.7187	23/32	
18.5	.7283		
18.65	.7344	47/64	
19.0	.7480		
19.05	7500	3/4	
19.45	.7656	49/64	
19.5	.7677		
19.84	.7812	25/32	
20.0	7874		
20.24	.7969	51/64	
20.5	.8071		
20.64	.8125	13/16	
21.0	.8268		
21.03	.8281	53/64	
21.43	.8437	27/32	
21.5	.8465		
21.83	.8594	55/64	
22.0	.8661		
22.23	.8750	7/8	
22.5	.8858		
22.62	.8906	57/64	
23.0	.9055		
23.02	.9062	29/32	
23.42	.9219	59/64	
23.5	.9252		
23.81	.9375	15/16	
24.0	.9449		
24.21	.9531	61/64	
24.5	.9646		
24.61	.9687	31/32	
25.0	.9843		
25.03	.9844	63/64	
25.4	1.0000	1	

Figure 3-63. Drill sizes (continued).

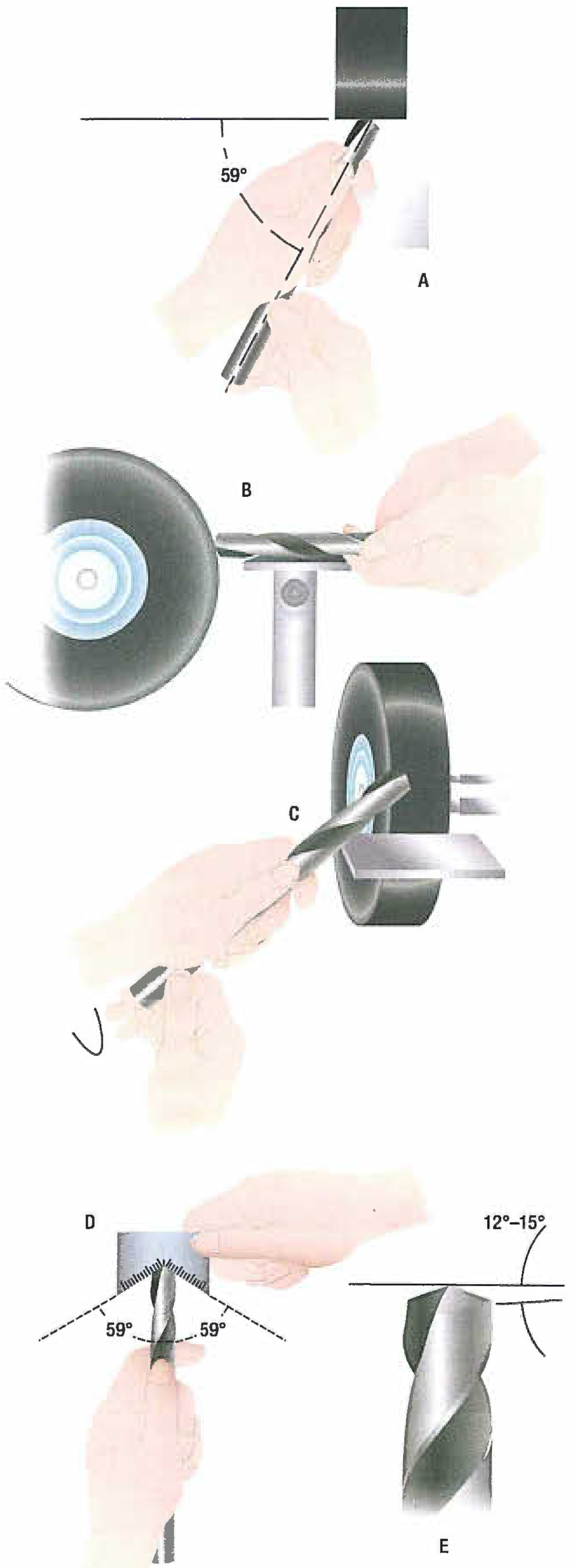


Figure 3-64. Drill sharpening procedures.

HOLE DRILLING TECHNIQUES

Precise location of drilled holes is sometimes required. When locating holes to close tolerances, accurately located punch marks need to be made. If a punch mark is too small, the chisel edge of the drill bit may bridge it and "walk off" the exact location before starting. If the punch mark is too heavy, it may deform the metal and/or result in a local strain hardening where the drill bit is to start cutting. The best size for a punch mark is about the width of the chisel edge of the drill bit to be used. This holds the drill point in place while starting. The procedure that ensures accurate holes follows: (***Figure 3-65***)

NOTE: The chisel edge is the least efficient operating surface element of the twist drill bit because it does not cut, but actually squeezes or extrudes the work material.

1. Measure and lay out the drill locations carefully and mark with crossed lines.
2. Use a sharp prick punch or spring-loaded center punch and magnifying glass to further mark the holes.
3. Seat a properly ground center punch (120°–135°) in the prick punch mark and, holding the center punch perpendicular to the surface, strike a firm square blow with a hammer.
4. Mark each hole with a small drill bit (1⁄16-inch recommended) to check and adjust the location prior to pilot drilling.
5. For holes 3⁄16-inch and larger, pilot drilling is recommended. Select a drill bit equal to the width of the chisel edge of the final drill bit size. Avoid using a pilot drill bit that is too large because it would cause the corners and cutting lips of the final drill bit to be dulled, burned, or chipped. It also contributes to chattering and drill motor stalling. Pilot drill at each mark.

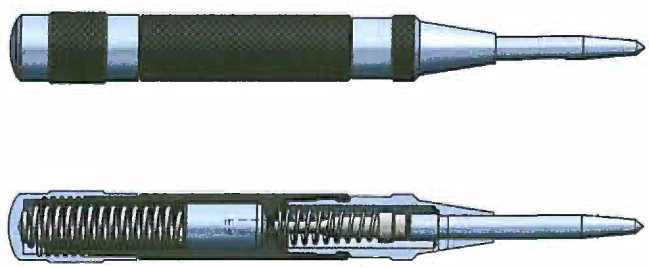


Figure 3-65. Center punch and cutaway.

6. Place the drill point at the center of the crossed lines, perpendicular to the surface, and, with light pressure, start drilling slowly. Stop drilling after a few turns and check to see if the drill bit is starting on the mark. It should be; if not, it is necessary to walk the hole a little by pointing the drill in the direction it should go, and rotating it carefully and intermittently until properly lined up.
7. Enlarge each pilot drilled hole to final size.

Figure 3-66. Drill stop.

DRILL STOPS
A spring drill stop is a wise investment. Properly adjusted, it can prevent excessive drill penetration that might damage underlying structure or injure personnel and prevent the drill chuck from marring the surface. Drill stops can be made from tubing, fiber rod, or hard rubber. (*Figure 3-66*)

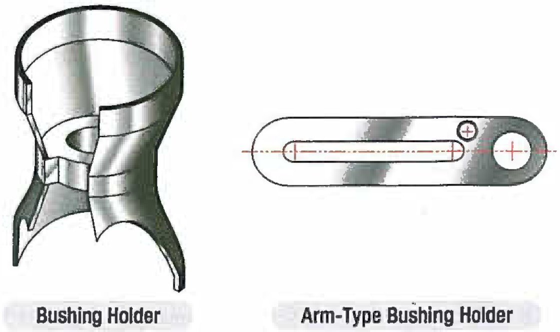


Figure 3-67. Drill bushings.

DRILL BUSHINGS
There are several types of tools available that aid in holding the drill perpendicular to the part. They consist of a hardened bushing anchored in a holder. (*Figure 3-67*)

Drill bushing types:
1. Tube—hand-held in an existing hole
2. Commercial—twist lock
3. Commercial—threaded


Figure 3-68. Bushing holder.

DRILL BUSHING HOLDER TYPES
There are four types of drill bushing holders:
1. Standard—fine for drilling flat stock or tubing/rod; uses insert-type bushings.
2. Egg cup—improvement on standard tripod base; allows drilling on both flat and curved material; interchangeable bushings allows flexibility. (*Figure 3-68*)
3. Plate—used primarily for interchangeable production components; uses commercial bushings and self-feeding drills.
4. Arm—used when drilling critical structure; can be locked in position; uses interchangeable commercial bushings.

DRILLING LARGE HOLES
The following technique can be used to drill larger holes. Special tooling has been developed to drill large holes to precise tolerances. (*Figure 3-69*)

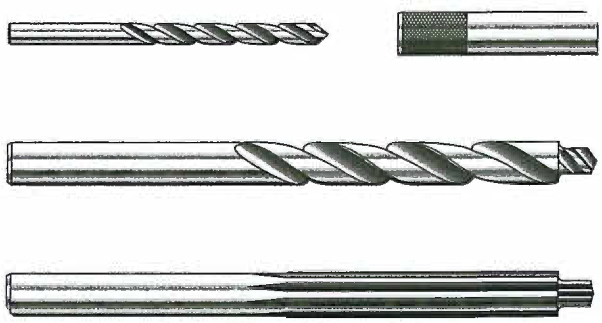


Figure 3-69. Drills for large holes.

NOTE: Holes can also be enlarged by using a series of step reamers:

1. Pilot drill using a drill bushing. Bushings are sized for 1/8, 3/16 or 1/4 drill bits.
2. Step drill bits are used to step the hole to approximately 1/64-inch smaller than the final hole size. The aligning step diameter matches the pilot drill bit size.
3. Finish ream to size using a step reamer. The aligning step diameter matches the core drill bit size. Reamers should be available for both clearance and interference fit hole sizes.

DRILL LUBRICATION

Normal drilling of sheet material does not require lubrication, but lubrication should be provided for all deeper drilling. Lubricants serve to assist in chip removal, which prolongs drill life and ensures a good finish and dimensional accuracy of the hole. It also prevents overheating. The use of a lubricant is always a good practice when drilling castings, forgings or heavy gauge stock. A good lubricant should be thin enough to help in chip removal but thick enough to stick to the drill. For aluminum, titanium and corrosion-resistant steel, a cetyl alcohol based lubricant is the most satisfactory. Cetyl alcohol is a nontoxic fatty alcohol chemical produced in liquid, paste and solid forms. Solid stick and block forms quickly liquefy at drilling temperatures.

For steel, sulfurized mineral cutting oil is superior. Sulfur has an affinity for steel, which aids in holding the cutting oil in place. In the case of deep drilling, the drill should be withdrawn at intervals to relieve chip packing and to ensure the lubricant reaches the point. As a general rule, if the drill is large or the material hard, use a lubricant.

REAMERS

Reamers are used to smooth and enlarge holes to exact size. Hand reamers have square end shanks so that they can be turned with a tap wrench or similar handle. The various types of reamers are illustrated in ***Figure 3-70.*** A hole that is to be reamed to exact size must be drilled about 0.003 to 0.007 inch under size. A cut that removes more than 0.007 inch places too much load on the reamer and should not be attempted.

Reamers are made of either carbon tool steel or high-speed steel. The cutting blades of a high-speed steel

Figure 3-70. Reamers.

reamer lose their original keenness sooner than those of a carbon steel reamer; however, after the first super keenness is gone, they are still serviceable. The high-speed reamer usually lasts much longer than the carbon steel type.

Reamer blades are hardened to the point of being brittle and must be handled carefully to avoid chipping them. When reaming a hole, rotate the reamer in the cutting direction only. Do not back a reamer out of a hole by rotating it opposite the cutting direction. Turn the reamer steadily and evenly to prevent chattering, or marking and scoring of the hole walls.

Reamers are available in any standard size. The straight fluted reamer is less expensive than the spiral fluted reamer, but the spiral type has less tendency to chatter. Both types are tapered for a short distance back of the end to aid in starting. Bottoming reamers have no taper and are used to complete the reaming of blind holes.

For general use, an expansion reamer is the most practical. This type is furnished in standard sizes from 1/4 inch to 1 inch, increasing in diameter by 1/32-inch increments.

Taper reamers, both hand and machine operated, are used to smooth and true taper holes and recesses.

Reamers, used for enlarging holes and finishing them smooth to a required size, are made in many styles. They can be straight or tapered, solid or expansive, and come with straight or helical flutes. ***Figure 3-71*** illustrates three types of reamers:

1. Three or four fluted production bullet reamers are customarily used where a finer finish and/or size is needed than can be achieved with a standard drill bit.
2. Standard or straight reamer.
3. Piloted reamer, with the end reduced to provide accurate alignment.

The cylindrical parts of most straight reamers are not cutting edges, but merely grooves cut for the full length of the reamer body. These grooves provide a way for chips to escape and a channel for lubricant to reach the cutting edge. Actual cutting is done on the end of the reamer. The cutting edges are normally ground to a bevel of 45° ± 5°.

Reamer flutes are not designed to remove chips like a drill. Do not attempt to withdraw a reamer by turning it in the reverse direction because chips can be forced into the surface, scarring the hole.

TAPS AND DIES

A tap is used to cut threads on the inside of a hole, while a die is for cutting external threads on round stock. They are made of hard tempered steel and ground to an exact size.

There are four types of threads that can be cut with standard taps and dies. They are: National Coarse, National Fine, National Extra Fine, and National Pipe. Hand taps are usually provided in sets of three taps for each diameter and thread series. Each set contains a taper tap, a plug tap, and a bottoming tap. The taps in a set are identical in diameter and cross section; the only difference is the amount of taper. (***Figure 3-72***)

The taper tap is used to begin the tapping process, because it is tapered back for 6 to 7 threads. This tap cuts a complete thread when it is cutting above the taper. It is the only tap needed when tapping holes that extend through thin sections. The plug tap supplements the taper tap for tapping holes in thick stock. The bottoming tap is not tapered. It is used to cut full threads to the bottom of a blind hole.

Dies may be classified as adjustable round split die and plain round split die. The adjustable split die has an adjusting screw that can be tightened so that the die is spread slightly. By adjusting the die, the diameter and fit of the thread can be controlled. (***Figure 3-73***)

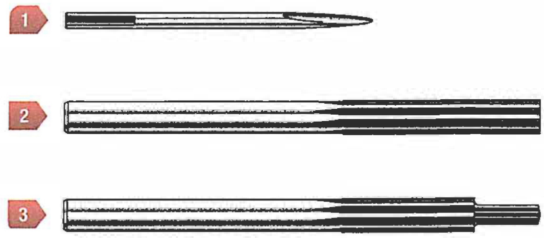


Figure 3-71. Reamers.

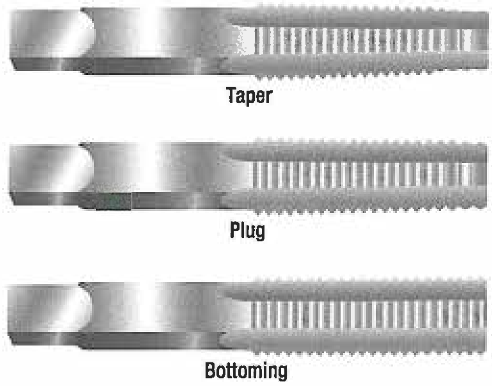


Figure 3-72. Hand taps.

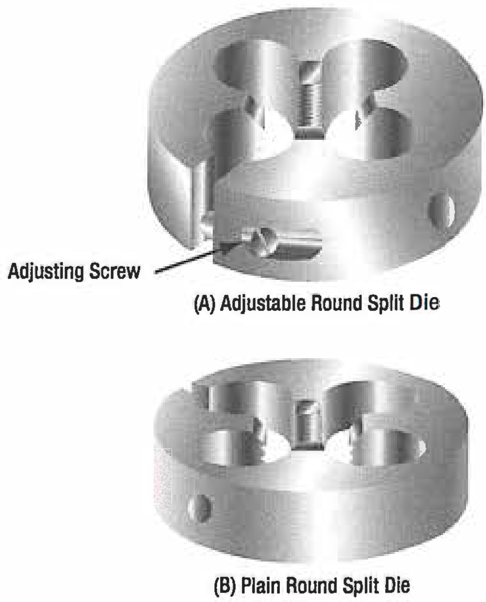


Figure 3-73. Types of dies.

Solid dies are not adjustable; therefore, a variety of thread fits cannot be obtained with this type. There are many types of wrenches for turning taps, as well as turning dies. The T-handle, the adjustable tap wrench, and the die stock for round split dies shown in ***Figure 3-74*** are a few of the more common types.

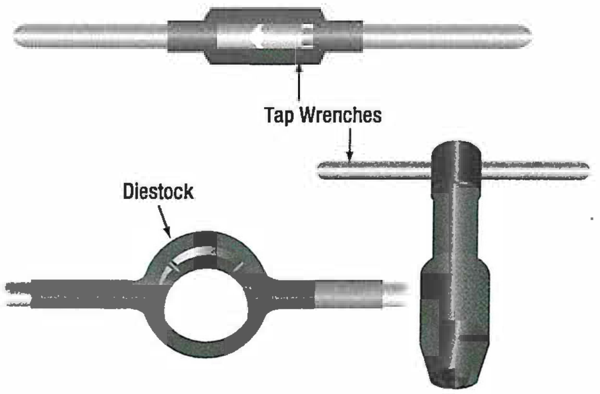


Figure 3-74. Diestock and tap wrenches.

Information on thread sizes, fits, types, and so forth, is shown in ***Figures 3-75, 3-76, and 3-77.***

The use of suitable lubricant, also know as cutting fluid, is essential with most tapping and reaming operations. Recommended lubricants for some common materials are:

- Carbon steel: petroleum or synthetic cutting fluid.
- Alloy steel: petroleum cutting fluid mixed 10% with kerosene.
- Cast iron: no lubricant required. Use are blasts to clear chips.
- Aluminum: kerosene mixed with 20% petroleum cutting fluid.
- Brass: kerosene or mineral spirits.
- Bronze: kerosene mixed with 15% petroleum cutting fluid.

National Coarse Thread Series Medium Fit Class 3 (NC)					National Fine Thread Series Medium Fit Class 3 (NF)				
			Tap Drill					Tap Drill	
Size and Threads	Diameter of body for thread	Body Drill	Preferred diameter of hole	Nearest standard drill size	Size and Threads	Diameter of body for thread	Body Drill	Preferred diameter of hole	Nearest standard drill size
					0-80	.060	52	.0472	3/64"
1-64	.073	47	.0575	#53	1-72	.073	47	.0591	#53
2-56	.086	42	.0682	#51	2-64	.086	42	.0700	#50
3-48	.099	37	.078	5/64	3-56	.099	37	.0810	#46
4-40	.112	31	.0866	#44	4-48	.112	31	.0911	#42
5-40	.125	29	.0995	#39	5-44	.125	25	1024	#38
6-32	.138	27	.1063	#36	6-40	.138	27	.113	#33
8-32	.164	18	.1324	#29	8-36	.164	18	.136	#29
10-24	.190	10	.1472	#26	10-32	.190	10	.159	#21
12-24	.216	2	.1732	#17	12-28	.216	2	.180	#15
¼-20	.250	¼	.1990	#8	¼-28	.250	F	.213	#3
5/16-18	.3125	5/16	.2559	#F	5/16-24	.3125	5/16	.2703	I
⅜-16	.375	⅜	.3110	5/16"	⅜-24	.375	⅜	.332	Q
7/16-14	.4375	7/16	.3642	U	7/16-20	.4375	7/16	.386	W
½-13	.500	½	.4219	27/64"	½-20	.500	½	.449	7/16"
9/16-12	.5625	9/16	.4776	31/64"	9/16-18	.5625	9/16	.506	½"
⅝-11	.625	⅝	.5315	17/64"	⅝-18	.625	⅝	.568	9/16"
¾-10	.750	¾	.6480	41/64"	¾-16	.750	¾	.6688	11/16"
⅞-9	.875	⅞	.7307	49/64"	⅞-14	.875	⅞	.7822	51/64"
1-8	1.000	1.0	.8376	⅞"	1-14	1.000	1.0	.9072	49/64"

Figure 3-75. American (National) screw thread sizes.

Nominal size (inches)	Number of threads per inch	Pitch Diameter		Size and Threads		Pipe o.d. (inches)	Depth of thread (inches)	Tap drill for pipe threads	
		A (inches)	B (inches)	L2 (inches)	L1 (inches)			Minor diameter small end of pipe	Size drill
1/8	27	.36351	.37476	.2638	.180	.405	.02963	.33388	R
1/4	18	.47739	.48989	.4018	.200	.540	.04444	.43294	7/16
3/8	18	.61201	.62701	.4078	.240	.675	.04444	.56757	37/64
1/2	14	.75843	.77843	.5337	.320	.840	.05714	.70129	23/32
3/4	14	.96768	.98887	.5457	.339	1.050	.5714	.91054	59/64
1	11 1/2	1.21363	1.23863	.6828	.400	1.315	.06957	1.14407	1 5/32
1 1/4	11 1/2	1.55713	1.58338	.7068	.420	1.660	.06957	1.48757	1 1/2
1 1/2	11 1/2	1.79609	1.82234	.7235	.420	1.900	.06957	1.72652	1 47/64
2	11 1/2	2.26902	2.29627	.7565	.436	2.375	.06957	2.19946	1 7/32
2 1/2	8	2.71953	2.76216	1.1375	.682	2.875	.10000	2.61953	2 5/8
3	8	3.34062	3.8850	1.2000	.766	3.500	.10000	3.24063	3 1/4
3 1/2	8	3.83750	3.88881	1.2500	.821	4.000	.10000	3.73750	3 3/4
4	8	4.33438	4.38712	1.3000	.844	4.500	.10000	4.23438	4 1/4

Figure 3-76. American (National) pipe thread dimensions and tap drill sizes.

Diameter of Drill	Soft Metals 300 F.P.M.	Plastic and Hard Rubber 200 F.P.M.	Annealed Cast Iron 140 F.P.M.	Mild Steel 100 F.P.M.	Malleable Iron 90 F.P.M.	Hard Cast Iron 80 F.P.M.	Tool or Hard Steel 60 F.P.M.	Alloy Steel Cast Steel 40 F.P.M.
1/16 (No. 53-80)	18320	12217	8554	6111	5500	4889	3667	2445
3/32 (No. 42-52)	12212	8142	5702	4071	3666	3258	2442	1649
1/8 (No. 31-41)	9160	6112	4278	3056	2750	2445	1833	1222
5/32 (No. 23-30)	7328	4888	3420	2444	2198	1954	1465	977
3/16 (No. 13-22)	6106	4075	2852	2037	1833	1630	1222	815
7/32 (No. 1-12)	5234	3490	444	1745	1575	1396	1047	698
1/4 (A-F)	4575	3055	2139	1527	1375	1222	917	611
9/32 (G-K)	4071	2715	1900	1356	1222	1084	814	542
5/16 (L, M, N)	3660	2445	1711	1222	1100	978	7333	489
11/32 (O -R)	3330	2220	1554	1110	1000	888	666	444
3/8 (S, T, U)	3050	2037	1426	1018	917	815	611	407
13/32 (V-Z)	2818	1878	1316	939	846	752	563	376
7/16	2614	1746	1222	873	786	698	524	349
15/32	2442	1628	1140	814	732	652	488	326
1/2	2287	1528	1070	764	688	611	458	306
9/16	2035	1357	950	678	611	543	407	271
5/8	1830	1222	856	611	550	489	367	244
11/16	1665	1110	777	555	500	444	333	222
3/4	1525	1018	713	509	458	407	306	204

Figure 3-77. Drill speeds.

BENDING AND FORMING TOOLS

Sheet metal forming dates back to the days of the blacksmith who used a hammer and hot oven to mold metal into the desired form. Today's aircraft technician relies on a wide variety of powered and hand-operated tools to precisely bend and fold sheet metal to achieve the perfect shape. Forming tools include straight line machines, such as the bar folder and press brake, as well as rotary machines, such as the slip roll former. Forming sheet metal requires a variety of tools and equipment (both powered and manual), such as the piccolo former, shrinking and stretching tools, form blocks, and specialized hammers and mallets. (***Figure 3-78***)

Tempered sheet stock is used in forming operations whenever possible in typical repairs. Forming that is performed in the tempered condition, usually at room temperature, is known as cold-forming. Cold forming eliminates heat treatment and the straightening and checking operations required to remove the warp and twist caused by the heat treating process. Cold-formed sheet metal experiences a phenomenon known as spring-back, which causes the worked piece to spring back slightly when the deforming force is removed. If the material shows signs of cracking during cold forming over small radii, the material should be formed in the annealed condition.

Annealing, the process of toughening steel by gradually heating and cooling it, removes the temper from metal, making it softer and easier to form. Parts containing small radii or compound curvatures must be formed in the annealed condition. After forming, the part is heat treated to a tempered condition before use on the aircraft.

Construction of interchangeable structural and nonstructural parts is achieved by forming flat sheet stock to make channel, angle, zee, and hat section members. Before a sheet metal part is formed, a flat pattern is made to show how much material is required in the bend areas, at what point the sheet must be inserted into the forming tool, or where bend lines are located. Determination of bend lines and bend allowances is discussed in greater detail in the section on layout and forming.

BAR FOLDING MACHINE

The bar folder is designed for use in making bends or folds along edges of sheets. (***Figure 3-79***)

This machine is best suited for folding small hems, flanges, seams, and edges to be wired. Most bar folders have a capacity for metal up to 22 gauge in thickness and 42 inches in length. Before using the bar folder, several adjustments must be made for thickness of material, width of fold, sharpness of fold, and angle of fold. The adjustment for thickness of material is made by adjusting the screws at each end of the folder. As this adjustment is made, place a piece of metal of the desired thickness in the folder and raise the operating handle until the small roller rests on the cam. Hold the folding blade in this position and adjust the setscrews until the metal is clamped securely and evenly the full length of the folding blade. After adjustment, test each end of the machine separately with a small piece of metal.

Figure 3-78. Basic metal forming tools.

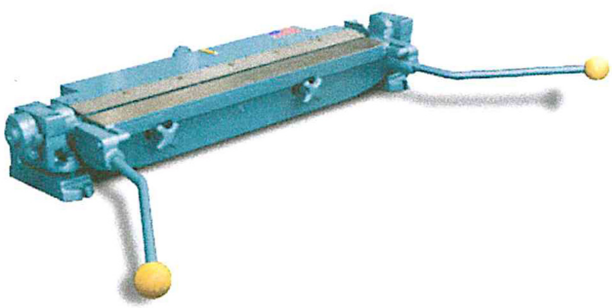


Figure 3-79. Adjustable bar folder.

There are two positive stops on the folder, one for 45° folds or bends and the other for 90° folds or bends. A collar is provided that can be adjusted to any degree of bend within the capacity of the machine.

For forming angles of 45° or 90°, the appropriate stop is moved into place. This allows the handle to be moved forward to the correct angle. For forming other angles, the adjustable collar is used. This is accomplished by loosening the setscrew and setting the stop at the desired angle. After setting the stop, tighten the setscrew and complete the bend. To make the fold, adjust the machine correctly and then insert the metal. The metal goes between the folding blade and the jaw. Hold the metal firmly against the gauge and pull the operating handle toward the body. As the handle is brought forward, the jaw automatically raises and holds the metal until the desired fold is made. When the handle is returned to its original position, the jaw and blade return to their original positions and release the metal.

CORNICE BRAKE

A brake is similar to a bar folder because it is also used for turning or bending the edges of sheet metal. The cornice brake is more useful than the bar folder because its design allows the sheet metal to be folded or formed to pass through the jaws from front to rear without obstruction. (***Figure 3-80***) In contrast, the bar folder can form a bend or edge only as wide as the depth of its jaws. Thus, any bend formed on a bar folder can also be made on the cornice brake.

In making ordinary bends with the cornice brake, the sheet is placed on the bed with the sight line (mark indicating line of bend) directly under the edge of the clamping bar. The clamping bar is then brought down to hold the sheet firmly in place. The stop at the right side of the brake is set for the proper angle or amount of bend and the bending leaf is raised until it strikes the stop. If other bends are to be made, the clamping bar is lifted and the sheet is moved to the correct position for bending.

The bending capacity of a cornice brake is determined by the manufacturer. Standard capacities of this machine are from 12 to 22 gauge sheet metal, and bending lengths are from 3 to 12 feet. The bending capacity of the brake is determined by the bending edge thickness of the various bending leaf bars.

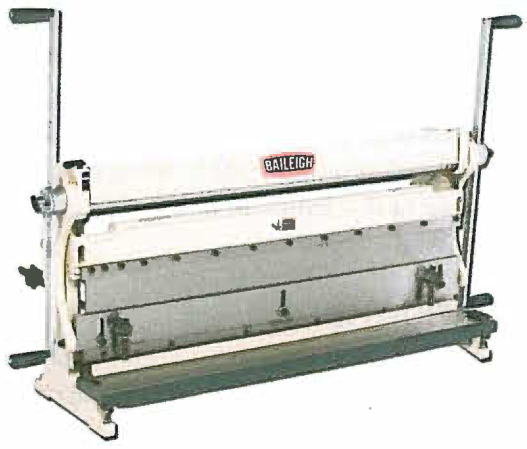


Figure 3-80. Cornice brake.

Most metals have a tendency to return to their normal shape—a characteristic known as spring-back. If the cornice brake is set for a 90° bend, the metal bent probably forms an angle of about 87° to 88°. Therefore, if a bend of 90° is desired, set the cornice brake to bend an angle of about 93° to allow for spring-back.

BOX AND PAN BRAKE (FINGER BRAKE)

The box and pan brake, often called the finger brake because it is equipped with a series of steel fingers of varying widths, lacks the solid upper jaw of the cornice brake. (***Figure 3-81***)

The box and pan brake can be used to do everything that the cornice brake can do, as well as several things the cornice brake cannot do.

The box and pan brake is used to form boxes, pans, and other similar shaped objects. If these shapes were formed on a cornice brake, part of the bend on one side of the box would have to be straightened in order to make the last bend. With a finger brake, simply remove the fingers that are in the way and use only the fingers required to

Figure 3-81. Box and pan brake.

make the bend. The fingers are secured to the upper leaf by thumbscrews. All the fingers not removed for an operation must be securely seated and firmly tightened before the brake is used. The radius of the nose on the clamping fingers is usually rather small and frequently requires nose radius shims to be custom made for the total length of the bend.

PRESS BRAKE

Since most cornice brakes and box and pan brakes are limited to a maximum forming capacity of approximately 0.090 inch annealed aluminum, 0.063-inch 7075T6, or 0.063-inch stainless steel, operations that require the forming of thicker and more complex parts use a press brake. (***Figure 3-82***)

Figure 3-82. Press brake.

The press brake is the most common machine tool used to bend sheet metal and applies force via mechanical and/or hydraulic components to shape the sheet metal between the punch and die. Narrow U-channels (especially with long legs) and hat channel stringers can be formed on the press brake by using special gooseneck or offset dies. Special urethane lower dies are useful for forming channels and stringers. Power press brakes can be set up with back stops (some are computer controlled) for high volume production. Press brake operations are usually done manually and require skill and knowledge of safe use.

SLIP ROLL FORMER

This machine is used to form sheets into cylinders or other straight curved surfaces. It consists of right and left end frames with three solid rolls mounted in between. Gears, which are operated by either a hand crank or a power drive, connect the two gripping rolls. These rolls can be adjusted to the thickness of the metal by using the two adjusting screws located on the bottom of each frame. The two most common of these forming machines are the slip roll former and the rotary former. Available in various sizes and capabilities, these machines come in manual or powered versions.

The slip roll former in ***Figure 3-83*** is manually operated and consists of three rolls, two housings, a base, and a handle. The handle turns the two front rolls through a system of gears enclosed in the housing. The front rolls serve as feeding, or gripping, rolls. The rear roll gives the proper curvature to the work. When the metal is started into the machine, the rolls grip the metal and carry it to the rear roll, which curves it. The desired radius of a bend is obtained by the rear roll. The bend radius of the part can be checked as the forming operation progresses by using a circle board or radius gauge. The gauge can be made by cutting a piece of material to the required finished radius and comparing it to the radius being formed by the rolling operation. On some material, the forming operation must be performed by passing the material through the rolls several times with progressive settings on the forming roll. On most machines, the top roll can be released on one end, permitting the formed sheet to be removed from the machine without distortion.

The front and rear rolls are grooved to permit forming of objects that have wired edges. The upper roll is equipped with a release that permits easy removal of the metal after it has been formed. When using the slip roll former, the lower front roll must be raised or lowered before inserting the sheet of metal. If the object has a folded edge, there must be enough clearance between the rolls to prevent flattening the fold. If a metal requiring special care (such as aluminum) is being formed, the rolls must be clean and free of imperfections.

The rear roll must be adjusted to give the proper curvature to the part being formed. There are no guages that indicate settings for a specific diameter; therefore, trial and error settings must be used to obtain the desired curvature. The metal should be inserted between the rolls from the front of the machine. Start the metal between the rolls by rotating the operating handle in a clockwise direction. A starting edge is formed by holding the operating handle firmly with the right hand

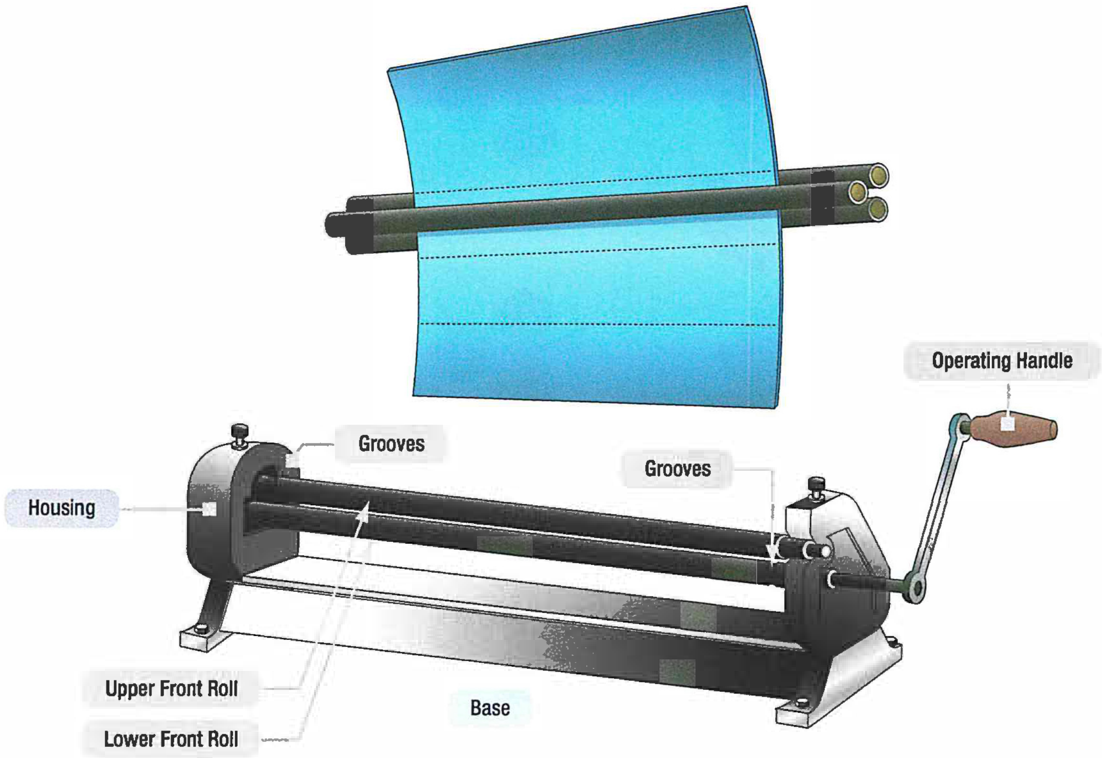


Figure 3-83. Slip roll former.

and raising the metal with the left hand. The bend of the starting edge is determined by the diameter of the part being formed. If the edge of the part is to be flat or nearly flat, a starting edge should not be formed.

Ensure that fingers and loose clothing are clear of the rolls before the actual forming operation is started. Rotate the operating handle until the metal is partially through the rolls and change the left hand from the front edge of the sheet to the upper edge of the sheet. Then, roll the remainder of the sheet through the machine. If the desired curvature is not obtained, return the metal to its starting position by rotating the handle counterclockwise. Raise or lower the rear roll and roll the metal through the rolls again. Repeat this procedure until the desired curvature is obtained, then release the upper roll and remove the metal. If the part to be formed has a tapered shape, the rear roll should be set so that the rolls are closer together on one end than on the opposite end. The amount of adjustment must be determined by experimentation.

If the job being formed has a wired edge, the distance between the upper and lower rolls and the distance between the lower front roll and the rear roll should be slightly greater at the wired end than at the opposite end. (***Figure 3-84***)

ROTARY MACHINE

The rotary machine is used on cylindrical and flat sheet metal to shape the edge or to form a bead along the edge. (***Figure 3-85***) Various shaped rolls can be installed on the rotary machine to perform these operations. The rotary machine works best with thinner annealed materials.

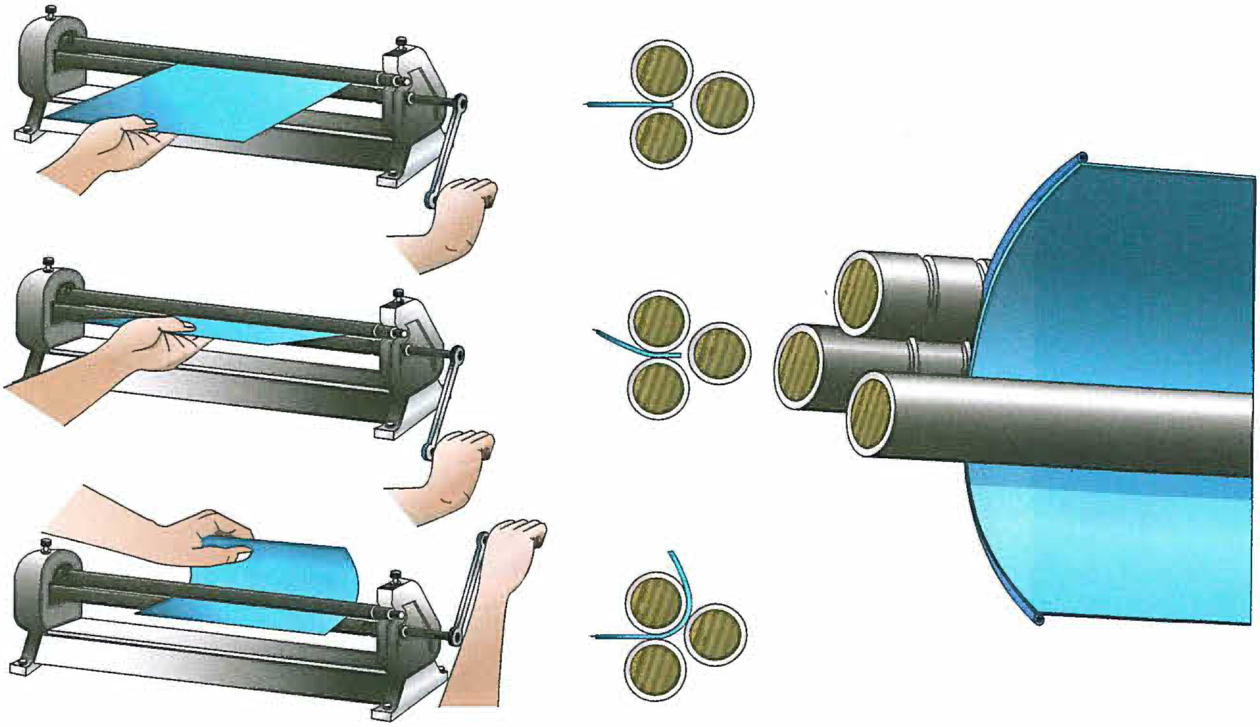


Figure 3-84. Slip roll operation.

Figure 3-85. Rotary machine.

SHRINKING AND STRETCHING TOOLS

SHRINKING TOOLS

Shrinking dies repeatedly clamp down on the metal, then shift inward. (*Figure 3-86*)

This compresses the material between the dies, which actually slightly increases the thickness of the metal. Strain hardening takes place during this process, so it is best to set the working pressure high enough to complete the shape rather quickly (eight passes could be considered excessive).

CAUTION: Avoid striking a die on the radius itself when forming a curved flange. This damages the metal in the radius and decreases the angle of bend.

STRETCHING TOOLS

Stretching dies repeatedly clamp down on the surface and then shift outward. This stretches the metal between the dies, which decreases the thickness in the stretched area. Striking the same point too many times weakens and eventually cracks the part. It is advantageous to deburr or even polish the edges of a flange that must undergo even moderate stretching to avoid crack formation. Forming flanges with existing holes causes the holes to distort and possibly crack or substantially weaken the flange.

STRETCH FORMING

In the process of stretch forming, a sheet of metal is shaped by stretching it over a formed block to just beyond the elastic limit where permanent set takes place with a minimum amount of spring-back. To stretch the metal, the sheet is rigidly clamped at two opposite edges in fixed vises. Then, the metal is stretched by moving a ram that carries the form block against the sheet with the pressure from the ram causing the material to stretch and wrap to the contour of the form block. Stretch forming is normally restricted to relatively large parts with large radii of curvature and shallow depth, such as contoured skin. Uniform contoured parts produced at a faster speed give stretch forming an advantage over hand formed parts. Also, the condition of the material is more uniform than that obtained by hand forming.

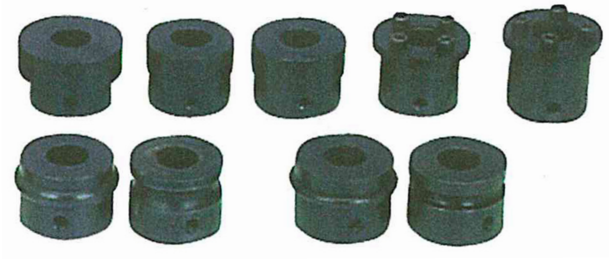


Figure 3-86. Shrinking and stretching dies.

DROP HAMMER

The drop hammer forming process produces shapes by the progressive deformation of sheet metal in matched dies under the repetitive blows of a gravity-drop hammer or a power-drop hammer. The configurations most commonly formed by the process include shallow, smoothly contoured double-curvature parts, shallow-beaded parts, and parts with irregular and comparatively deep recesses. Small quantities of cup-shaped and box-shaped parts, curved sections, and contoured flanged parts are also formed. Drop hammer forming is not a precision forming method and cannot provide tolerances as close as 0.03-inch to 0.06-inch. Nevertheless, the process is often used for sheet metal parts, such as aircraft components, that undergo frequent design changes, or for which there is a short run expectancy.

HYDROPRESS FORMING

The rubber pad hydropress can be utilized to form many varieties of parts from aluminum and its alloys with relative ease. Phenolic, masonite, kirksite, and some types of hard-setting moulding plastic have been used successfully as form blocks to press sheet metal parts, such as ribs, spars, fans, etc. To perform a press forming operation:

1. Cut a sheet metal blank to size and deburr edges.
2. Set the form block (normally male) on the lower press platen.
3. Place the prepared sheet metal blank with locating pins to prevent shifting of the blank when the pressure is applied.
4. Lower or close the rubber pad-filled press head over the form block and the rubber envelope.
5. The form block forces the blank to conform to its contour.

Hydropress forming is usually limited to relatively flat parts with flanges, beads, and lightening holes. However, some types of large radii contoured parts can be formed by a combination of hand forming and pressing operations.

SPIN FORMING

In spin forming, a flat circle of metal is rotated at a very high speed to shape a seamless, hollow part using the combined forces of rotation and pressure. For example, a flat circular blank such as an aluminum disk, is mounted in a lathe in conjunction with a form block (usually made of hardwood). As the aircraft technician revolves the disc and form block together at high speeds, the disk is molded to the form block by applying pressure with a spinning stick or tool. It provides an economical alternative to stamping, casting, and many other metal forming processes. Propeller spinners are sometimes fabricated with this technique.

Aluminum soap, tallow, or ordinary soap can be used as a lubricant. The best adapted materials for spinning are the softer aluminum alloys, but other alloys can be used if the shape to be spun is not excessively deep or if the spinning is done in stages utilizing intermediate annealing to remove the effect of strain hardening that results from the spinning operation. Hot forming is used in some instances when spinning thicker and harder alloys. (***Figure 3-87***)

FORMING WITH AN ENGLISH WHEEL

The English wheel, a popular type of metal forming tool used to create double curves in metal, has two steel wheels between which metal is formed. (***Figure 3-88***)

Keep in mind that the English wheel is primarily a stretching machine, so it stretches and thins the metal before forming it into the desired shape. Thus, the operator must be careful not to over-stretch the metal.

To use the English wheel, place a piece of sheet metal between the wheels (one above and one below the metal). Then, roll the wheels against one another under a pre-adjusted pressure setting. Steel or aluminum can be shaped by pushing the metal back and forth between the wheels. Very little pressure is needed to shape the panel, which is stretched or raised to the desired shape. It is important to work slowly and gradually curve the metal into the desired shape. Monitor the curvature with frequent references to the template.

The English wheel is used for shaping low crowns on large panels and polishing or planishing (to smooth the surface of a metal by rolling or hammering it) parts that have been formed with power hammers or hammer and shot bag.

PICCOLO FORMER

The piccolo former is used for cold forming and rolling sheet metal and other profile sections (extrusions). (***Figure 3-89***) The position of the ram is adjustable in height by means of either a handwheel or a foot pedal that permits control of the working pressure. Be sure to utilize the adjusting ring situated in the machine head to control the maximum working pressure. The forming tools are located in the moving ram and the lower tool holder. Depending on the variety of forming tools included, the operator can perform such

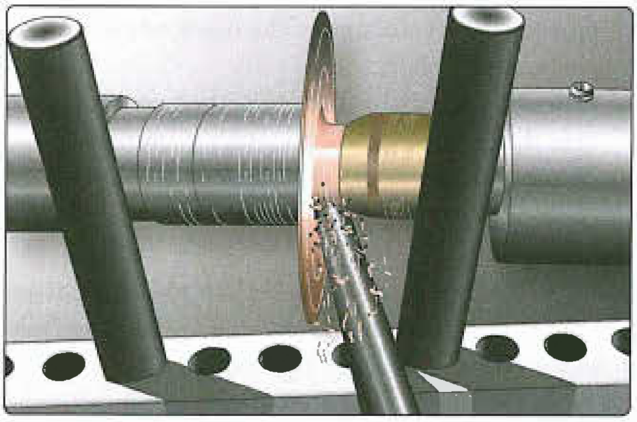


Figure 3-87. Spin forming.

Figure 3-88. English wheel.

Figure 3-89. Piccolo former.

procedures as forming edges, bending profiles, removing wrinkles, spot shrinking to remove buckles and dents, or expanding dome sheet metal. Available in either fiberglass (to prevent marring the surface) or steel (for working harder materials) faces, the tools are the quick-change type.

MANUAL FOOT-OPERATED SHEET METAL SHRINKER

The manual foot-operated sheet metal shrinker operates very similarly to the Piccolo former though it only has two primary functions: shrinking and stretching. The only dies available are steel faced and therefore tend to mar the surface of the metal. When used on aluminum, it is necessary to gently blend out the surface irregularities (primarily in the cladding), then treat and paint the part.

Since this is a manual machine, it relies on leg power, as the operator repeatedly steps on the foot pedal. The more force is applied, the more stresses are concentrated at that single point. It yields a better part with a series of smaller stretches (or shrinks) than with a few intense ones. Squeezing the dies over the radius damages the metal and flattens out some of the bend. It may be useful to tape a thick piece of plastic or micarta to the opposite leg to shim the radius of the angle away from the clamping area of the dies.

NOTE: Watch the part change shape while slowly applying pressure. A number of small stretches works more effectively than one large one. If applying too much pressure, the metal has the tendency to buckle.

HAND-OPERATED SHRINKER AND STRETCHER

The hand-operated shrinker and structure is similar to the manual foot-operated unit, except a handle is used to apply force to shrinking and stretching blocks. The dies are all metal and leave marks on aluminum that need to be blended out after the shrinking or stretching operation. (***Figure 3-90***)

DOLLIES AND STAKES

Sheet metal is often formed or finished (planished) over anvils, available in a variety of shapes and sizes, called dollies and stakes. These are used for forming small, odd-shaped parts, or for putting on finishing touches for which a large machine may not be suited. Dollies are meant to be held in the hand, whereas stakes are designed to be supported by a flat cast iron bench plate fastened to the workbench. (***Figure 3-91***)

Most stakes have machined, polished surfaces that have been hardened. Use of stakes to back up material when chiseling, or when using any similar cutting tool, defaces the surface of the stake and makes it useless for finish work.

Figure 3-90. Hand operated shrinker and stretcher unit.

Figure 3-91. Dollies and stakes.

HARDWOOD FORM BLOCKS

Hardwood form blocks can be constructed to duplicate practically any aircraft structural or nonstructural part. The wooden block or form is shaped to the exact dimensions and contour of the part to be formed.

V-BLOCKS

V-blocks made of hardwood are widely used in airframe metalwork for shrinking and stretching metal, particularly angles and flanges. The size of the block depends on the work being done and on personal preference. Although any type of hardwood is suitable, maple and ash are recommended for best results when working with aluminum alloys.

SHRINKING BLOCKS

A shrinking block consists of two metal blocks and some device for clamping them together. One block forms the base and the other is cut away to provide space where the crimped material can be hammered. The legs of the upper jaw clamp the material to the base block on each side of the crimp to prevent the material from creeping away, but remains stationary while the crimp is hammered flat (being shrunk). This type of crimping block is designed to be held in a bench vise. Shrinking blocks can be made to fit any specific need. The basic form and principle remain the same, even though the blocks may vary considerably in size and shape.

SANDBAGS

A sandbag is generally used as a support during the bumping process. A serviceable bag can be made by sewing heavy canvas or soft leather to form a bag of the desired size, and filling it with sand which has been sifted through a fine mesh screen. Before filling canvas bags with sand, use a brush to coat the inside of the bag with softened paraffin or beeswax, which forms a sealing layer and prevents the sand from working through the pores of the canvas. Bags can also be filled with shot as an alternative to sand.

SHEET METAL HAMMERS AND MALLETS

The sheet metal hammer and the mallet are metal fabrication hand tools used for bending and forming sheet metal without marring or indenting the metal. The hammer head is usually made of high carbon, heat-treated steel, while the head of the mallet, which is usually larger than that of the hammer, is made of rubber, plastic, wood, or leather. In combination with a sandbag, V-blocks, and dies, sheet metal body hammers and mallets are used to form annealed metal. (*Figure 3-92*)

Figure 3-92. Sheet metal mallet and hammers.

LUBRICATION EQUIPMENT

There are tools for lubricating various aircraft parts. Some oil-lubricated parts are lubricated via a dispensing spout on an oil storage container. These are often long, sometimes flexible delivery spouts designed for placing drops of oil exactly where required. (*Figure 3-93*) If the oil is in an aerosol type can under pressure, it may be dispensed simply by pressing the spray nozzle. Often a straw is inserted in the nozzle for pinpointing the direction of the spray. Occasionally, application of oil to an aircraft part is with a brush.

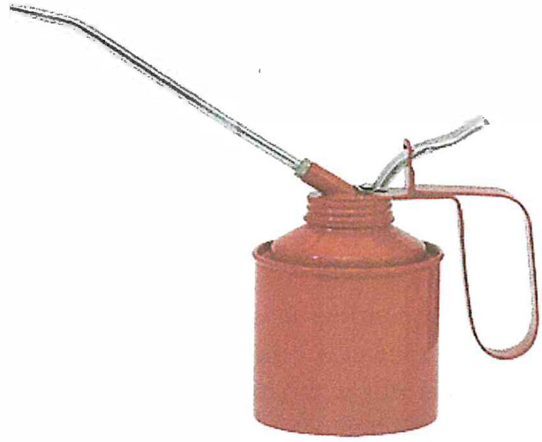


Figure 3-93. An oil can for lubricating.

Grease is the required lubricant for many aircraft parts. From hinges to bearings to jackscrews, tracks, and doors, there are numerous locations on the aircraft that must receive regular servicing with grease. Most of the locations are fitted with Zerk fittings. These fittings are mounted in the structure surrounding a particular bearing surface that needs grease. A tiny spring-loaded ball check valve inside the fitting allows easy servicing with a grease gun.

Figure 3-94. A typical zerk fitting and the grease gun adapter that fits on it.

By seating the grease gun tip onto the head of the Zerk fitting, the ball is pushed back as grease is pumped past it onto the bearing surface. When the tip is removed the spring seats the ball protecting the bearing surfaces from contamination. (*Figure 3-94*)

There are many variations of the Zerk grease fitting which include both protruding and flush fittings. The type used in a particular location is chosen by the manufacturer based on clearances and accessibility. Note that it takes a different grease gun tip to grease through a flush mounted fitting than a regular protruding fitting. (*Figure 3-95*)

Figure 3-95. Flush mount grease fitting for a rod end bearing and grease gun tip.

Most shops have numerous grease guns set up with particular greases and both types of tips. It is critical that only the manufacturer specified grease be used in any lubrication operation.

Hand powered and pneumatic powered grease guns are used. The powered guns simply attach to shop air. When the trigger is pulled, air pressure pushed the grease out of the gun and into the fitting and bearing. Most shops that maintain transport category aircraft use pneumatic grease guns. (*Figure 3-96*)

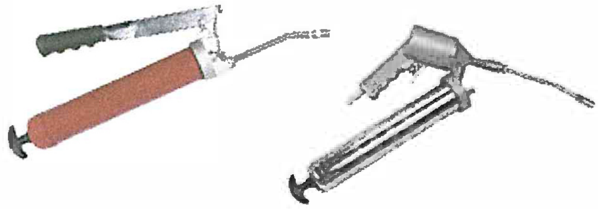


Figure 3-96. Hand powered and pneumatic powered grease guns are common in aviation.

TOOLS

ELECTRICAL GENERAL TEST EQUIPMENT OPERATION, FUNCTION AND USE

DC MEASURING EQUIPMENT

Understanding the functional design and operation of electrical measuring instruments is very important, since they are used in repairing, maintaining, and troubleshooting electrical circuits. The best and most expensive measuring instrument is of no use unless the technician knows what is being measured and what each reading indicates. The purpose of the meter is to measure quantities existing in a circuit. For this reason, when a meter is connected to a circuit, it must not change the characteristics of that circuit. Meters are either self-excited or externally excited. Those that are self-excited operate from a power source within the meter. Externally excited meters get their power source from the circuit that they are connected to. The most common analog meters in use today are the voltmeter, ammeter, and ohmmeter. All of which operate on the principles of electromagnetism.

The fundamental principle behind the operation of the meter is the interaction between magnetic fields created by a current gathered from the circuit in some manner. This interaction is between the magnetic fields of a permanent magnet and the coils of a rotating magnet. The greater the current through the coils of the rotating magnet, the stronger the magnetic field produced. A stronger field produces greater rotation of the coil.

While some meters can be used for both DC and AC circuit measurement, only those used as DC instruments are discussed in this section. The meters used for AC, or for both AC and DC, are discussed in the study of AC theory and circuitry.

D'ARSONVAL METER MOVEMENT

This basic DC type of meter movement, first employed by the French scientist, d'Arsonval, in making electrical measurement, is a current measuring device, which is used in the ammeter, voltmeter, and ohmmeter. The pointer is deflected in proportion to the amount of current through the coil. Basically, both the ammeter and the voltmeter are current measuring instruments, the principal difference being the method in which they are connected in a circuit. While an ohmmeter is also basically a current measuring instrument, it differs from the ammeter and voltmeter in that it provides its own source (self-excited) of power and contains other auxiliary circuits.

CURRENT SENSITIVITY AND RESISTANCE

The current sensitivity of a meter movement is the amount of current required to drive the meter movement to a full-scale deflection. A simple example would be a meter movement that has 1mA sensitivity. What this indicates is that meter movement will require 1mA of current to move the needle to a full-scale indication. Likewise a half scale deflection will require only 0.5mA of current. Additionally, what is called movement resistance is the actual DC resistance of the wire used to construct the meter coil.

A standard d'Arsonval meter movement may have a current sensitivity of 1mA and a resistance of 50Ω. If the meter is going to be used to measure more than 1mA then additional circuitry will be required to accomplish the task. This additional circuitry is a simple shunt resistor. The purpose of the shunt resistor is to bypass current that exceeds the 1mA limitation of the meter movement. To illustrate this, assume that the 1mA meter in question is needed to measure 10mA. The shunt resistor used should carry 9mA while the remaining 1mA is allowed to pass through the meter. (***Figure 3-97***)

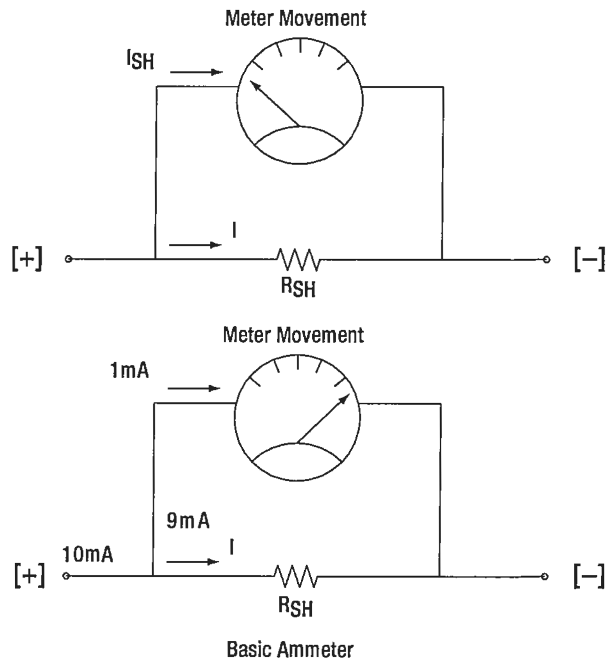


Figure 3-97. Basic meter drawing.

To determine the proper shunt resistance for this situation:

RSH = Shunt resistance
RM = Meter resistance = 50Ω

Because the shunt resistance and the 50Ω meter resistance are in parallel, the voltage drop across both of them is the same.

$$E_{SH} = E_M$$

Using Ohm's law, this relationship can be rewritten as:

$$E_{SH} = I_{SH} \times R_{SH}$$
$$E_M = I_M \times R_M$$

$$I_{SH} \times R_{SH} = I_M \times R_M$$

Simply solve for R_{SH}:

$$R_{SH} \frac{I_M \times R_M}{I_{SH}}$$

Substituting the values:

$$R_{SH} = \frac{1mA \times 50\Omega}{9mA} = 5.56\Omega$$

DAMPING

To make meter readings quickly and accurately, it is desirable that the moving pointer overshoot its proper position only a small amount and come to rest after not more than one or two small oscillations. The term "damping" is applied to methods used to bring the pointer of an electrical meter to rest after it has been set in motion. Damping may be accomplished by electrical means, by mechanical means, or by a combination of both.

Electrical Damping

A common method of damping by electrical means is to wind the moving coil on an aluminum frame. As the coil moves in the field of the permanent magnet, eddy currents are set up in the aluminum frame. The magnetic field produced by the eddy currents opposes the motion of the coil. The pointer will therefore swing more slowly to its proper position and come to rest quickly with very little oscillation.

Mechanical Damping

Air damping is a common method of damping by mechanical means. As shown in ***Figure 3-98***, a vane is attached to the shaft of the moving element and enclosed in an air chamber. The movement of the shaft is retarded because of the resistance that the air offers to the vane. Effective damping is achieved if the vane nearly touches the walls of the chamber.

A BASIC MULTIRANGE AMMETER

Building upon the basic meter previously discussed is the more complex and useful multirange meter, which is more practical. The basic idea of a multirange ammeter is to make the meter usable over a wide range of voltages. In order to accomplish this, each range must utilize a different shunt resistance. The example given in this text is that of a two-range meter. However, once the basics of a two range multirange ammeter are understood, the concepts can easily be transferred to the design of meters with many selectable ranges.

Figure 3-99 shows the schematic of an ammeter with two selectable ranges. This example builds upon the previous 10mA range meter by adding a 100mA range.

With the switch selected to the 10mA range, the meter will indicate 10mA when the needle is deflected to full scale and will likewise indicate 100mA at full scale when selected to 100mA.

The value of the 100mA shunt resistor is determined the same way the 10mA shunt resistor was determined. Recall that the meter movement can only carry 1mA.

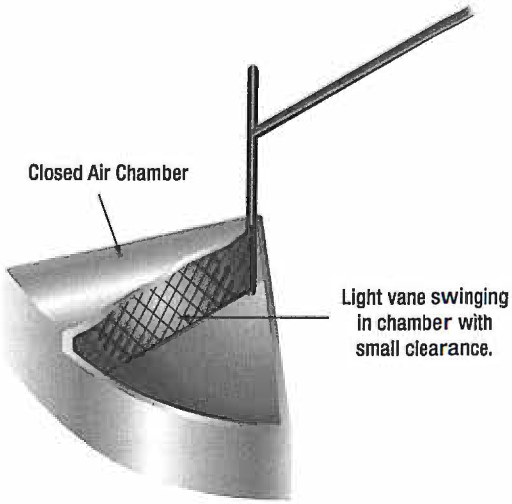


Figure 3-98. Air damping.

This means that in a 100mA range the remaining current of 99mA must pass through the shunt resistor.

$$R_{SH} \frac{I_M \times R_M}{I_{SH}}$$

Substituting the values:

$$R_{SH} = \frac{ImA \times 50\Omega}{99mA} = 0.51\Omega$$

PRECAUTIONS

The precautions to observe when using an ammeter are summarized as follows:

1. Always connect an ammeter in series with the element through which the current flow is to be measured.
2. Never connect an ammeter across a source of voltage, such as a battery or generator. Remember that the resistance of an ammeter, particularly on the higher ranges, is extremely low and that any voltage, even a volt or so, can cause very high current to flow through the meter, causing damage to it.
3. Use a range large enough to keep the deflection less than full scale. Before measuring a current, form some idea of its magnitude. Then switch to a large enough scale or start with the highest range and work down until the appropriate scale is reached. The most accurate readings are obtained at approximately half-scale deflection. Many milliammeters have been ruined by attempts to measure amperes. Therefore, be sure to read the lettering either on the dial or on the switch positions and choose proper scale before connecting the meter in the circuit.
4. Observe proper polarity in connecting the meter in the circuit. Current must flow through the coil in a definite direction in order to move the indicator needle up scale. Current reversal because of incorrect connection in the circuit results in a reversed meter deflection and frequently causes bending of the meter needle. Avoid improper meter connections by observing the polarity markings on the meter.

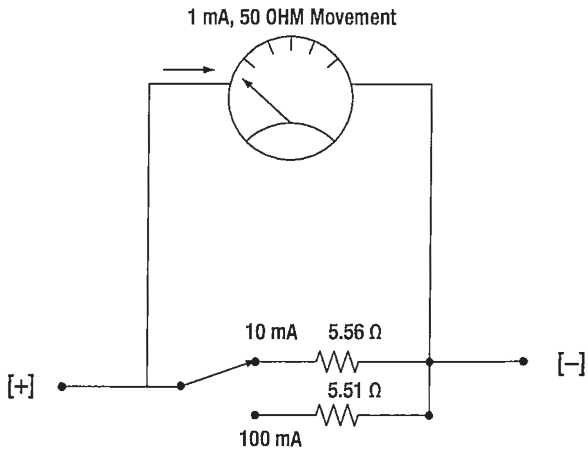


Figure 3-99. Ammeter with two ranges.

THE VOLTMETER

The voltmeter uses the same type of meter movement as the ammeter but employs a different circuit external to the meter movement.

As shown before, the voltage drop across the meter coil is a function of current and the coil resistance. In another example, 50µA × 1000Ω = 50mV. In order for the meter to be used to measure voltages greater than 50mV, there must be added a series resistance to drop any excess voltage greater than that which the meter movement requires for a full scale deflection. In the case of the voltmeter, this resistance is called multiplier resistance and will be designated as RM.

Figure 3-100 illustrates a basic voltmeter. This voltmeter only has one multiplier resistor for use in one range. In this example, the full scale reading will be 1 volt.

RM is determined in the following way:

The meter movement drops 50mV at a full scale deflection of 50µA. The multiplying resistor RM must drop the remaining voltage of 1V – 50mV = 950 mV. Since RM is in series with the movement, it also carries 50µA at full scale.

$$RM = \frac{950 \text{ mV}}{50\mu A} = 19 \text{ k}\,\Omega$$

Therefore, for 1 volt full scale deflection, the total resistance of the voltmeter is 20 k Ω. That is, the multiplier resistance and the coil resistance.

VOLTMETER SENSITIVITY

Voltmeter sensitivity is defined in terms of resistance per volt (Ω/V). The meter used in the previous example has a sensitivity of 20 k Ω and a full scale deflection of 1 volt.

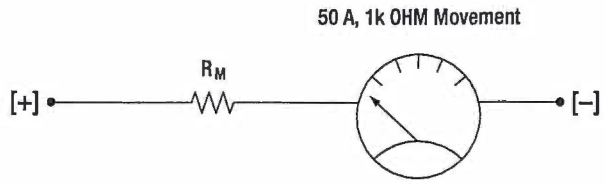


Figure 3-100. Basic voltmeter.

MULTIPLE RANGE VOLTMETERS

The simplified voltmeter has only one range (1 volt), which means that it can measure voltages from 0 volts to 1 volt. In order for the meter to be more useful, additional multiplier resistors must be used. One resistor must be used for each desired range.

For a 50μA movement, the total resistance required is 20 k Ω for each volt of full scale reading. In other words, the sensitivity for a 50μA movement is always 20 k Ω regardless of the selected range. The full-scale meter current is 50μA at any range selection. To find the total meter resistance, multiply the sensitivity by the full scale voltage for that particular range. For example for a 10 volt range, RT = (20k Ω/V)/(10 V) = 200k Ω. The total resistance for the 1 volt range is 20k Ω, so RM for a 10 V range will be 200k Ω - 20k Ω = 180k Ω. This two-range voltmeter is illustrated in ***Figure 3-101.***

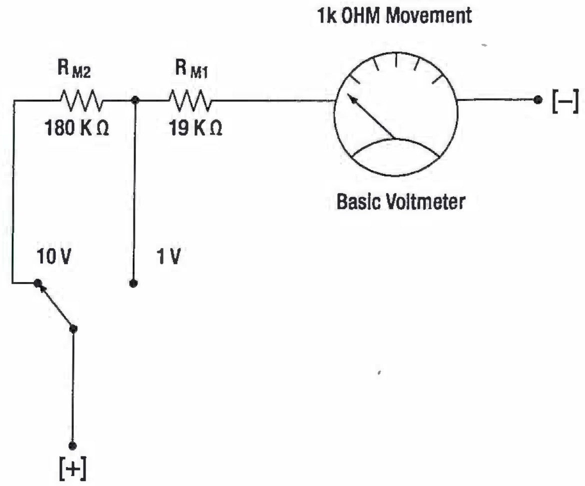


Figure 3-101. Two range voltmeter.

VOLTMETER CIRCUIT CONNECTIONS

When voltmeters are used, they are connected in parallel with a circuit. If unsure about the voltage to be measured, take the first reading at the high value on the meter and then progressively move down through the range until a suitable reading is obtained. Observe that the polarity is correct before connecting the meter to the circuit or damage will occur by driving the movement backwards.

INFLUENCE OF THE VOLTMETER IN THE CIRCUIT

When a voltmeter is connected across two points in a circuit, current will be shunted. If the voltmeter has low resistance, it will draw off a significant amount of current. This will lower the effective resistance of the circuit and change the voltage readings. When taking a voltage measurement, use a high resistance voltmeter to prevent shunting of the circuit.

THE OHMMETER

The meter movement used for the ammeter and the voltmeter can also be used for the ohmmeter. The function of the ohmmeter is to measure resistance.

A simplified one-stage ohmmeter is illustrated in ***Figure 3-102***, which shows that the basic ohmmeter contains a battery and a variable resistor in series with the meter movement. To measure resistance, the leads of the meter are connected across an external resistance, which is to be measured. By doing this the ohmmeter circuit is completed. This connection allows the internal battery to produce a current through the movement coil, causing a deflection of the pointer proportional to the value of the external resistance being measured.

ZERO ADJUSTMENT

When the ohmmeter leads are open as shown in ***Figure 3-103***, the meter is at a full scale deflection, indicating an infinite (∞) resistance or an open circuit. When the leads are shorted as shown in figure "zero adjustment," the pointer will be at the full right hand position, indicating a short circuit or zero resistance. The purpose of the variable resistor in this figure is to adjust the current so that the pointer is at exactly zero when the

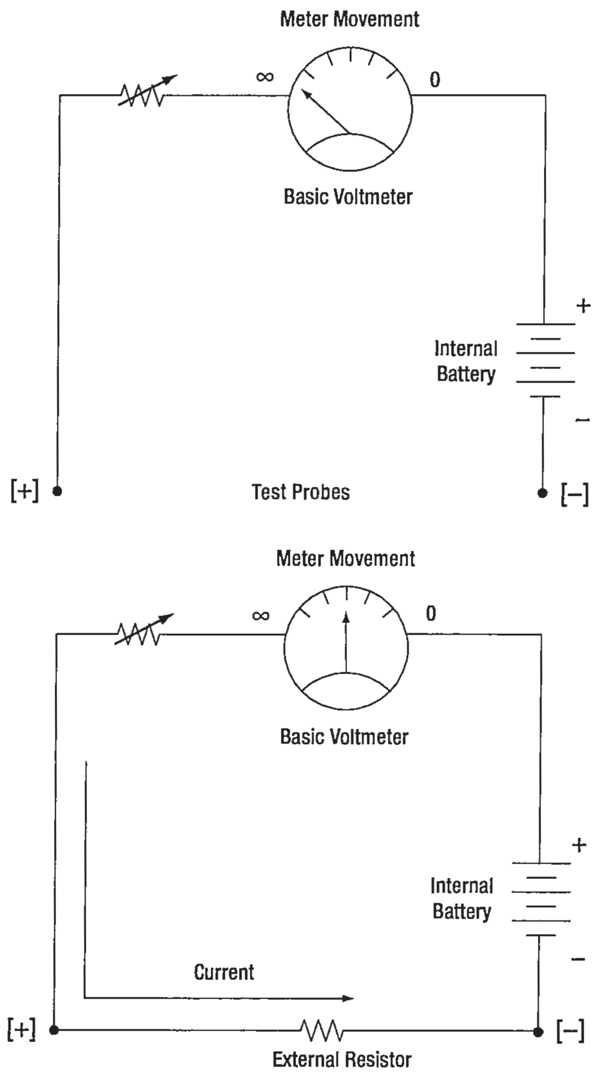


Figure 3-102. Basic ohmmeter.

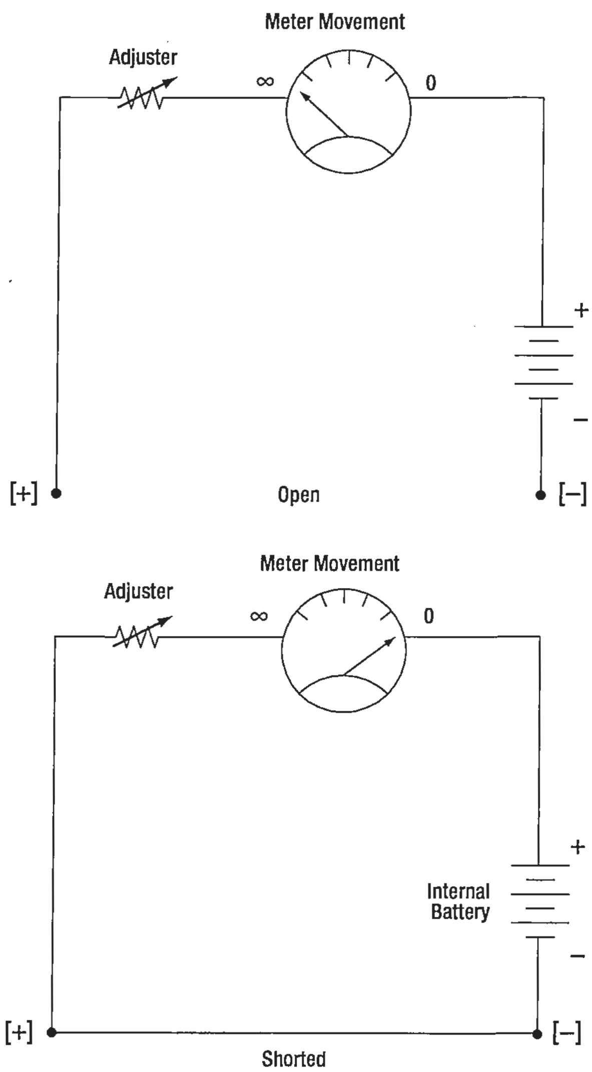


Figure 3-103. Zero adjustment.

leads are shorted. This is used to compensate for changes in the internal battery voltage due to aging.

OHMMETER SCALE

Figure 3-104 shows a typical analog ohmmeter scale. Between zero and infinity (∞), the scale is marked to indicate various resistor values. Because the values decrease from left to right, this scale is often called a back-off scale. In the case of the example given, assume that a certain ohmmeter uses a 50μA, 1 000Ω meter movement and has an internal 1.5 volt battery. A current of 50μA produces a full-scale deflection when the test leads are shorted.

To have 50μA, the total ohmmeter resistance is 1.5 V/50μA = 30kΩ. Therefore, since the coil resistance is 1kΩ, the variable zero adjustment resistor must be set to 30kΩ – 1kΩ = 29kΩ.

Now consider that a 120kΩ resistor is connected to the ohmmeter leads. Combined with the 30kΩ internal resistance, the total R is 150kΩ. The current is 1.5 V/150kΩ = 10μA, which is 20% of the full scale current and which appears on the scale as shown in ***Figure 3-104.***

Now consider further that a 120kΩ resistor is connected to the ohmmeter leads. This will result in a current of 1.5V/75kΩ = 10μA, which is 40% of the full scale current and which is marked on the scale as shown. Additional calculations of this type show that the scale is nonlinear. It is more compressed toward the left side than the right side. The center scale point corresponds to the internal meter resistance of 30kΩ.

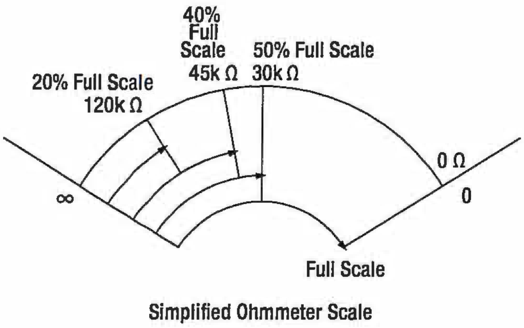


Figure 3-104. Ohm scale.

The reason is as follows:

> With 30kΩ connected to the leads, the current is 1.5V/60kΩ = 25μA, which is half of the full scale current of 50μA.

THE MULTIRANGE OHMMETER

A practical ohmmeter usually has several operational ranges. These typically are indicated by R × 1, R × 10, R × 100, R × 1k, R × 100k and R × 1M. These range selections are interpreted in a different manner than that of an ammeter or voltmeter.

The reading on the ohmmeter scale is multiplied by the factor indicated by the range setting. For example, if the pointer is set on the scale and the range switch is set at R × 100, the actual resistance measurement is 20 × 100 or 2kΩ.

To measure small resistance values, the technician must use a higher ohmmeter current than is needed for measuring large resistance values. Shunt resistors are needed to provide multiple ranges on the ohmmeter to measure a range of resistance values from the very small to very large. For each range, a different value of shunt resistance is switched in. The shunt resistance increases for higher ohm ranges and is always equal to the center scale reading on any selected range. In some meters, a higher battery voltage is used for the highest ohm range. A common circuit arrangement is shown in ***Figure 3-105***.

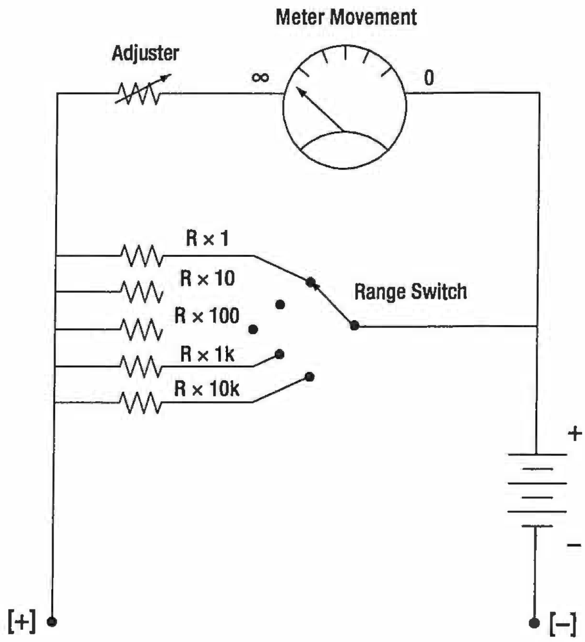


Figure 3-105. Multirange ohmmeter.

MEGGER (MEGOHMMETER)

The megger, or megohmmeter, is a high range ohmmeter containing a hand-operated generator. It is used to measure insulation resistance and other high resistance values. It is also used for ground, continuity, and short circuit testing of electrical power systems. The chief advantage of the megger over an ohmmeter is its capacity to measure resistance with a high potential, or "breakdown" voltage. This type of testing ensures that insulation or a dielectric material will not short or leak under potential electrical stress.

The megger consists of two primary elements, both of which are provided with individual magnetic fields from a common permanent magnet: (1) a hand-driven DC generator, G, which supplies the necessary current for making the measurement, and (2) the instrument portion, which indicates the value of the resistance being measured. The instrument portion is of the opposed coil type. Coils A and B are mounted on the movable member with a fixed angular relationship to each other and are free to turn as a unit in a magnetic field. Coil B tends to move the pointer counterclockwise and coil A, clockwise. The coils are mounted on a light, movable frame that is pivoted in jewel bearings and free to move about axis 0. (***Figure 3-106***)

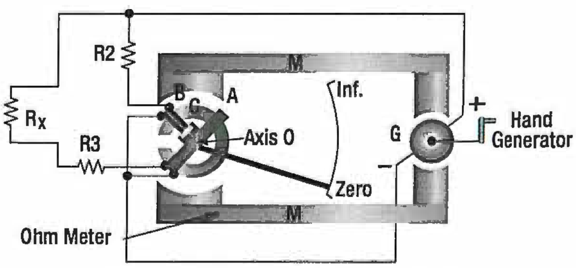


Figure 3-106. Simplified megger circuit.

Coil A is connected in series with R3 and the unknown resistance, R_X, to be measured. The series combination of coil A, R3, and Rx is connected between the + and – brushes of the DC generator. Coil B is connected in series with R2 and this combination is also connected across the generator. There are no restraining springs on the movable member of the instrument portion of the megger. When the generator is not in operation, the pointer floats freely and may come to rest at any position on the scale.

If the terminals are open circuited, no current flows in coil A, and the current in coil B alone controls the movement of the moving element. Coil B takes a position opposite the gap in the core (since the core cannot move and coil B can), and the pointer indicates infinity on the scale. When a resistance is connected between the terminals, current flows in coil A, tending to move the pointer clockwise. At the same time, coil B tends to move the pointer counterclockwise. Therefore, the moving element, composed of both coils and the pointer, comes to rest at a position at which the two forces are balanced. This position depends upon the value of the external resistance, which controls the relative magnitude of current of coil A. Because changes in voltage affect both coils A and B in the same proportion, the position of the moving element is independent of the voltage. If the terminals are short circuited, the pointer rests at zero because the current in A is relatively large. The instrument is not damaged under these circumstances because the current is limited by R3.

There are two types of hand-driven meggers: the variable type and the constant pressure type. The speed of the variable pressure megger is dependent on how fast the hand crank is turned. The constant pressure megger uses a centrifugal governor, or slip clutch. The governor becomes effective only when the megger is operated at a speed above its slip speed, at which speed its voltage remains constant.

AC MEASURING INSTRUMENTS

A DC meter, such as an ammeter, connected in an AC circuit will indicate zero, because the meter movements used in a d'Arsonval type movement is restricted to direct current. Since the field of a permanent magnet in the d'Arsonval type meter remains constant and in the same direction at all times, the moving coil follows the polarity of the current. The coil attempts to move in one direction during half of the AC cycle and in the reverse direction during the other half when the current reverses.

The current reverses direction too rapidly for the coil to follow, causing the coil to assume an average position. Since the current is equal and opposite during each half of the AC cycle, the direct current meter indicates zero, which is the average value. Thus, a meter with a permanent magnet cannot be used to measure alternating voltage and current. For AC measurements of current and voltage, additional circuitry is required. The additional circuitry has a rectifier, which converts AC to DC. There are two basic types of rectifiers: One is the half-wave rectifier and the other is the full-wave rectifier. Both of these are depicted in block diagram form in ***Figure 3-107***.

Figure 3-107 also shows a simplified block diagram of an AC meter. In this depiction, the full-wave rectifier precedes the meter movement. The movement responds to the average value of the pulsating DC. The scale can then be calibrated to show anything the designer wants. In most cases, it will be root mean square (RMS) or peak value.

ELECTRODYNAMOMETER METER MOVEMENT

The electrodynamometer can be used to measure alternating or direct voltage and current. It operates on the same principles as the permanent magnet moving coil meter, except that the permanent magnet is replaced by an air core electromagnet. The field of the electrodynamometer is developed by the same current that flows through the moving coil. (***Figure 3-108***)

Because this movement contains no iron, the electrodynamometer can be used as a movement for both AC and DC instruments. Alternating current can be measured by connecting the stationary and moving coils in series. Whenever the current in the moving coil reverses, the magnetic field produced by the stationary coil reverses. Regardless of the direction of the current, the needle will move in a clockwise direction.

However, for either voltmeter or ammeter applications, the electrodynamometer is too expensive to economically compete with the d'Arsonval type movement.

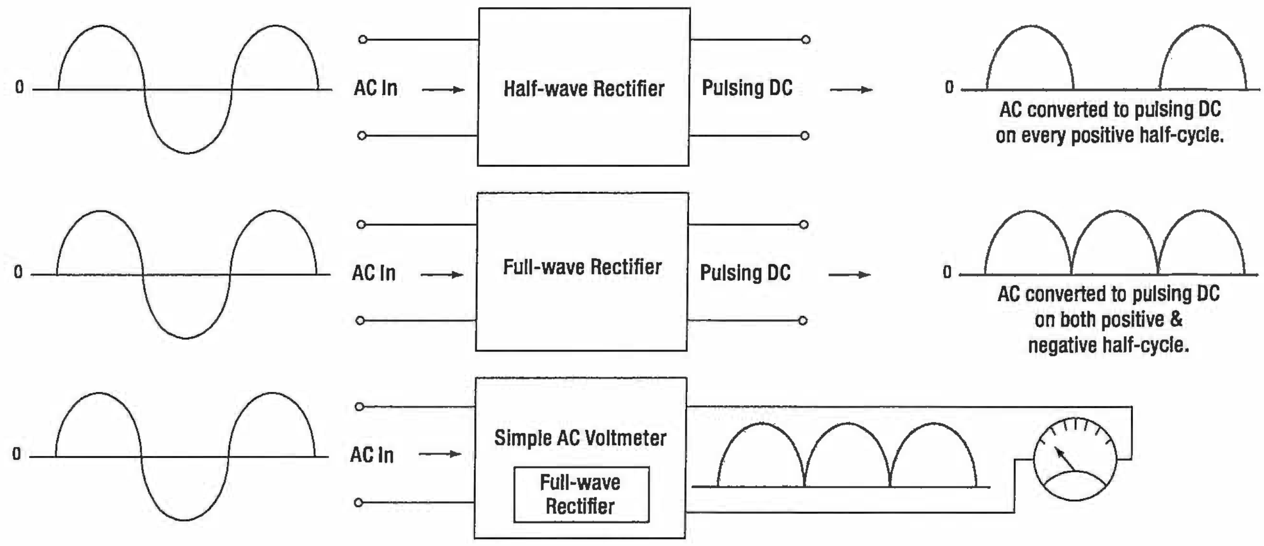


Figure 3-107. Simplified block diagram of AC meter.

MOVING IRON VANE METER

The moving iron vane meter is another basic type of meter. It can be used to measure either AC or DC. Unlike the d'Arsonval meter, which employs permanent magnets, it depends on induced magnetism for its operation. It utilizes the principle of repulsion between two concentric iron vanes, one fixed and one movable, placed inside a solenoid. A pointer is attached to the movable vane. (***Figure 3-109***)

When current flows through the coil, the two iron vanes become magnetized with north poles at their upper ends and south poles at their lower ends for one direction of current through the coil.

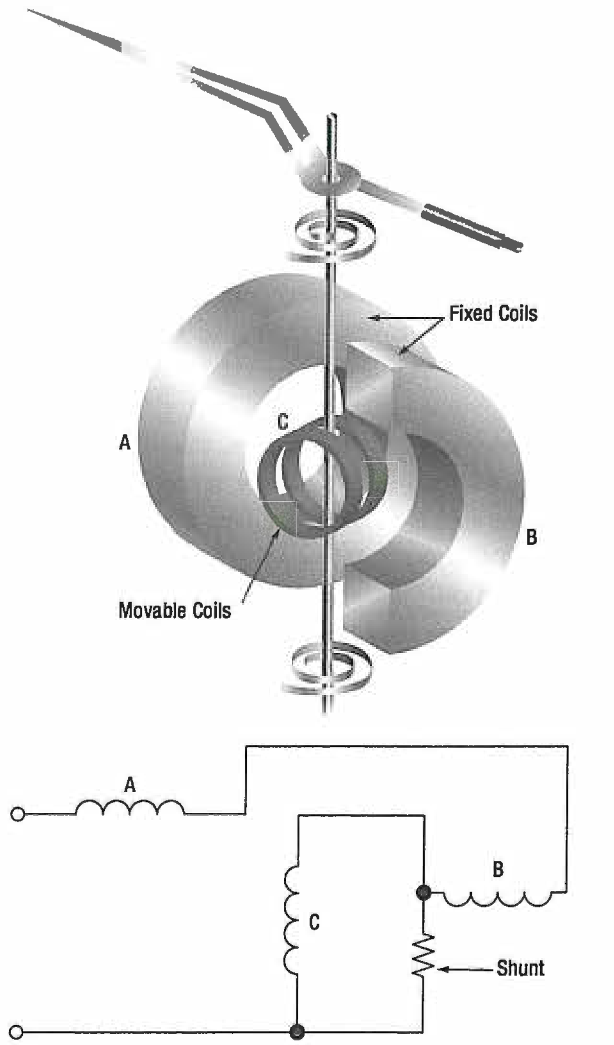


Figure 3-108. Simplified diagram of an electrodynamometer movement.

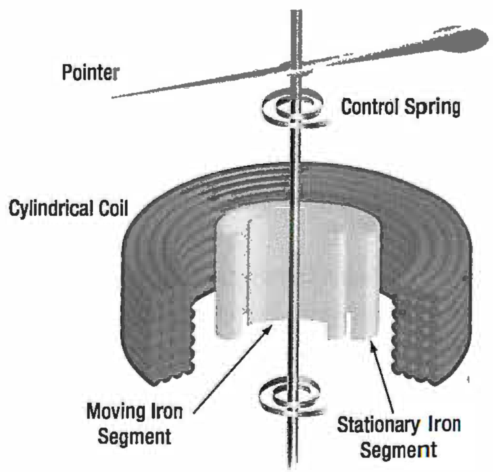


Figure 3-109. Moving iron vane meter.

Because like poles repel, the unbalanced component of force, tangent to the movable element, causes it to turn against the force exerted by the springs. The movable vane is rectangular in shape and the fixed vane is tapered. This design permits the use of a relatively uniform scale.

When no current flows through the coil, the movable vane is positioned so that it is opposite the larger portion of the tapered fixed vane, and the scale reading is zero. The amount of magnetization of the vanes depends on the strength of the field, which, in turn, depends on the amount of current flowing through the coil.

The force of repulsion is greater opposite the larger end of the fixed vane than it is nearer the smaller end. Therefore, the movable vane moves toward the smaller end through an angle that is proportional to the magnitude of the coil current. The movement ceases when the force of repulsion is balanced by the restraining force of the spring.

Because the repulsion is always in the same direction (toward the smaller end of the fixed vane), regardless of the direction of current flow through the coil, the moving iron vane instrument operates on either DC or AC circuits.

Mechanical damping in this type of instrument can be obtained by the use of an aluminum vane attached to the shaft so that, as the shaft moves, the vane moves in a restricted air space.

When the moving iron vane meter is used as an ammeter, the coil is wound with relatively few turns of large wire in order to carry the rated current.

When the moving iron vane meter is used as a voltmeter, the solenoid is wound with many turns of small wire. Portable voltmeters are made with self-contained series resistance for ranges up to 750 volts. Higher ranges are obtained by the use of additional external multipliers.

The moving iron vane instrument may be used to measure direct current but has an error due to residual magnetism in the vanes. Reversing the meter connections and averaging the readings may minimize the error. When used on AC circuits, the instrument has an accuracy of 0.5 percent. Because of its simplicity, relatively low cost, and the fact that no current is conducted to the moving element, this type of movement is used extensively to measure current and voltage in AC power circuits. However, because the reluctance of the magnetic circuit is high, the moving iron vane meter requires much more power to produce full-scale deflection than is required by a d'Arsonval meter of the same range. Therefore, the moving iron vane meter is seldom used in high resistance low power circuits.

INCLINED COIL IRON VANE METER

The principle of the moving iron vane mechanism is applied to the inclined coil type of meter, which can be used to measure both AC and DC. The inclined coil, iron vane meter has a coil mounted at an angle to the shaft. Attached obliquely to the shaft, and located inside the coil, are two soft iron vanes. When no current flows through the coil, a control spring holds the pointer at zero, and the iron vanes lie in planes parallel to the plane of the coil. When current flows through the coil, the vanes tend to line up with magnetic lines passing through the center of the coil at right angles to the plane of the coil. Thus, the vanes rotate against the spring action to move the pointer over the scale.

The iron vanes tend to line up with the magnetic lines regardless of the direction of current flow through the coil. Therefore, the inclined coil, iron vane meter can be used to measure either alternating current or direct current. The aluminum disk and the drag magnets provide electromagnetic damping.

Like the moving iron vane meter, the inclined coil type requires a relatively large amount of current for full-scale deflection and is seldom used in high resistance low power circuits. As in the moving iron vane instruments, the inclined coil instrument is wound with few turns of relatively large wire when used as an ammeter and with many turns of small wire when used as a voltmeter.

VARMETERS

Multiplying the volts by the amperes in an AC circuit gives the apparent power: the combination of the true power (which does the work) and the reactive power (which does no work and is returned to the line). Reactive power is measured in units of vars (volt-amperes reactive) or kilovars (kilovolt-amperes reactive, abbreviated kVAR). When properly connected, wattmeters measure the reactive power. As such, they are called varmeters. ***Figure 3-110*** shows a varmeter connected in an AC circuit.

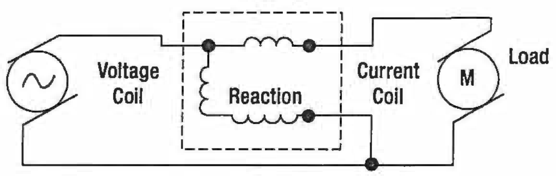


Figure 3-110. A varmeter connected in an AC circuit.

WATTMETER

Electric power is measured by means of a wattmeter. Because electric power is the product of current and voltage, a wattmeter must have two elements, one for current and the other for voltage. For this reason, wattmeters are usually of the electrodynamometer type. (***Figure 3-111***)

The movable coil with a series resistance forms the voltage element, and the stationary coils constitute the current element. The strength of the field around the potential coil depends on the amount of current that flows through it. The current, in turn, depends on the load voltage applied across the coil and the high resistance in series with it. The strength of the field around the current coils depends on the amount of current flowing through the load. Thus, the meter deflection is proportional to the product of the voltage across the potential coil and the current through the current coils.

The effect is almost the same (if the scale is properly calibrated) as if the voltage applied across the load and the current through the load were multiplied together.

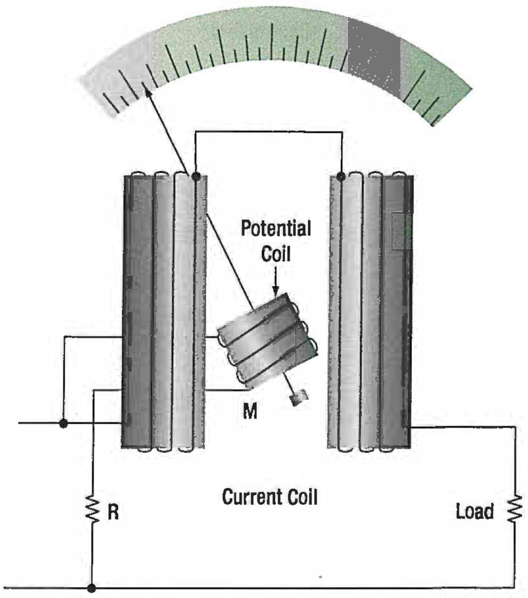


Figure 3-111. Simplified electrodynamometer wattmeter circuit.

If the current in the line is reversed, the direction of current in both coils and the potential coil is reversed, the net result is that the pointer continues to read up scale. Therefore, this type of wattmeter can be used to measure either AC or DC power.

FREQUENCY MEASUREMENT/OSCILLOSCOPE

The oscilloscope is by far one of the more useful electronic measurements available. The viewing capabilities of the oscilloscope make it possible to see and quantify various waveform characteristics such as phase relationships, amplitudes, and durations. While oscilloscopes come in a variety of configurations and presentations, the basic operation is typically the same. Most oscilloscopes in general bench or shop applications use a cathode-ray tube (CRT), which is the device or screen that displays the waveforms.

The CRT is a vacuum instrument that contains an electron gun, which emits a very narrow and focused beam of electrons. A phosphorescent coat applied to the back of the screen forms the screen. The beam is electronically aimed and accelerated so that the electron beam strikes the screen. When the electron beam strikes the screen, light is emitted at the point of impact.

Figure 3-112 shows the basic components of the CRT with a block diagram. The heated cathode emits electrons. The magnitude of voltage on the control grid determines the actual flow of electrons and thus controls the intensity of the electron beam. The acceleration anodes increase the speed of the electrons, and the focusing anode narrows the beam down to a fine point. The surface of the screen is also an anode and will assist in the acceleration of the electron beam.

The purpose of the vertical and horizontal deflection plates is to bend the electron beam and position it to a specific point of the screen.

Figure 3-113 illustrates how the deflection plates are used to position the beam on the screen. By providing a neutral or zero voltage to a deflection plate, the electron beam will be unaffected. By applying a negative voltage to a plate, the electron beam with be repelled and driven

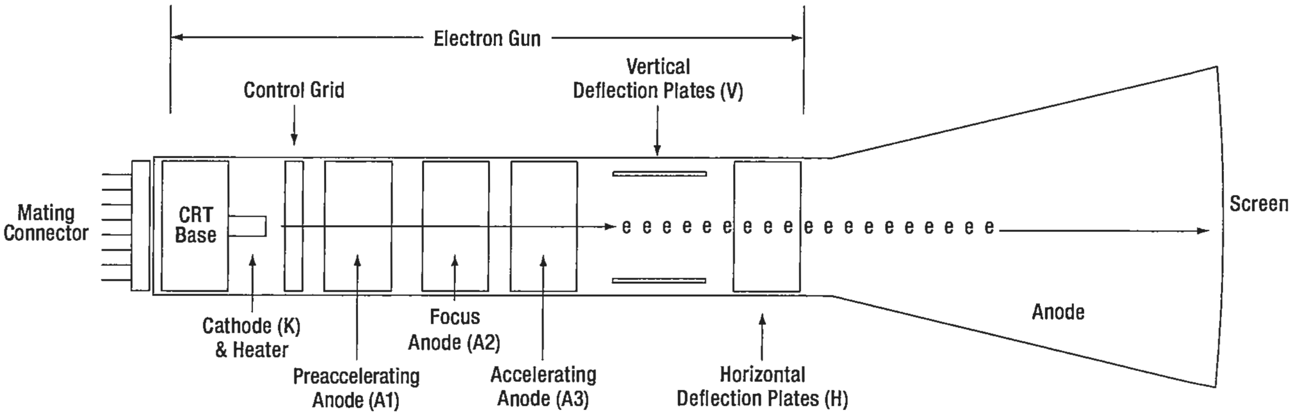


Figure 3-112. Basic components of the CRT with a block diagram.

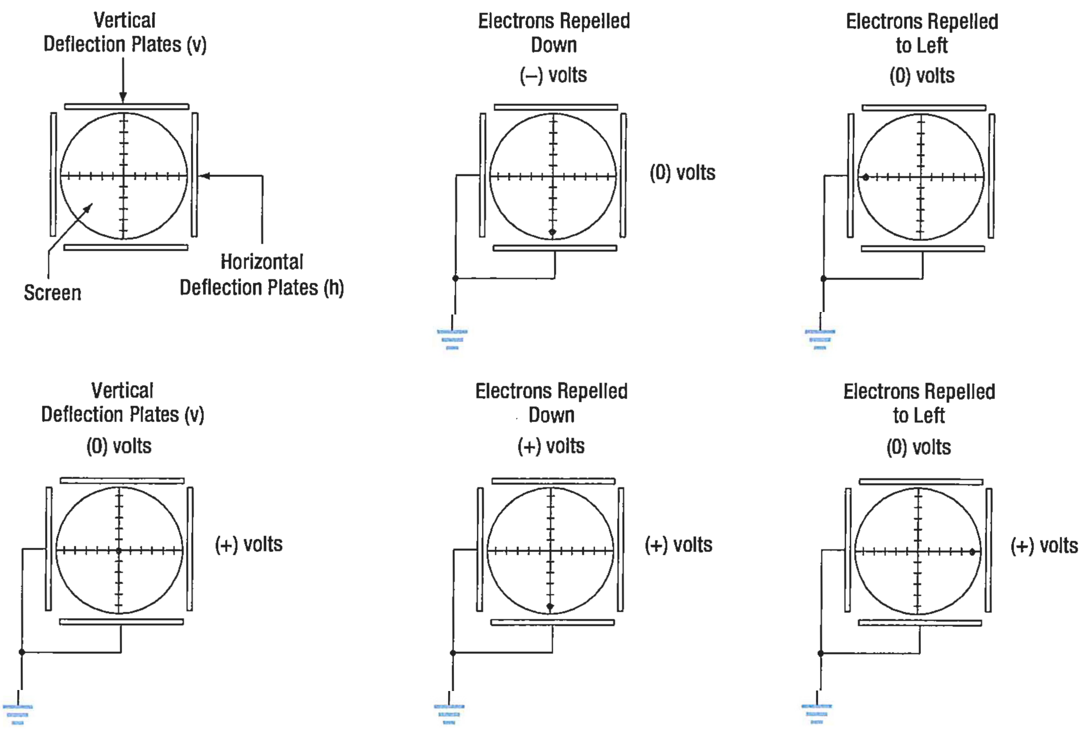


Figure 3-113. Possible plate voltage combinations and the resultant beam position.

away from the plate. Finally, by applying a positive voltage, the electron beam will be drawing to the plate. ***Figure 3-113*** provides a few possible plate voltage combinations and the resultant beam position.

HORIZONTAL DEFLECTION

To get a visual representation of the input signal, an internally generated saw-tooth voltage is generated and then applied to the horizontal deflection plates. ***Figure 3-114*** illustrates that the saw-tooth is a pattern of voltage applied, which begins at a negative voltage and increases at a constant rate to a positive voltage. This applied varying voltage will draw or trace the electron beam from the far left of the screen to the far right side of the screen.

The resulting display is a straight line, if the sweep rate is fast enough. This saw-tooth applied voltage is a repetitive signal so that the beam is repeatedly swept across the tube. The rate at which the saw-tooth voltage goes from negative to positive is determined by the frequency. This rate then establishes the sweep rate of the beam.

When the saw-tooth reaches the end of its sweep from left to right, the beam then rapidly returns to the left side and is ready to make another sweep. During this time, the electron beam is stopped or blanked out and does not produce any kind of a trace. This period of time is called flyback.

VERTICAL DEFLECTION

If this same signal were applied to the vertical plates, it would also produce a vertical line by causing the beam to trace from the down position to the up position.

TRACING A SINE WAVE

Reproducing the sine wave on the oscilloscope combines both the vertical and horizontal deflection patterns. (***Figure 3-115***) If the sine wave voltage signal is applied across the vertical deflection plates, the result will be the vertical beam oscillation up and down on the screen. The amount that the beam moves above the centerline will depend on the peak value of the voltage. While the beam is being swept from the left to the right by the horizontal plates, the sine wave voltage is being applied to the vertical plates, causing the form of the input signal to be traced out on the screen.

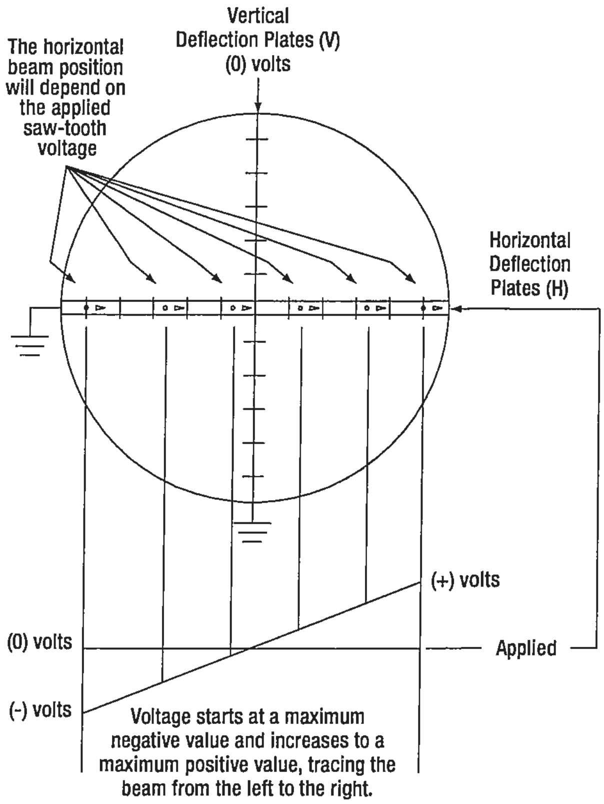


Figure 3-114. Saw-tooth applied voltage.

CONTROL FEATURES ON AN OSCILLOSCOPE

While there are many different styles of oscilloscopes, which range from the simple to the complex, they all have some controls in common. Apart from the screen and the ON/OFF switch, some of these controls are listed below.

- Horizontal Position: allows for the adjustment of the neutral horizontal position of the beam. Use this control to reposition the waveform display in order to have a better view of the wave or to take measurements.
- Vertical Position: moves the traced image up or down allowing better observations and measurements.
- Focus: controls the electron beam as it is aimed and converges on the screen. When the beam is in sharp focus, it is narrowed down to a very fine point and does not have a fuzzy appearance.
- Intensity: essentially the brightness of the trace. Controlling the flow of electrons onto the screen varies the intensity. Do not keep the intensity too high for extended testing or when the beam is motionless and forms a dot on the screen. This can damage the screen.

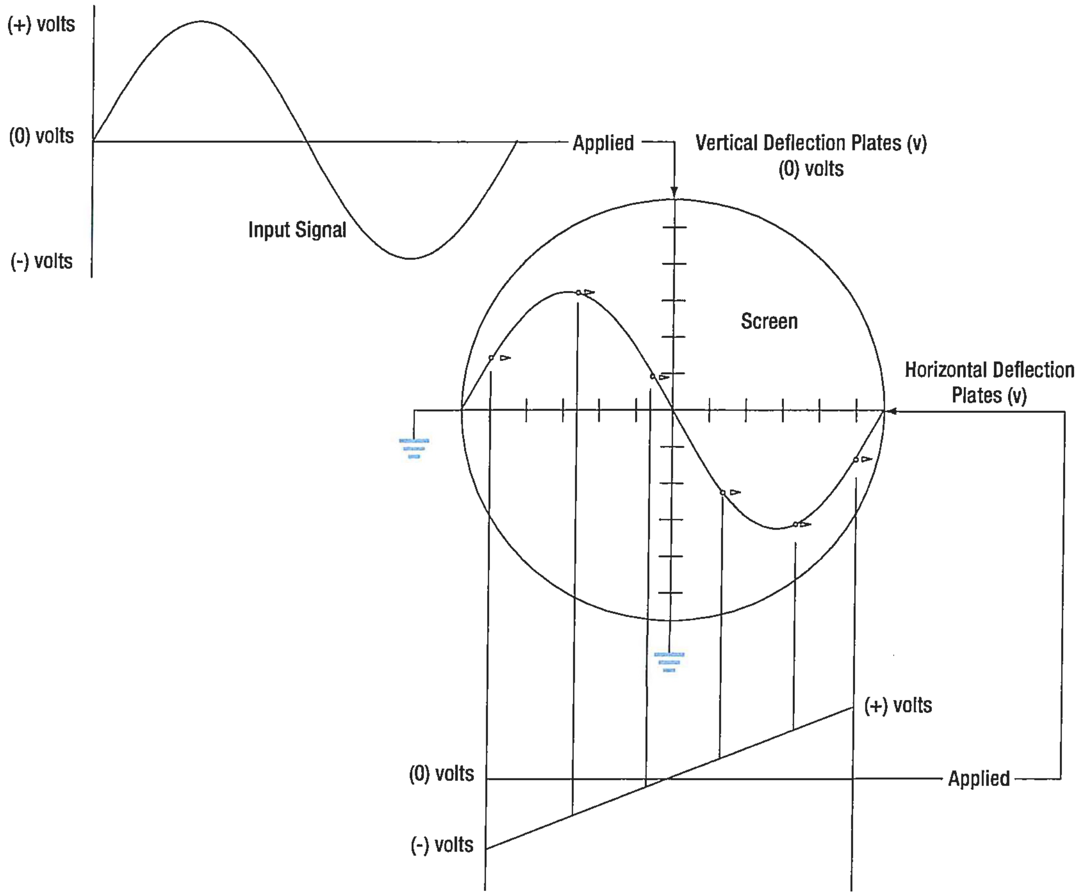


Figure 3-115. Sine wave voltage signal.

- Seconds/Division: a time-based control, which sets the horizontal sweep rate. Basically, the switch is used to select the time interval that each division on the horizontal scale will represent. These divisions can be seconds, milliseconds or even microseconds. A simple example would be if the technician had the seconds/division control set to 10 μS. If this technician is viewing a waveform that has a period of 4 divisions on the screen, then the period would be 40 μS. The frequency of this waveform can then be determined by taking the inverse of the period. In this case, 1/40 μS will equal a frequency of 25 kHz.
- Volts/Division: used to select the voltage interval that each division on the vertical scale will represent. For example, suppose each vertical division was set to equal 10 mV.
  If a waveform was measured and had a peak value of 4 divisions, then the peak value in voltage would be 40 mV.
- Trigger: The trigger control provides synchronization between the saw-tooth horizontal sweep and the applied signal on the vertical plates. The benefit is that the waveform on the screen appears to be stationary and fixed and not drifting across the screen. A triggering circuit is used to initiate the start of a sweep rather than the fixed saw-tooth sweep rate. In a typical oscilloscope, this triggering signal comes from the input signal itself at a selected point during the signal's cycle. The horizontal signal goes through one sweep, retraces back to the left side and waits there until it is triggered again by the input signal to start another sweep.

FLAT PANEL COLOR DISPLAYS FOR OSCILLOSCOPES

While the standard CRT design of oscilloscopes is still in service, the technology of display and control has evolved into use of the flat panel monitors. Furthermore, the newer oscilloscopes can even be integrated with the common personal computer (PC). This level of integration offers many diagnostic options unheard of only a few years ago. Some of the features of this technology include easy data capture, data transfer, documentation, and data analysis.

DIGITAL MULTIMETER

Traditionally, the meters that technicians have used have been the analog voltmeter, ammeter, and the ohmmeter. These have usually been combined into the same instrument and called a multimeter or a VOM (volt-ohm-milliammeter). This approach has been both convenient and economical.

Digital multimeters (DMM) and digital voltmeters (DVM) have now become more common due to their ease of use. These meters are easier to read and provide greater accuracy when compared to the older analog units with needle movement. The multimeter's single-coil movement requires a number of scales, which are not always easy to read accurately. In addition, the loading characteristics due to the internal resistance sometimes affect the circuit and the measurements. Not only does the DVM offer greater accuracy and less ambiguity, but also higher input resistance, which has less of a loading effect and influence on a circuit.

BASIC CIRCUIT ANALYSIS AND TROUBLESHOOTING

Troubleshooting is the systematic process of recognizing the symptoms of a problem, identifying the possible cause, and locating the failed component or conductor in the circuit. To be proficient at troubleshooting, the technician must understand how the circuit operates and know how to properly use the test equipment.

There are many ways in which a system can fail and to cover all of the possibilities is beyond the scope of this text. However, there are some basic concepts that will enable the technician to handle many of the common faults encountered in the aircraft.

Before starting a discussion on basic circuits and troubleshooting, the following definitions are given.

- Short circuit—an unintentional low resistance path between two components in a circuit or between a component/conductor and ground. It usually creates high current flow, which will burn out or cause damage to the circuit conductor or components.
- Open circuit—a circuit that is not a complete or continuous path. An open circuit represents an infinitely large resistance. Switches are common devices used to open and close a circuit. Sometimes a circuit will open due to a component failure, such as a light bulb or a burned out resistor.
- Continuity—the state of being continuous, uninterrupted or connected together; the opposite of a circuit that is not broken or does not have an open.
- Discontinuity—the opposite of continuity, indicating that a circuit is broken or not continuous.

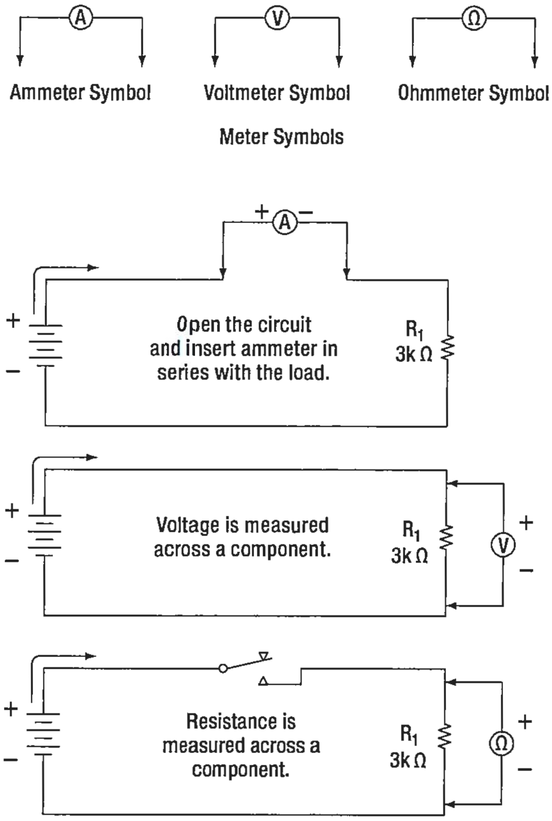
VOLTAGE MEASUREMENT

Voltage is measured across a component with a voltmeter or the voltmeter position on a multimeter. Usually, there is a DC and an AC selection on the meter. Before the meter is used for measurements, make sure that the meter is selected for the correct type of voltage. When placing the probes across a component to take a measurement, take care to ensure that the polarity is correct. (***Figure 3-120***) Standard practice is for the red meter lead to be installed in the positive (+) jack and the black meter lead to be installed in the negative meter jack (–). Then when placing the probes across or in parallel with a component to measure the voltage, the leads should match the polarity of the component. The red lead shall be on the positive side of the component and the black on the negative side, which will prevent damage to the meter or incorrect readings.

All meters have some resistance and will shunt some of the current. This has the effect of changing the characteristic of the circuit because of this change in current. This is typically more of a concern with older analog type meters. If there are any questions about the magnitude of the voltage across a component, then the meter should be set to measure on the highest voltage range. This will prevent the meter from "pegging" and possible damage. The range should then be selected to low values until the measured voltage is read at the mid-scale deflection. Readings taken at mid-scale are the most accurate.

CURRENT MEASUREMENT

Current is measured with the ammeter connected in the current path by opening or breaking the circuit and inserting the meter in series as shown in ***Figure 3-116***. Standard practice is for the red meter lead to be installed in the positive (+) jack and the black meter lead to be installed in the negative meter jack (–). The positive side of the meter is connected towards the positive voltage source. Ideally, the meter should not alter the current nor influence the circuit and the measurements. However, the meter does have some effect because of its



Simplified Use of Meters.

Figure 3-116. Current measurement.

internal resistance that is connected with the rest of the circuit in series. The resistance is rather small and for most practical purposes, this can be neglected.

CHECKING RESISTANCE IN A CIRCUIT

The ohmmeter is used to measure the resistance in a circuit. In its more basic form, the ohmmeter consists of a variable resistor in series with a meter movement and a voltage source. The meter must first be adjusted before use. Refer to ***Figure 3-117*** for meter configurations during adjustments.

When the meter leads are not connected (open), the needle will point to the full left-hand position, indicating infinite resistance or and open circuit. With the lead placed together, the circuit is shorted as shown with the meter needle to the full right-hand position.

When a connection is made, the internal battery is allowed to produce a current through the movement coil, causing a deflection of the needle in proportion to the value of the external resistance. In this case, the resistance is zero because the leads are shorted.

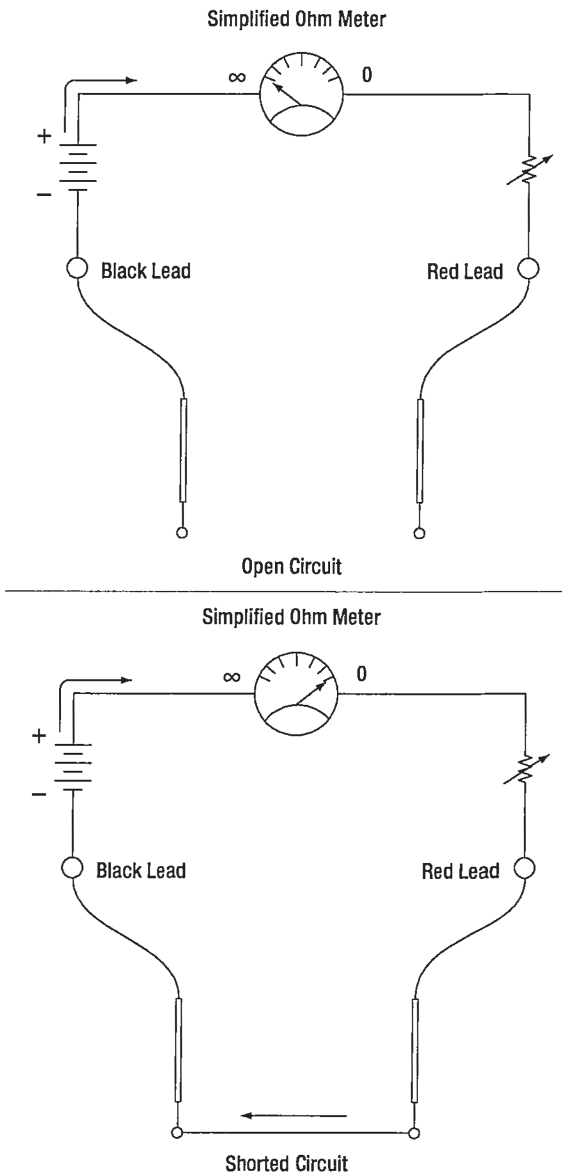


Figure 3-117. Meter configurations during adjustments.

The purpose of the variable resistor in the meter is to adjust the current so that the pointer will read exactly zero when the leads are shorted. This is needed because as the battery continues to be used, the voltage will change, thus requiring an adjustment. The meter should be "zeroed" before each use. To check the value of a resistor, the resistor must be disconnected from the circuit. This will prevent any possible damage to the ohmmeter, and it will prevent the possibility of any inaccurate readings due to the circuit being in parallel with the resistor in question. (***Figure 3-118***)

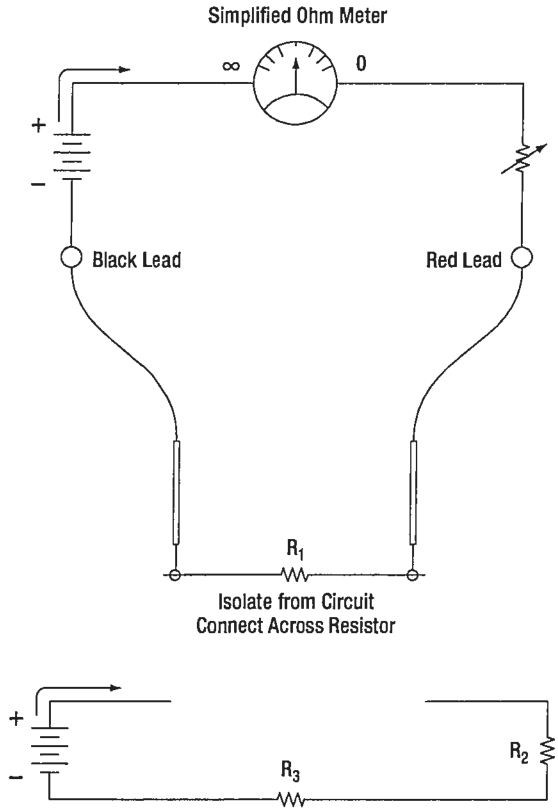


Figure 3-118. Meter adjustment.

CONTINUITY CHECKS

In many cases, the ohmmeter is not used for measuring the resistance of a component but to simply check the integrity of a connection from one portion of a circuit to another.

If there is a good connection, then the ohmmeter will read a near zero resistance or a short. If the circuit is open or has a very poor connection at some point like an over-crimped pin in a connector, then the ohmmeter will read infinity or some very high resistance. Keep in mind that while any measurement is being taken, contact with the circuit or probes should be avoided. Contact can introduce another parallel path and provide misleading indications.

CAPACITANCE MEASUREMENT

Figure 3-119 illustrates a basic test of a capacitor with an ohmmeter. There are usually two common modes of fail for a capacitor. One is a complete failure characterized by short circuit through the capacitor due to the dielectric breaking down or an open circuit. The more insidious failure occurs due to degradation, which is a gradual deterioration of the capacitor's characteristics.

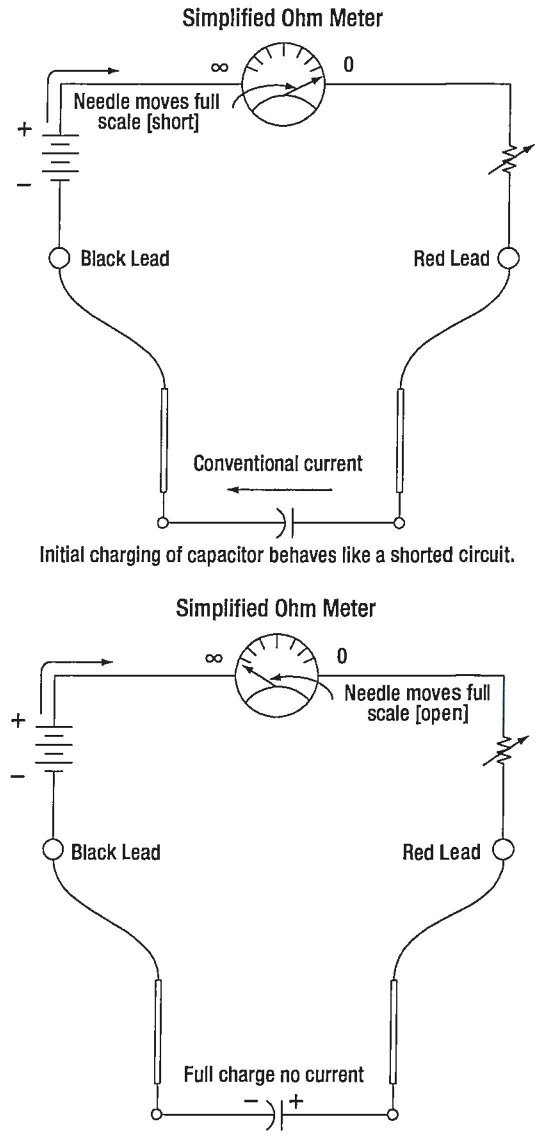


Figure 3-119. Meter adjustment.

If a problem is suspected, remove the capacitor from the circuit and check with an ohmmeter. The first step is to short the two leads of the capacitor to ensure that it is entirely discharged. Next, connect the two leads as shown in ***Figure 3-120*** across the capacitor and observe the needle movement. At first, the needle should indicate a short circuit. Then as the capacitor begins to charge, the needle should move to the left or infinity and eventually indicate an open circuit. The capacitor takes its charge from the internal battery of the ohmmeter. The greater the capacitance, the longer it will take to charge. If the capacitor is shorted, then the needle will remain at a very low or shorted resistance. If there is some internal deterioration of the dielectric, then the needle will never reach a high resistance but some intermediate value, indicating a current.

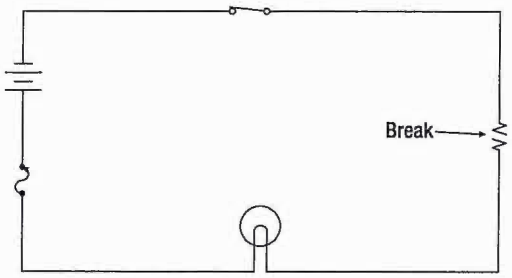


Figure 3-120. An open circuit.

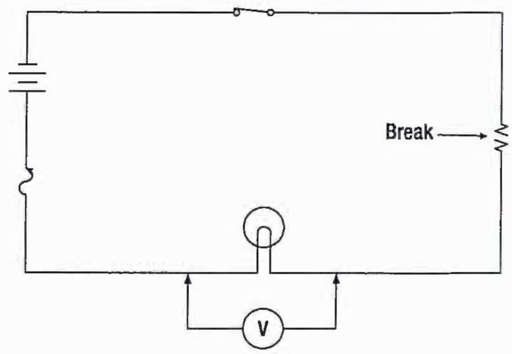


Figure 3-121. Voltmeter across a lamp in an open circuit.

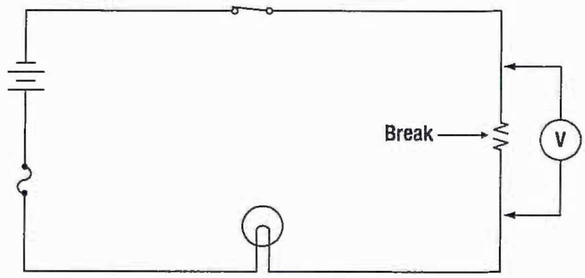


Figure 3-122. Voltmeter across a resistor in an open circuit.

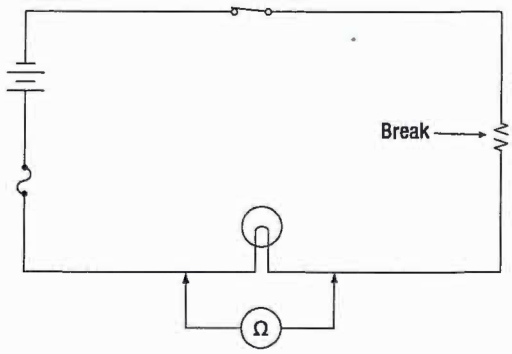


Figure 3-123. Using an ohmmeter to check a circuit component.

INDUCTANCE MEASUREMENT

The common mode of failure in an inductor is an open. To check the integrity of an inductor, it must be removed from the circuit and tested as an isolated component just like the capacitor. If there is an open in the inductor, a simple check with an ohmmeter will show it as an open circuit with infinite resistance. If in fact the inductor is in good condition, then the ohmmeter will indicate the resistance of the coil.

On occasions, the inductor will fail due to overheating. When the inductor is overheated, it is possible for the insulation covering the wire in the coil to melt, causing a short. The effects of a shorted coil are that of reducing the number of turns. At this point, further testing of the inductor must be done with test equipment not covered in this text.

TROUBLESHOOTING THE OPEN FAULTS IN SERIES CIRCUITS

One of the most common modes of failure is the "open" circuit. A component, such as a resistor, can overheat due to the power rating being exceeded. Other more frustrating problems can happen when a "cold" solder joint cracks leaving a wire disconnected from a relay or connector. This type of damage can occur during routine maintenance after a technician has accessed an area for inspections. In many cases, there is no visual indication that a failure has occurred, and the soon-to-be-frustrated technician is unaware that there is a problem until power is reapplied to the aircraft in the final days leading up to aircraft delivery and scheduled operations.

The first example is a simplified diagram shown in ***Figures 3-121 through 3-123***.

The circuit depicted in ***Figure 3-121*** is designed to cause current to flow through a lamp, but because of the open resistor, the lamp will not light. To locate this open, a voltmeter or an ohmmeter should be used.

TRACING OPENS WITH THE VOLTMETER

A general procedure to follow in this case is to measure the voltage drop across each component in the circuit, keeping in mind the following points. If there is an open in a series circuit, then the voltage drops on sides of the component. In this case, the total voltage must appear across the open resistor as per Kirchhoff's voltage law.

If a voltmeter is connected across the lamp, as shown in ***Figure 3-124***, the voltmeter will read zero. Since no current can flow in the circuit because of the open resistor, there is no voltage drop across the lamp indicating that the lamp is good.

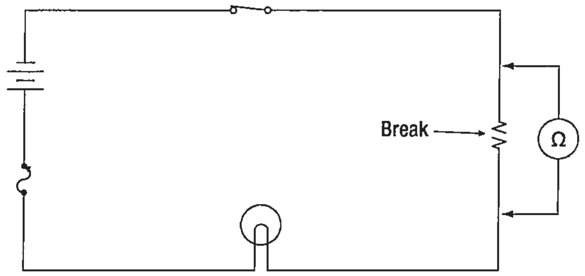


Figure 3-124. Locating an open in a circuit component.

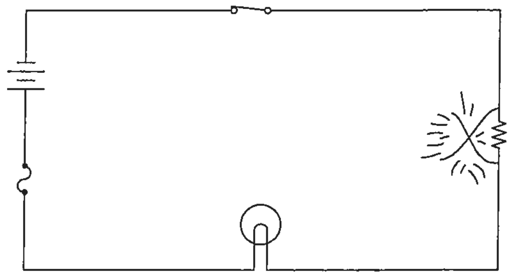


Figure 3-125. A shorted resistor.

Next, the voltmeter is connected across the open resistor, as shown in ***Figure 3-125***. The voltmeter has closed the circuit by shunting (paralleling) the burned out resistor, allowing current to flow. Current will flow from the negative terminal of the battery, through the switch, through the voltmeter and the lamp, back to the positive terminal of the battery. However, the resistance of the voltmeter is so high that only a very small current flows in the circuit. The current is too small to light the lamp, but the voltmeter will read the battery voltage.

TRACING OPENS WITH THE OHMMETER

When an ohmmeter is used, the circuit component to be tested must be isolated and the power source removed from the circuit. In this case, as shown in ***Figure 3-126***, these requirements can be met by opening the circuit switch. The ohmmeter is zeroed and across all good components will be zero. The voltage drop across the open component will equal the total voltage across the series combination.

A simplified circuit as shown in ***Figures 3-127 and 3-128*** illustrates how to locate an open in a series circuit using the ohmmeter. A general rule when troubleshooting with an ohmmeter is: when an ohmmeter is properly connected across a circuit component and a resistance reading is obtained, the component has continuity and is not open. This condition happens because the open component will prevent current to pass through the series circuit. With there being no current, there can be no voltage drop across any of the good components.

Because the current is zero, it can be determined by Ohm's law that E = IR = 0 volts across a component. The voltage is the same on both places across (in parallel with) the lamp. In this testing configuration, some value of resistance is read indicating that the lamp is in good condition and is not the source of the open in the circuit.

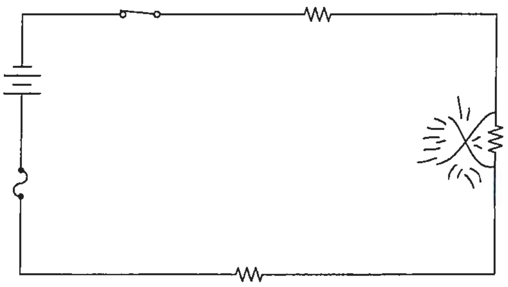


Figure 3-126. A short that does not open the circuit.

Now the technician should move to the resistor and place the ohmmeter probe across it as shown in ***Figure 3-127***. When the ohmmeter is connected across the open resistor, it indicates infinite resistance, or a discontinuity. Thus, the circuit open has now been located.

TROUBLESHOOTING THE SHORTING FAULTS IN SERIES CIRCUITS

An open fault can cause a component or system not to work, which can be critical and hazardous. A shorting fault can potentially be more of a severe nature than the open type of fault. A short circuit, or "short," will cause the opposite effect. A short across a series circuit produces a greater than normal current flow. Faults of this type can develop slowly when a wire bundle is not properly secured and is allowed to chafe against the

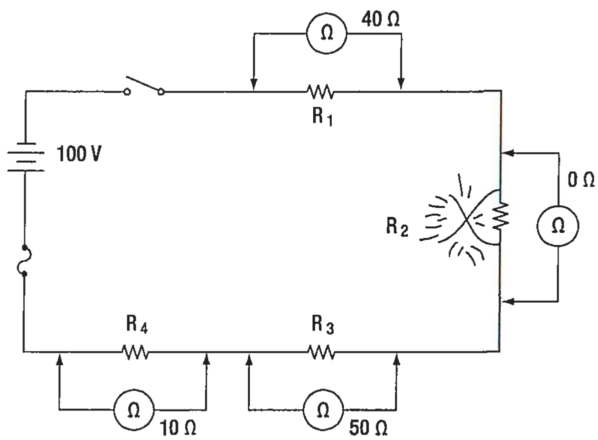


Figure 3-127. Using an ohmmeter to locate a shorted resistor.

TOOLS

airframe structure or other systems such as hydraulic lines. Shorts can also occur due to a careless technician using incorrect hardware when installing an interior. If screws that are too long are used to install trim, it is possible to penetrate a wire bundle immediately causing numerous shorts. Worse yet, are the shorts that are not immediately seen but "latent" and do not show symptoms until the aircraft is in service. Another point to keep in mind is when closing panels. Wires can become pinched between the panel and the airframe causing either a short or a latent, intermittent short.

The simplified circuit, shown in ***Figures 3-128 through 3-130, and Figure 3-131*** will be used to illustrate troubleshooting a short in a series circuit.

In ***Figure 3-128***, a circuit is designed to light a lamp. A resistor is connected in the circuit to limit current flow. If the resistor is shorted, as shown in the illustration, the current flow will increase and the lamp will become brighter. If the applied voltage were high enough, the lamp would burn out, but in this case the fuse would protect the lamp by opening first.

Usually a short circuit will produce an open circuit by either blowing (opening) the fuse or burning out a circuit component. But in some circuits, such as that illustrated in ***Figure 3-130***, there may be additional resistors that will not allow one shorted resistor to increase the current flow enough to blow the fuse or burn out a component. Thus, with one resistor shorted out, the circuit will still function since the power dissipated by the other resistors does not exceed the rating of the fuse.

TRACING SHORTS WITH THE OHMMETER

The shorted resistor shown in ***Figure 3-130*** can be located with an ohmmeter. First the switch is opened to isolate the circuit components. In ***Figure 3-130***, this circuit is shown with an ohmmeter connected across each of the resistors. Only the ohmmeter connected across the shorted resistor shows a zero reading, indicating that this resistor is shorted.

TRACING SHORTS WITH THE VOLTMETER

To locate the shorted resistor while the circuit is functioning, a voltmeter can be used. ***Figure 3-131*** illustrates that when a voltmeter is connected across any of the resistors, which are not shorted, a portion of the applied voltage will be indicated on the voltmeter scale. When it is connected across the shorted resistor, the voltmeter will read zero.

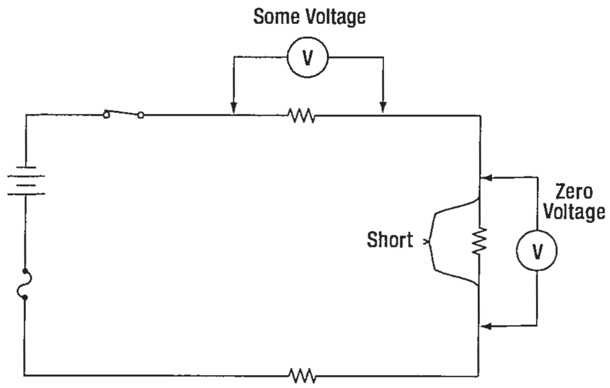


Figure 3-128. Voltmeter connected across resistors.

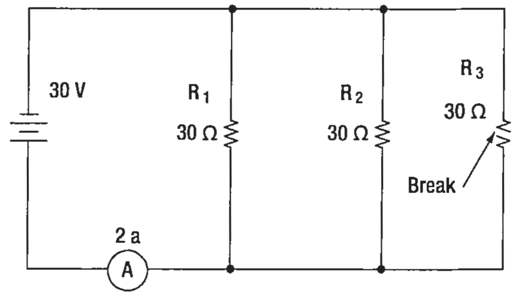


Figure 3-129. Finding an open branch in a parallel circuit.

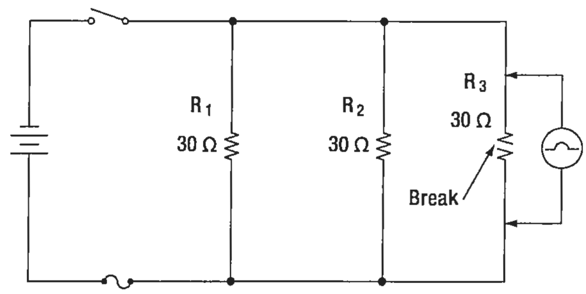


Figure 3-130. A misleading ohm meter indication.

TROUBLESHOOTING THE OPEN FAULTS IN PARALLEL CIRCUITS

The procedures used in troubleshooting a parallel circuit are sometimes different from those used in a series circuit. Unlike a series circuit, a parallel circuit has more than one path in which current flows.

A voltmeter cannot be used, since, when it is placed across an open resistor, it will read the voltage drop in a parallel branch. But an ammeter or the modified use of an ohmmeter can be employed to detect an open branch in a parallel circuit.

If the open resistor shown in ***Figure 3-132*** was not visually apparent, the circuit might appear to be functioning properly, because current would continue to flow in the other two branches of the circuit. To determine that the circuit is not operating properly, a determination must be made as to how the circuit should behave when working properly. First, the total resistance, total current, and the branch currents of the circuit should be calculated as if there were no open in the circuit. In this case, the total resistance can be simply determined by:

$$R_T = \frac{R}{N}$$

Where R_T is the total circuit resistance
N is the number of resistors
R is the resistor value

$$R_T = \frac{30\ \Omega}{3} = 10\ \Omega$$

The total current of the circuit can now be determined by using Ohm's law:

$$I_T = \frac{E_S}{R_T}$$

Where I_T is the total current
ES is the source voltage across the parallel branch
RT is the total resistance of the parallel branch

$$I_T = \frac{30\ v}{10\ \Omega} = 3 \text{ amperes (total current)}$$

Each branch current should be determined in a similar manner. For the first branch, the current is:

$$I_1 = \frac{E_1}{R_1}$$

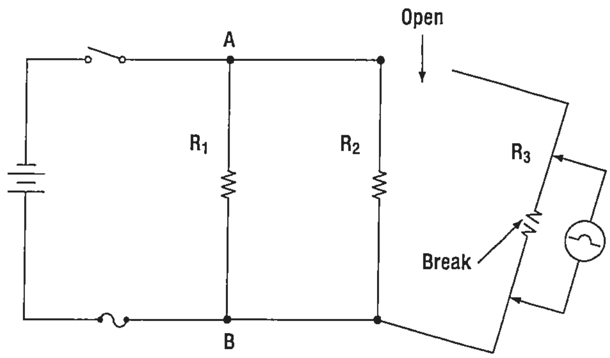


Figure 3-131. Opening a branch circuit to obtain an accurate ohmmeter reading.

Where I_1 is the current in the first branch
E_1 is the source voltage across the parallel branch
R_1 is the resistance of the first branch

$$I_1 = \frac{30\ v}{30\ \Omega} = 1 \text{ amperes}$$

Because the other two branches are of the same resistive value, then the current in each of those branches will be 1 ampere also. Adding up the amperes in each branch confirms the initial calculation of total current being 3 amperes.

TRACING AN OPEN WITH AN AMMETER

If the technician now places an ammeter in the circuit, the total current would be indicated as 2 amperes as shown in ***Figure 3-132*** instead of the calculated 3 amperes. Since 1 ampere of current should be flowing through each branch, it is obvious that one branch is open. If the ammeter is then connected into the branches, one after another, the open branch will eventually be located by a zero ammeter reading.

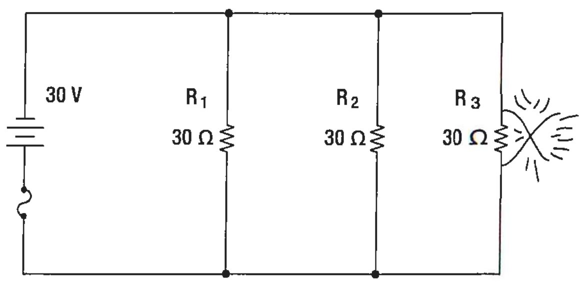


Figure 3-132. Shorted component causes the fuse to open.

TOOLS

TRACING AN OPEN WITH AN OHMMETER

A modified use of the ohmmeter can also locate this type of open. If the ohmmeter is connected across the open resistor, as shown in ***Figure 3-133***, an erroneous reading of continuity would be obtained. Even though the circuit switch is open, the open resistor is still in parallel with R_1 and R_2, and the ohmmeter would indicate the open resistor had a resistance of 15 ohms, the equivalent resistance of the parallel combination of R_1 and R_2.

Therefore, it is necessary to open the circuit as shown in ***Figure 3-134*** in order to check the resistance of R_3. In this way, the resistor is not shunted (paralleled) by R_1 and R_2. The reading on the ohmmeter will now indicate infinite resistance, which means the open component has been isolated.

TROUBLESHOOTING THE SHORTING FAULTS IN PARALLEL CIRCUITS

As in a series circuit, a short in a parallel circuit will usually cause an open circuit by blowing the fuse. But, unlike a series circuit, one shorted component in a parallel circuit will stop current flow by causing the fuse to open. Refer to the circuit in ***Figure 3-135.*** If resistor R_3 is shorted, a path of almost zero resistance will be offered the current, and all the circuit current will flow through the branch containing the shorted resistor. Since this is practically the same as connecting a wire between the terminals of the battery, the current will rise to an excessive value, and the fuse will open. Since the fuse opens almost as soon as a resistor shorts out, there is no time to perform a current or voltage check. Thus, troubleshooting a parallel DC circuit for a shorted component should be accomplished with an ohmmeter. But, as in the case of checking for an open resistor in a parallel circuit, a shorted resistor can be detected with an ohmmeter only if one end of the shorted resistor is disconnected and isolated from the rest of the circuit.

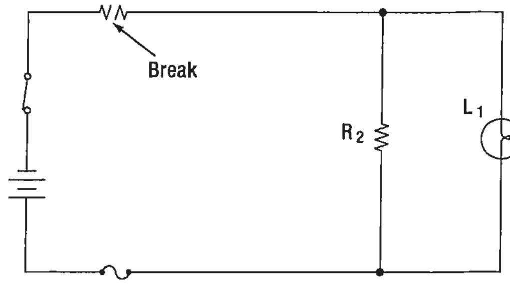


Figure 3-133. An open in the series portion of a series-parallel circuit.

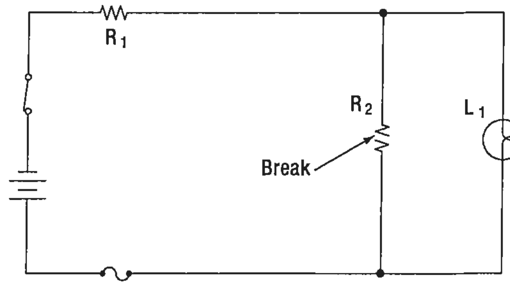


Figure 3-134. An open in the parallel portion of a series-parallel circuit.

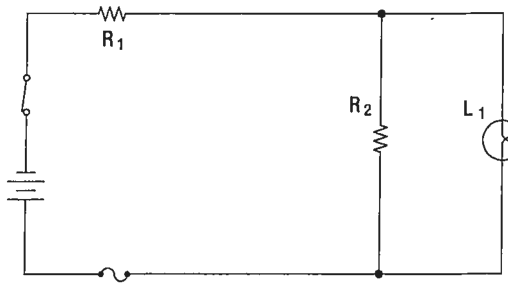


Figure 3-135. An open lamp in a series-parallel circuit.

TROUBLESHOOTING THE SHORTING FAULTS IN SERIES-PARALLEL CIRCUITS

LOGIC IN TRACING AN OPEN CIRCUIT

Troubleshooting a series-parallel resistive circuit involves locating malfunctions similar to those found in a series or a parallel circuit.

Figures 3-136 illustrate three points of failure in a series-parallel circuit and their generalized effects.

1. In the circuit shown in ***Figure 3-136***, an open has occurred in the series portion of the circuit. When the open occurs anywhere in the series portion of a series-parallel circuit, current flow in the entire circuit will stop. In this case, the circuit will not function, and the lamp, L1, will not be lit.
2. If the open occurs in the parallel portion of a series-parallel circuit, part of the circuit will continue to function. In this case, the lamp will continue to burn, but its brightness will diminish, since the total resistance of the circuit has increased and the total current has decreased.
3. If the open occurs in the branch containing the lamp, the circuit will continue to function with increased resistance and decreased current, but the lamp will not light.

TRACING OPENS WITH THE VOLTMETER

To explain how the voltmeter and ohmmeter can be used to troubleshoot series-parallel circuits, the circuit shown in ***Figure 3-136*** has been labeled at various points. A point-to-point description is listed below with expected results:

1. By connecting a voltmeter between points A and D, the battery and switch can be checked for opens.
2. By connecting the voltmeter between points A and B, the voltage drop across R1 can be checked. This voltage drop is a portion of the applied voltage.
3. If R1 is open, the reading between B and D will be zero.
4. By connecting a voltmeter between A and E, the continuity of the conductor between the positive terminal of the battery and point E, as well as the fuse, can be checked. If the conductor or fuse is open, the voltmeter will read zero.
5. If the lamp is burning, it is obvious that no open exists in the branch containing the lamp, and the voltmeter could be used to detect an open in the branch containing R2 by removing lamp, L1, from the circuit.

Troubleshooting the series portion of a series-parallel circuit presents no difficulties, but in the parallel portion of the circuit, misleading readings can be obtained.

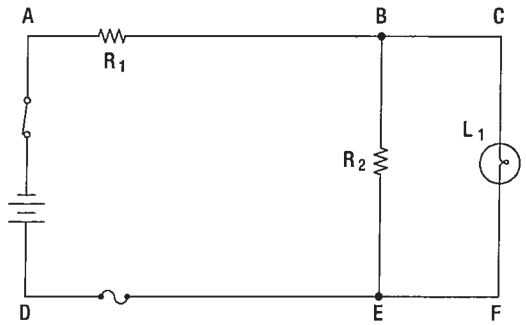


Figure 3-136. Using the voltmeter to troubleshoot a series-parallel circuit.

TOOLS

Question: 3-1
Metal head hammers are usually sized according to the ________________ of the head without the handle.

Question: 3-2
Solid punches are classified according to the ________________ of their points.

Question: 3-3
A ________________ is used when a specific force must be applied to a nut or bolt as it is installed.

Question: 3-4
Name three distinguishing features of files.

Question: 3-5
Which type of drill is preferred around flammable material?

Question: 3-6
A ________________ differs from the trisquare in that the head slides along the blade and can be clamped at any desired place.

Question: 3-7
________________ are used for measuring diameters and distances or for comparing distances and sizes.

Question: 3-8
Some micrometers are equipped with a ________________ scale.

ANSWERS

Answer: 3-1
weight.

Answer: 3-2
shape.

Answer: 3-3
calibrated torque wrench.

Answer: 3-4
cut, length, and shape.

Answer: 3-5
Pneumatic.

Answer: 3-6
combination set.

Answer: 3-7
Calipers.

Answer: 3-8
vernier.

Question: 3-9
The _________________ saw is an electrically operated, portable circular cutting saw that uses blades of various diameters.

Question: 3-10
The _________________ of the band saw and the type and style of the blade depends on the material to be cut.

Question: 3-11
_________________ acts as a lubricant for faster grinding while it continuously cools the edge of the metal.

Question: 3-12
_________________ drill bits can withstand temperatures nearing the critical range of 1 400 ÅãF (dark cherry red) without losing their hardness.

Question: 3-13
A wide variety of powered and hand operated tools are used to precisely bend and fold sheet metal to achieve the perfect _________________.

Question: 3-14
The _________________ brake is the most common machine tool used to bend sheet metal and applies force via mechanical and/or hydraulic components to shape sheet metal between the punch and die.

Question: 3-15
In ____________ forming, a flat circle of metal is rotated at a very high speed to shape a seamless, hollow part using the combined forces of rotation and pressure.

Question: 3-16
The vise consists of two fixed or adjustable _________________ that are opened or closed by a screw or a lever.

ANSWERS

Answer: 3-9
Kett.

Answer: 3-10
speed.

Answer: 3-11
Water.

Answer: 3-12
HSS (high speed steel).

Answer: 3-13
shape.

Answer: 3-14
press.

Answer: 3-15
spin.

Answer: 3-16
jaws.

Question: 3-17
An ohmmeter is basically a ________________ measuring instrument; it differs from the ammeter and voltmeter in that it is self-excited and contains other auxiliary circuits.

Question: 3-18
Voltmeter ________________ is defined in terms of resistance per volt (Ω/V).

Question: 3-19
A ________________ is used to measure insulation resistance and other high resistance values.

Question: 3-20
The inclined coil iron vane meter has a coil mounted at ________________ to the shaft.

Question: 3-21
Reproducing the sine wave on the oscilloscope combines both the ________________ and ________________ deflection patterns.

Question: 3-22
Current is measured with the ammeter connected in ________________.

Question: 3-23
The common mode of failure in an inductor is ________________.

ANSWERS

Answer: 3-17
current.

Answer: 3-18
sensitivity.

Answer: 3-19
Megger or Megohmmeter.

Answer: 3-20
an angle.

Answer: 3-21
vertical.
horizontal.

Answer: 3-22
series.

Answer: 3-23
an open.

MAINTENANCE PRACTICES

AVIONIC GENERAL TEST EQUIPMENT

SUB-MODULE 04

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 04 AVIONIC GENERAL TEXT EQUIPMENT Knowledge Requirements		
7.4 - Avionic General Text Equipment Operation, function and use of avionic general test equipment.	2	3

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

OPERATION, FUNCTION AND USE OF AVIONIC GENERAL TEST EQUIPMENT

BUILT-IN TEST EQUIPMENT

In most aviation maintenance operations, electronic troubleshooting and repair of avionics Line Replacement Units (LRU's) and avionics systems are performed by the B-2 technician specially trained in such matters. Use of Built In Test Equipment (BITE) may be the only exposure to avionics testing a B-1 engineer experiences. Built in test equipment is a common feature on all modern aircraft.

BITE can be built in to an individual LRU or it can be part of a computerized central maintenance system. If part of a system, the system likely contains several individual BITE electronic units used to handle the testing of the numerous LRU's onboard the aircraft. Signals are sent and received by the BITE to determine if there are any faults, to isolate the faults, and to verify correct operating parameters, especially after repair or replacement of an LRU.

Fault detection of electronic circuits is a continuous function. Once a fault is detected, an isolation sequence is initiated to pinpoint the problem and display it to the technician. BITE displays are selected on the central maintenance computer Control Display Units (CDU's). These are typically located on the flight deck and in the avionics compartment. On the flight decks of many aircraft, a Flight Management System (FMS) incorporates the central maintenance computer system interface on the same CDU panel(s) used by the flight crew. (***Figure 4-1***) The on-screen display of faults and corrective actions, can be printed or electronic downloaded to capture the BITE produced data.

An automatic Aircraft Communications Addressing and Reporting System (ACARS) sends BITE maintenance data to the ground maintenance station while the aircraft is en-route.

Replacement parts can be readied for installation so that, when the plane arrives, maintenance personnel can begin the repair immediately. A quick turn-around keeps the aircraft flying as scheduled to produce anticipated revenue.

Figure 4-1. The control display unit (CDU) of an FMS.

Latest generation maintenance diagnostic systems allow for wireless communication for troubleshooting. WiFi, cellular and satellite technologies are used.

Many systems and components have their own BITE dedicated to servicing just that particular system or unit. Some of those are listed below:

- Air Data Computer
- Antiskid - Autobrake
- Arinc
- ATC Transponder
- Automatic Direction Finder
- Distance Measuring Equipment
- Electronic Flight Instruments
- Engine Indicating and Crew Alerting System
- Fire and Overheat
- Flight Management Computer
- Fuel Quantity
- HF Communications Radios
- Hydraulic Management
- Inertial Reference System
- Instrument Landing System
- Lighting
- Passenger Address System
- Selective Calling
- VHF Communication Radios
- Weather Radar
- Window Heat

Follow the manufacturer's instructions on how to operate the BITE system interface to obtain maintenance data.

While in flight, a fault initiates a BITE recording of parameters that is later displayed to the technician when accessing the BITE on the ground. The maintenance function of BITE is accessible only when the aircraft is on the ground. The technician can select options for display on a Computer Display Unit (CDU). For example, display of recorded flight information can be chosen or a new BITE test of the system.

To interrogate the Central Maintenance Computer (CMC) or conduct a BITE check of a system, the technician selects from the menu in the CDU. There are large buttons next to the CDU display screen, each button is known as a Line Select Key (LSK). (*Figure 4-2*)

As the technician enters the option by pressing the LSK adjacent to the listing, a new menu appears and provides additional options from which to choose. It is important for the technician to check if there are more page options available which can be determined by looking in the corner of the screen. A page 1 of 1 means the displayed page is as far as the options extend for that particular system. Page 1 of 2 means the technician is viewing page 1 of 2 and page 2 contains additional options to select from. When a new test is selected, a complete check of circuitry and software occurs that yields output data that is both recorded and displayed.

Figure 4-2. Line select keys (LSK) used for selecting options while interrogating the central maintenance computer on the CDU.

CLASSIFICATION OF AVIONICS TEST EQUIPMENT

All troubleshooting and testing of aircraft electronic equipment is not preformed by built in test equipment. Trained technicians use a wide variety of avionics testing equipment to investigate, test and repair the aircraft's electronic units and systems.

Avionics test equipment can be classified into two categories: shop test equipment and portable test equipment. Extensive testing on a piece of equipment while installed may be inconvenient or expensive if the aircraft is held from service because of it. Replacement of the unit suspected of malfunction can be accomplished quickly and the unit can be sent to the avionics shop for extensive testing using shop test equipment. However, a quick check of a unit with a portable test unit can answer critical questions concerning the serviceability of a unit.

A modulized, remove and replace approach to avionics maintenance allows quick and easy resolution of many avionics malfunctions. But replacing a piece of avionic equipment may not solve a reported malfunction. Today, aircraft electronics are part of an integrated system connected via a data bus. The problem with a certain avionics unit may be present only when installed and integrated with the aircraft's other avionics. Portable avionic test equipment allows the technician to test the suspected unit while it is installed.

Another way to classify avionics testing equipment is by function. Two basic categories exist - generators and analyzers. A generator provides a known signal or stimulus which is then processed by the tested unit. The second type of test equipment, an analyzer, is used to determine whether the output of the unit is within design tolerances. Generators often have interaction with the unit being tested and release the test signal after conditions are met. These more sophisticated signal generators are known as test sets.

Analyzers can be shop-based or portable units. The common multimeter is one type of analyzer. The ability to measure voltage current and resistance is very useful. Many modern digital multimeters include expanded capabilities to measure frequency, capacitance and temperature. Oscilloscopes are another commonly used analyzer. Frequency domain analyzers are also common. Examples include spectrum analyzers, modulation meters and distortion meters. Many modern aircraft make use of computer-based analyzing. A connection is made to a portable laptop computer for processing and display of information. In some cases, an adapter unit allows access directly into the digital data bus.

AVIONICS TEST EQUIPMENT

Every piece of avionics test equipment must be operated according the manufacturer's instructions. The technician should be aware of the dangers of high voltage and electrocution when utilizing test equipment on both energized and de-energized avionics.

OSCILLOSCOPE

An oscilloscope measures variations of a parameter as a function of time and displays them graphically on a screen. Typically, they measure voltage and other parameters obtained by processing the voltage signal. Since oscilloscopes include the time domain, they are useful in indicating rapid variations such as AC voltages, pulses, spikes and complex waveforms. They are primarily used in bench testing of equipment and rarely used on the actual aircraft. (*Figure 4-3*) See more on oscilloscopes on page 3.68.

TIME DOMAIN REFLECTOMETER (TDR)

A TDR is often used to check for standing waves in transmission lines. The unit is similar in appearance to an oscilloscope. The indication provided by the trace signal displays an open or short and provides the distance along the transmission line where the open or short occurs as read from the graticule. (*Figure 4-4*)

A TDR can also indicate if a cable is pinched or frayed. A pinch condition will appear on the graticule as a dip due to added impedance. A fray will cause the trace to drift up. These two conditions are often found as a partial open or partial short and will appear on the graticule as minor dips or rises in the trace signal.

SPREAD SPECTRUM TIME DOMAIN REFECTOMETER (SSTDR)

The SSTDR performs the same function and provides the same information as the TDR. The advantage of SSTDR technology for the technician is ease of use, greater precision and portability. SSTDR's do not interfere with digital circuits and the aircraft circuits do not affect the diagnostic equipment readings.

SSTDR's are found as small as a digital multimeter and directly state whether the circuit is in an open or shorted state. The unit also indicates how far down a transmission line is in feet or meters. Knowing a discrepancy is located where the problem is in the transmission line allows the technician to go directly to that location to repair or replace the line. (*Figure 4-5*)

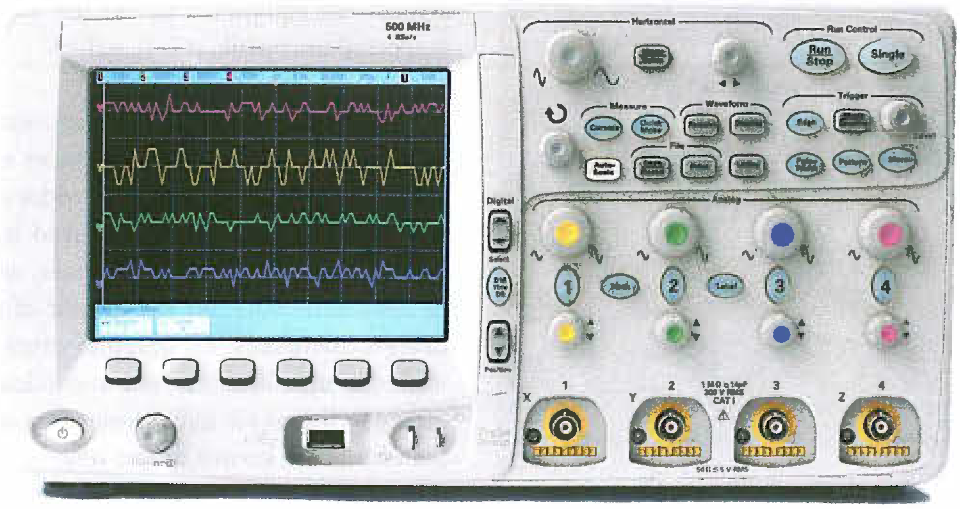


Figure 4-3. An oscilloscope.

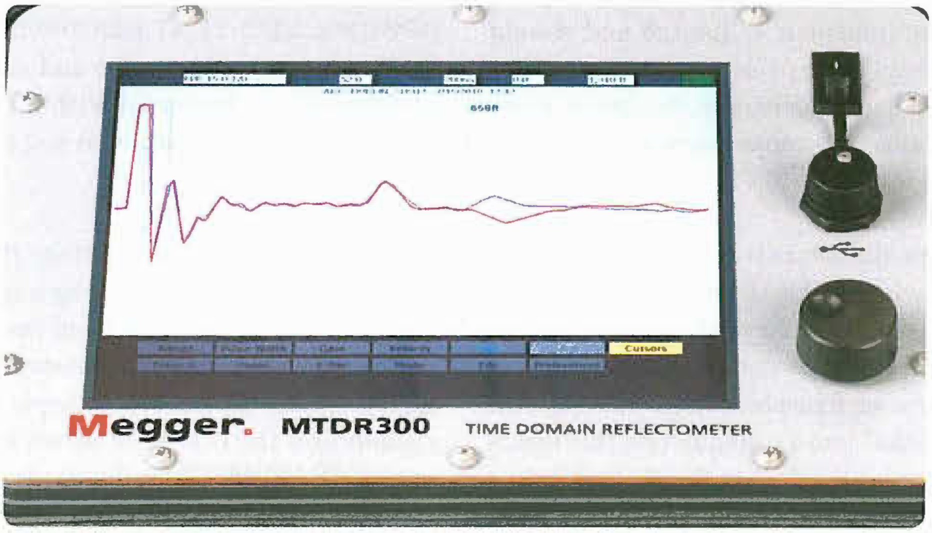


Figure 4-4. A time domain reflectometer.

Figure 4-5. An SSTDR showing an open at 0 feet.

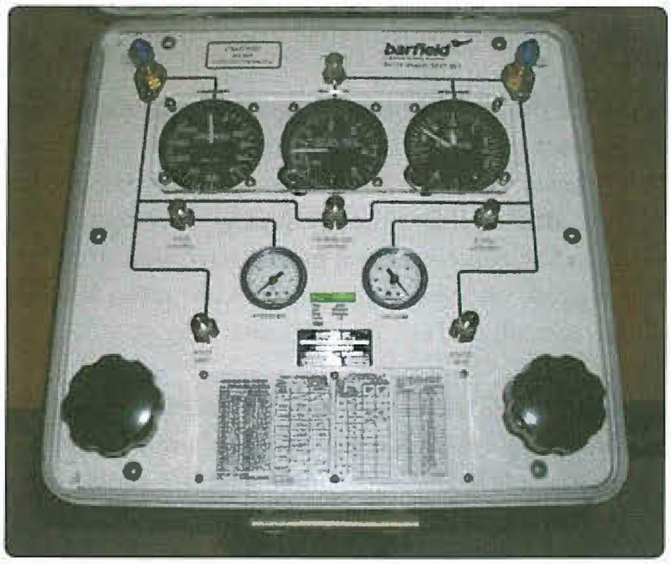


Figure 4-6. A pitot static test unit with calibration certification.

PITOT-STATIC TEST EQUIPMENT

The pitot-static system must be tested periodically to ensure instrumentation that uses pitot and static pressures as inputs provide accurate indications to the flight crew. Typical instrumentation on pitot-static test equipment includes an altimeter, vertical speed indicator, and airspeed indicators.

Optional features of many testers includes a chronograph and pressure indicators for the test unit pitot and static pressures. (***Figure 4-6***)

There are two types of diagnostic equipment used for testing the pitot-static system based on their mode of operation. One type operates by the technician manually pumping a small hand pump to change the system pressure. The second type operates on electrical power to change the system pressure.

The aircraft maintenance manual describes how to safely connect and conduct testing on the aircraft. The test equipment manufacturer includes instructions with the equipment on how the equipment is connected to the aircraft and its safe and proper operation. The technician must ensure that equipment and aircraft limitations are not exceeded when using this equipment as serious damage to the avionics systems can result from improper testing procedures.

Pitot-static test equipment is calibrated and should be checked for compliance prior to starting testing procedures. The equipment generally consists of a test kit or box that contains the various valves and indicators needed for testing.

Connect the kit to the aircraft with the hoses and fittings that come with the kit. To prepare the aircraft for testing of the pitot-static system the technician must block off the appropriate static ports using tape or approved covers. In some transport category aircraft, the aircraft must be "*fooled*" into a configuration that makes the on board computer think that the aircraft is in a flying configuration.

Be sure to check your aircraft manual for the proper configuration for the test being conducted.

Connect the test equipment hoses to their respective locations. Ensure that hoses are placed about the aircraft in a manner that reduces the odds of being stepped on or interfered with by other ground support equipment. Perform the functional test paying particular attention to airspeed, and vertical ascent/descent rates, keeping within aircraft and equipment limitations.

Electronic versions of the pitot-static tester are available and provide digital display of information and programmable limits for operational rates to avoid system and equipment damage.

If the system fails during testing, double check that all ports are properly sealed and the aircraft is correctly configured. If the system fails the check again, review the entries in the aircraft logbook for the last time an avionics component was maintained or replaced. A loose fittings around that component is likely. Should the system still not pass the test, another test unit can be used to ensure that there is not a problem with the tester. If the system continues to fail, the technician must either replace a defective aircraft indicator or check all fittings in the pitot-static system until the malfunction is corrected. As always, record results with a logbook entry or work card sign off.

Upon completion of the test procedures, ensure the removal of blocking covers and tape used. Carefully store all equipment ensuring no hoses are pinched or damaged.

SPECIALIZED TEST EQUIPMENT

Each unit of communication and navigation electronic equipment may be tested with an electronic testing device designed specifically to test that particular type of equipment.

This is common even for other types of electronic equipment and systems. Having a specifically designed testing device makes testing and troubleshooting easier. Follow the manufacturer's instructions when using such a testing device. An example of specialized test equipment is the IFR 4000 shown in ***Figure 4-7*** which tests VHF NAV/COM radio bands.

AUTOMATIC TEST EQUIPMENT

Computer based Automatic Test Equipment (ATE) is built to interface with and test the enormous variety of avionics found on a modern aircraft. The sophisticated test circuitry can provide stimuli and analysis of any specific device for which software has been incorporated. A test unit adapter connects the LRU to the ATE. While a computer controls the test sequence through its software, there are usually prompts for an operator to select various settings on the device under test to complete a full diagnosis.

VME/VXI

Versa Model Eurocard (VME) is a connector system for avionics that uses European plug-in card architecture.

Figure 4-7. An example of specialized avionics test equipment.

VXI stands for VME bus expansion for instrumentation.

VXI instruments have a main frame chassis that contains the power supply for a variety of electronics as well as the computer that controls the functions and testing of any number of instruments that may be plugged into the chassis via a circuit card. VXI is a standardized system shared by any manufacturers that wish to produce components for the architecture. It is a fast system that can test components that are plugged in automatically through the computer's software or with a human interface.

VXI packages are usually smaller than standard instrument packages and are interconnected with a high-speed bus. VXI units cannot operate unless they are plugged into the system and the control computer is plugged in as well.

DATA BUS ANALYZERS

Avionics on aircraft are interconnected and function through the use of standardized data buses. The standard used is chosen by the aircraft designers. Data bus analyzers are carry-on portable type test equipment. They are used to trouble shoot digital systems. The analyzer must be compatible with the type of data bus standard being used by the aircraft components.

The data bus analyzer typically plugs into where an LRU is removed so that incoming signals to the LRU can be evaluated. Signals may also be dispatched by the analyzer to determine effective interface between various components. A data bus analyzer may also access the bus through a made-for-testing plug-in location. Most analyzers will have a record mode of operation to capture data and display it numerically or graphically. Follow the manufacturer's instruction when using a data bus analyzer.

SS TEST EQUIPMENT CALIBRATION STANDARDS

There would be no purpose in checking the function of avionics equipment with test equipment that is not calibrated. First, the test equipment must be suitable for testing the intended unit. The manufacturer of the equipment under test or the aircraft manufacturer are the best authorities of what testing equipment can be used.

Test equipment calibration standards must be derived from and traceable to one of the following:

1. The National Institute of Standards and Technology.
2. Standards established by the test equipment manufacturer.
3. If foreign-manufactured test equipment, the standards of the country where it was manufactured.

It is the technician's responsibility to make sure that the test equipment used is the equipment called for by the manufacturer or equivalent. Before acceptance, a comparison should be made between the specifications of the test equipment recommended by the manufacturer and those proposed for use by a repair facility. The test equipment must be capable of performing all normal tests and checking all parameters of the equipment under test. The level of accuracy should be equal to or better than that recommended by the manufacturer. For a description of avionics test equipment used for troubleshooting, refer to the equipment or aircraft manufacturer's instruction manual.

The calibration intervals for test equipment varies with the type of equipment, environment, and use. The accepted industry practice for calibration intervals is usually one year. Considerations for acceptance of the intervals include the manufacturer's recommendation for the type of equipment and the repair facility's past calibration history if applicable.

NOTE: If a manufacturer's manual does not describe a particular test procedure, the repair facility must coordinate with the manufacturer to develop an acceptable procedure prior to the use of the equipment.

FUNCTIONAL CHECKS

While it is the responsibility of the pilot in command to ensure the equipment on the aircraft to be flown is functioning properly, it is also the engineer's job to do so as well. This is particularly true after a repair or replacement of a particular avionics unit has been made. Familiarization of the intended use of the equipment and performance of a thorough operational check in accordance with the manufacturer's instruction is required.

Question: 4-1
BITE can be built in to an individual LRU or it can be part of a ____________________.

Question: 4-2
Avionics test equipment can be classified into two categories: shop test equipment and ________________ test equipment.

Question: 4-3
________________ is a connector system for avionics that use European plug-in card architecture.

Question: 4-4
The accepted industry practice for avionics test equipment calibration intervals is usually ________________.

ANSWERS

Answer: 4-1
centralized maintenance system.

Answer: 4-2
portable.

Answer: 4-3
Versa Model Eurocard (VME).

Answer: 4-4
one year.

MAINTENANCE PRACTICES

ENGINEERING DRAWINGS, DIAGRAMS AND STANDARDS

SUB-MODULE 05

PART-66 SYLLABUS CERTIFICATION CATEGORY →	LEVELS B1	 B2
Sub-Module 05 ENGINEERING DRAWINGS, DIAGRAMS AND STANDARDS Knowledge Requirements		
7.5 - Engineering Drawings, Diagrams and Standards		
Drawing types and diagrams, their symbols, dimensions, tolerances and projections; Identifying title block information; Microfilm, microfiche and computerized presentations; Specification 100 of the Air Transport Association (ATA) of America; Aeronautical and other applicable standards including ISO, AN, MS, NAS and MIL; Wiring diagrams and schematic diagrams.	2	2

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
- (a) The applicant should be able to understand the theoretical fundamentals of the subject.
- (b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- (c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
- (d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- (e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

ENGINEERING DRAWINGS, DIAGRAMS, AND STANDARDS

The exchange of ideas is essential to everyone, regardless of his or her vocation or position. Usually, this exchange is carried on by the oral or written word; but under some conditions, the use of these alone is impractical. Industry discovered that it could not depend entirely upon written or spoken words for the exchange of ideas because misunderstandings and misinterpretations arose frequently. A written description of an object can be changed in meaning just by misplacing a comma; the meaning of an oral description can be completely changed by the use of a wrong word. To avoid these possible errors, industry uses drawings to describe objects. For this reason, drawing is the draftsman's language.

Drawing as used here is a method of conveying ideas concerning the construction or assembly of objects. This is done with the help of lines, notes, abbreviations, and symbols. It is very important that the aviation mechanic who is to make or assemble the object understands the meaning of the different lines, notes, abbreviations, and symbols that are used in a drawing. (See especially the "*Lines and Their Meanings*" section of this Sub-Module.)

COMPUTER GRAPHICS

From the early days of aviation, development of aircraft engines, and other components relied heavily on aircraft drawings. For most of the 20th century, drawings were created on a drawing "board" with pen or pencil and paper. However, with the introduction and advancement of computers in the later decades of the 20th century, the way drawings are created changed dramatically. Computers were used not only to create drawings, but they were being used to show items in "virtual reality," from any possible viewing angle. Further development saw computer software programs with the capability of assembling separately created parts to check for proper fit and possible interferences. Additionally, with nearly instantaneous information sharing capability through computer networking and the Internet, it became much easier for designers to share their work with other designers and manufacturers virtually anytime, anywhere in the world. Using new computer controlled manufacturing techniques, it literally became possible to design a part and have it precisely manufactured without ever having it shown on paper. New terms and acronyms became commonplace.

The more common of these terms are:

- Computer Graphics
  Drawing with the use of a computer,
- Computer Aided Design Drafting (CADD)
  Where a computer is used in the design and drafting process,
- Computer Aided Design (CAD)
  Where a computer is used in the design of a product,
- Computer Aided Manufacturing (CAM)
  Where a computer is used in the manufacturing of a product, and
- Computer Aided Engineering (CAE)
  Where a computer is used in the engineering of a product.

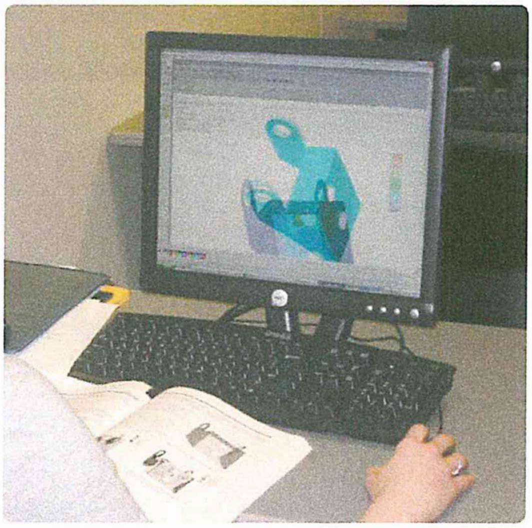


Figure 5-1. Computer graphics work station.

As computer hardware and software continue to evolve, there continues to be a greater amount of CAE done in less time at lower cost. In addition to product design, some of the other uses of CAE are product analysis, assembly, simulations and maintenance information. (*Figure 5-1*)

PURPOSE AND FUNCTION OF AIRCRAFT DRAWINGS

Drawings and prints are the link between the engineers who design an aircraft and the workers who build, maintain, and repair it. A print may be a copy of a working drawing for an aircraft part or group of parts, or for a design of a system or group of systems. They are made by placing a tracing of the drawing over a sheet of chemically treated paper and exposing it to a strong light for a short period of time. When the exposed paper is developed, it turns blue where the light has penetrated the transparent tracing. The inked lines of the tracing, having blocked out the light, show as white lines on a blue background. Other types of sensitized paper have been developed; prints may have a white background with colored lines or a colored background with white lines.

Drawings created using computers may be viewed as they appear on the computer monitor, or they may be printed out in "hard copy" by use of an ink jet or laser printer. Larger drawings may be printed by use of a plotter or large format printer. Large printers can print drawings up to 42 inches high with widths up to 600 inches by use of continuous roll paper. (*Figure 5-2*)

Figure 5-2. Large format printer.

CARE AND USE OF DRAWINGS

Drawings are both expensive and valuable; consequently, they should be handled carefully. Open drawings slowly and carefully to prevent tearing the paper. When the drawing is open, smooth out the fold lines instead of bending them backward.

To protect drawings from damage, never spread them on the floor or lay them on a surface covered with tools or other objects that may make holes in the paper. Hands should be free of oil, grease, or other unclean matter that can soil or smudge the print.

Never make notes or marks on a print as they may confuse other persons and lead to incorrect work. Only authorized persons are permitted to make notes or changes on prints, and they must sign and date any changes they make.

When finished with a drawing, fold and return it to its proper place. Prints are folded originally in a proper size for filing, and care should be taken so that the original folds are always used.

TYPES OF DRAWINGS

Drawings must give such information as size and shape of the object and all of its parts, specifications for material to be used, how the material is to be finished, how the parts are to be assembled, and any other information essential to making and assembling the particular object.

Drawings may be divided into three classes:
(1) detail, (2) assembly, and (3) installation. (*Figure 5-3*)

DETAIL DRAWING

A detail drawing is a description of a single part, describing by lines, notes, and symbols the specifications for size, shape, material, and methods of manufacture to be used in making the part. Detail drawings are usually rather simple; and, when single parts are small, several detail drawings may be shown on the same sheet or print. (See detail drawing at the top of ***Figure 5-3.***)

ASSEMBLY DRAWING

An assembly drawing is a description of an object made up of two or more parts. Examine the assembly drawing in the center of ***Figure 5-3.*** It describes the object by stating, in a general way, size and shape. Its primary purpose is to show the relationship of the various parts. An assembly drawing is usually more complex than a detail drawing, and is often accompanied by detail drawings of various parts.

INSTALLATION DRAWING

An installation drawing is one which includes all necessary information for a part or an assembly in the final installed position in the aircraft. It shows the dimensions necessary for the location of specific parts with relation to the other parts and reference dimensions that are helpful in later work in the shop. (See installation drawing at the bottom of ***Figure 5-3.***)

SECTIONAL VIEW DRAWINGS

A section or sectional view is obtained by cutting away part of an object to show the shape and construction at the cutting plane. The part or parts cut away are shown by the use of section (crosshatching) lines. Types of sections are described in the following paragraphs.

FULL SECTION

A full section view is used when the interior construction or hidden features of an object cannot be shown clearly by exterior views. For example, ***Figure 5-4,*** a sectional view of a coaxial cable connector, shows the internal construction of the connector.

HALF SECTION

In a half section, the cutting plane extends only halfway across the object, leaving the other half of the object as an exterior view.

Half sections are used to advantage with symmetrical objects to show both the interior and exterior. ***Figure 5-5*** is a half sectional view of a quick disconnect used in aircraft fluid systems.

REVOLVED SECTION

A revolved section drawn directly on the exterior view shows the shape of the cross section of a part, such as the spoke of a wheel. An example of a revolved section is shown in ***Figure 5-6.***

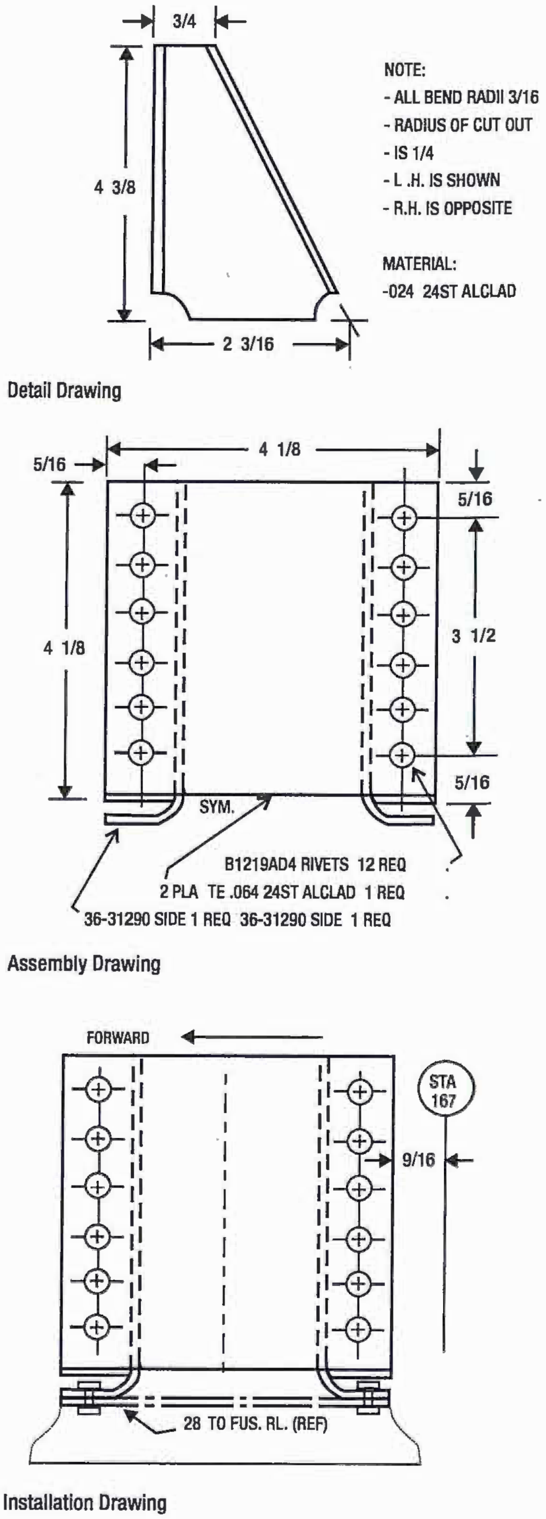


Figure 5-3. Types of drawings.

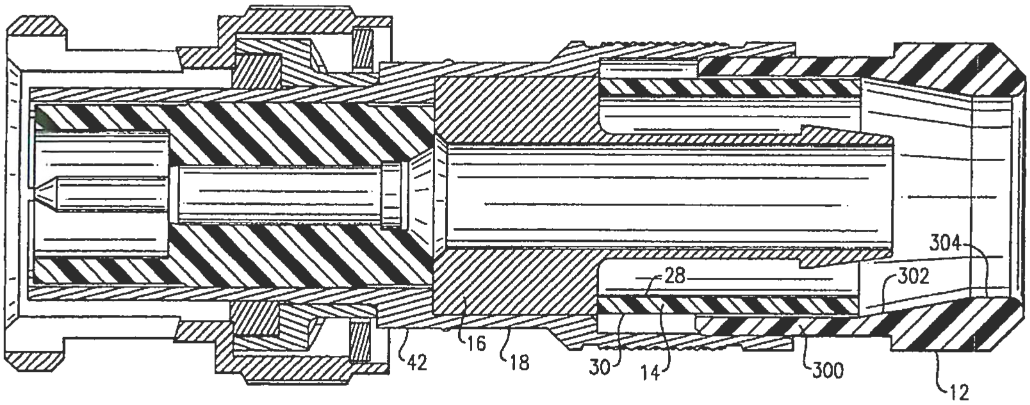


Figure 5-4. Sectional view of a cable connector.

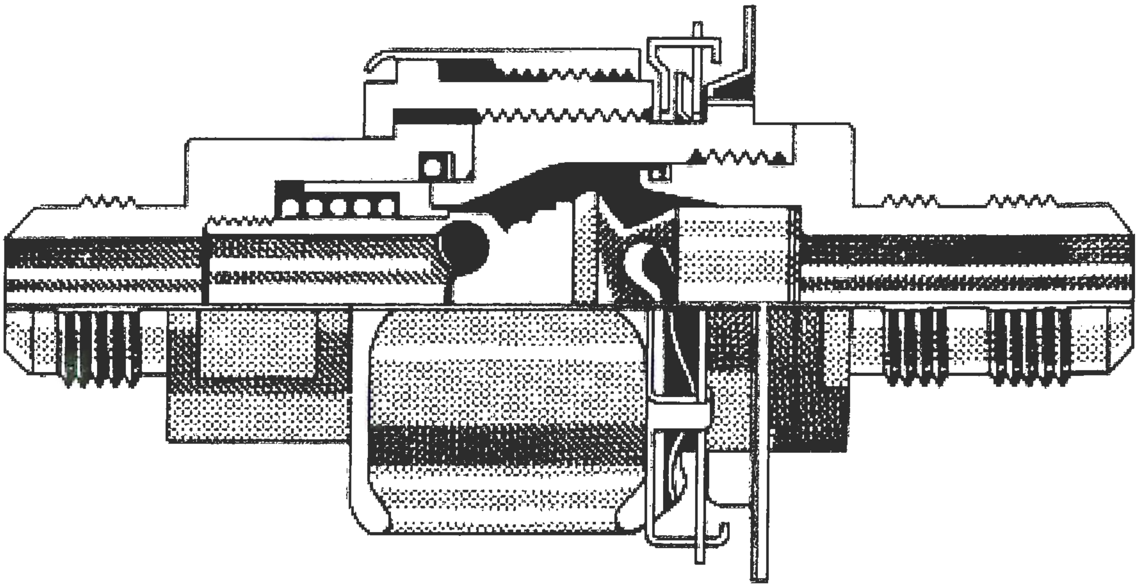


Figure 5-5. Half section.

REMOVED SECTION

A removed section illustrates particular parts of an object. It is drawn like revolved sections, except it is placed at one side and, to bring out pertinent details, often drawn to a larger scale than the view on which it is indicated.

Figure 5-7 is an illustration of removed sections. Section A-A shows the cross-sectional shape of the object at cutting plane line A-A. Section B-B shows the cross-sectional shape at cutting plane line B-B.

These sectional views are drawn to the same scale as the principal view. Note that they are often drawn to a larger scale to bring out pertinent details.

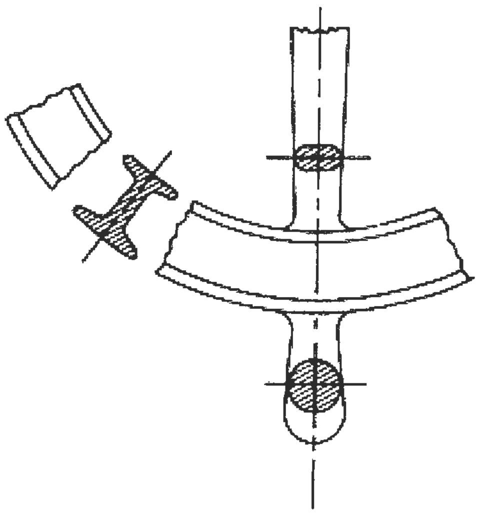


Figure 5-6. Revolved sections.

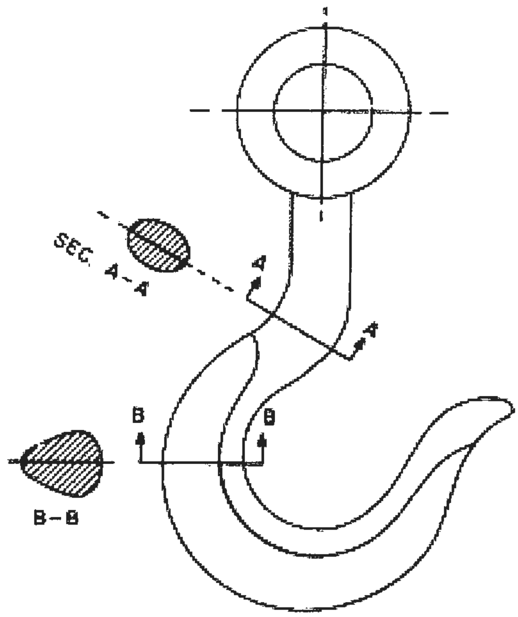


Figure 5-7. Removed sections.

TITLE BLOCKS

Every print must have some means of identification. This is provided by a title block. (***Figure 5-8***) The title block consists of a drawing number and certain other data concerning the drawing and the object it represents. This information is grouped in a prominent place on the print, usually in the lower right-hand corner. Sometimes the title block is in the form of a strip extending almost the entire distance across the bottom of the sheet.

Although title blocks do not follow a standard form insofar as layout is concerned, all of them present essentially the following information:

1. A drawing number to identify the print for filing purposes and to prevent confusing it with any other print.
2. The name of the part or assembly.
3. The scale to which it is drawn.
4. The date.
5. The name of the firm.
6. The name of the draftsmen, the checker, and the person approving the drawing.

DRAWING OR PRINT NUMBERS

All prints are identified by a number, which appears in a number block in the lower right-hand corner of the title block. It may also be shown in other places such as near the top border line, in the upper right-hand corner, or on the reverse side of the print at both ends so that the number will show when the print is folded or rolled. The purpose of the number is quick identification of a print. If a print has more than one sheet and each sheet has the same number, this information is included in the number block, indicating the sheet number and the number of sheets in the series.

REFERENCE AND DASH NUMBERS

Reference numbers that appear in the title block refer you to the numbers of other prints. When more than one detail is shown on a drawing, dash numbers are used. Both parts would have the same drawing number plus an individual number, such as 40267-1 and 40267-2. In addition to appearing in the title block, dash numbers may appear on the face of the drawing near the parts they identify. Dash numbers are also used to identify right-hand and left-hand parts.

In aircraft, many parts on the left side are like the corresponding parts on the right side but in reverse. The left-hand part is always shown in the drawing. The right-hand part is called for in the title block. Above the title block a notation is found, such as: 470204-1LH shown; 470204-2RH opposite. Both parts carry the same number, but the part called for is distinguished by a dash number. Some prints have odd numbers for left-hand parts and even numbers for right-hand parts.

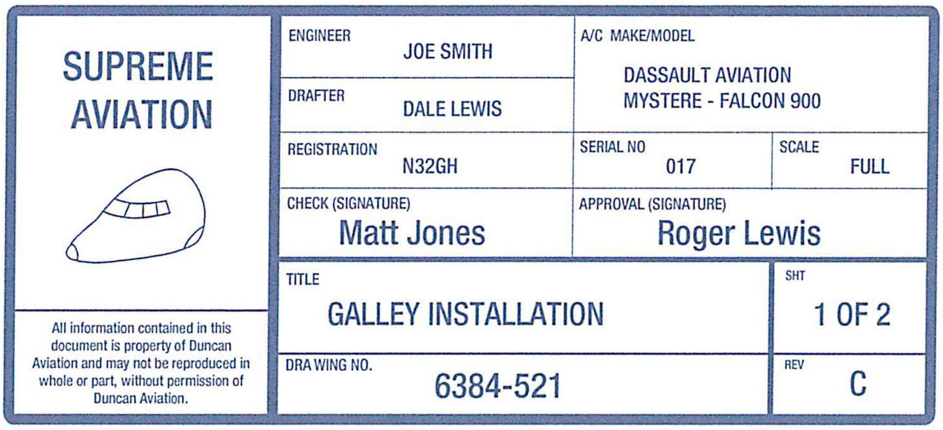


Figure 5-8. Title block.

UNIVERSAL NUMBERING SYSTEM

The universal numbering system provides a means of identifying standard drawing sizes. In the universal numbering system, each drawing number consists of six or seven digits. The first digit is always 1, 2, 4, or 5, and indicates the size of the drawing. The remaining digits identify the drawing. Many firms have modified this basic system to conform to their particular needs. Letters may be used instead of numbers. The letter or number depicting the standard drawing size may be prefixed to the number, separated from it by a dash. Other numbering systems provide a separate box preceding the drawing number for the drawing size identifier. In another modification of this system, the part number of the depicted assembly is assigned as the drawing number.

BILL OF MATERIAL

A list of the materials and parts necessary for the fabrication or assembly of a component or system is often included on the drawing. The list is usually in ruled columns in which are listed the part number, name of the part, material from which the part is to be constructed, the quantity required, and the source of the part or material.

A typical bill of material is shown in ***Figure 5-9***. On drawings that do not have a bill of material, the data may be indicated directly on the drawing. On assembly drawings, each item is identified by a number in a circle or square. An arrow connecting the number with the item assists in locating it in the bill of material.

Bill of Material

ITEM	PART NO.	REQUIRED	SOURCE
CONNECTOR	UO-21 D/U	2	STOCK

Figure 5-9. A bill of material.

OTHER DRAWING DATA

REVISION BLOCK

Revisions to a drawing are necessitated by changes in dimensions, design, or materials. The changes are usually listed in ruled columns either adjacent to the title block or at one corner of the drawing. All changes to approved drawings must be carefully noted on all existing prints of the drawing. When drawings contain such corrections, attention is directed to the changes by lettering or numbering them and listing those changes against the symbol in a revision block. (***Figure 5-10***) The revision block contains the identification symbol, the date, the nature of the revision, the authority for the change, and the name of the draftsman who made the change.

To distinguish the corrected drawing from its previous version, many firms are including, as part of the title block, a space for entering the appropriate symbol to designate that the drawing has been changed or revised.

NOTES

Notes are added to drawings for various reasons. Some of these notes refer to methods of attachment or construction. Others give alternatives, so that the drawing can be used for different styles of the same object. Still others list modifications that are available. Notes may be found alongside the item to which they refer. If the notes are lengthy, they may be placed elsewhere on the drawing and identified by letters or numbers. Notes are used only when the information cannot be conveyed in the conventional manner or when it is desirable to avoid crowding the drawing. ***Figure 5-3*** illustrates one method of depicting notes.

When the note refers to a specific part, a light line with an arrowhead leads from the note to the part. If it applies to more than one part, the note is so worded to eliminate ambiguity as to the parts to which it pertains. If there are several notes, they are generally grouped together and numbered consecutively.

ZONE NUMBERS

Zone numbers on drawings are similar to the numbers and letters printed on the borders of a map. They help locate a particular point. To find a point, mentally draw horizontal and vertical lines from the letters and numerals specified; the point where these lines intersect is the area sought.

Use the same method to locate parts, sections, and views on large drawings, particularly assembly drawings. Parts numbered in the title block can be located on the drawing by finding the numbers in squares along the lower border. Zone numbers read from right to left.

STATION NUMBERS AND LOCATION IDENTIFICATION ON AIRCRAFT

A numbering system is used on large assemblies for aircraft to locate stations such as fuselage stations. Fuselage station 185 indicates a location that is 185 inches from the datum of the aircraft. The measurement is usually taken from the nose or zero station, but in some instances it may be taken from the firewall or some other point chosen by the manufacturer. Just as forward and aft locations on aircraft are made by reference to the datum, locations left and right of the aircraft's longitudinal axis are made by reference to the buttock line and are called butt stations. Vertical locations on an airplane are made in reference to the waterline.

The same station numbering system is used for wing and stabilizer frames. The measurement is taken from the centerline or zero station of the aircraft. ***Figure 5-11*** shows use of the fuselage stations (FS), waterline locations (WL), and left and right buttock line locations (RBL and LBL).

REV	ZONE	REVISION DESCRIPTION	DATE	APPR
A	ALL SHTS	INITIAL RELEASE	12/05/05	RL
B	PG2 C-2	ADDED ADDITIONAL MOUNTING POINTS	12/05/05	RL
C	PG2 A-1	ADDED AC	01/02/06	RL

Figure 5-10. Revision block.

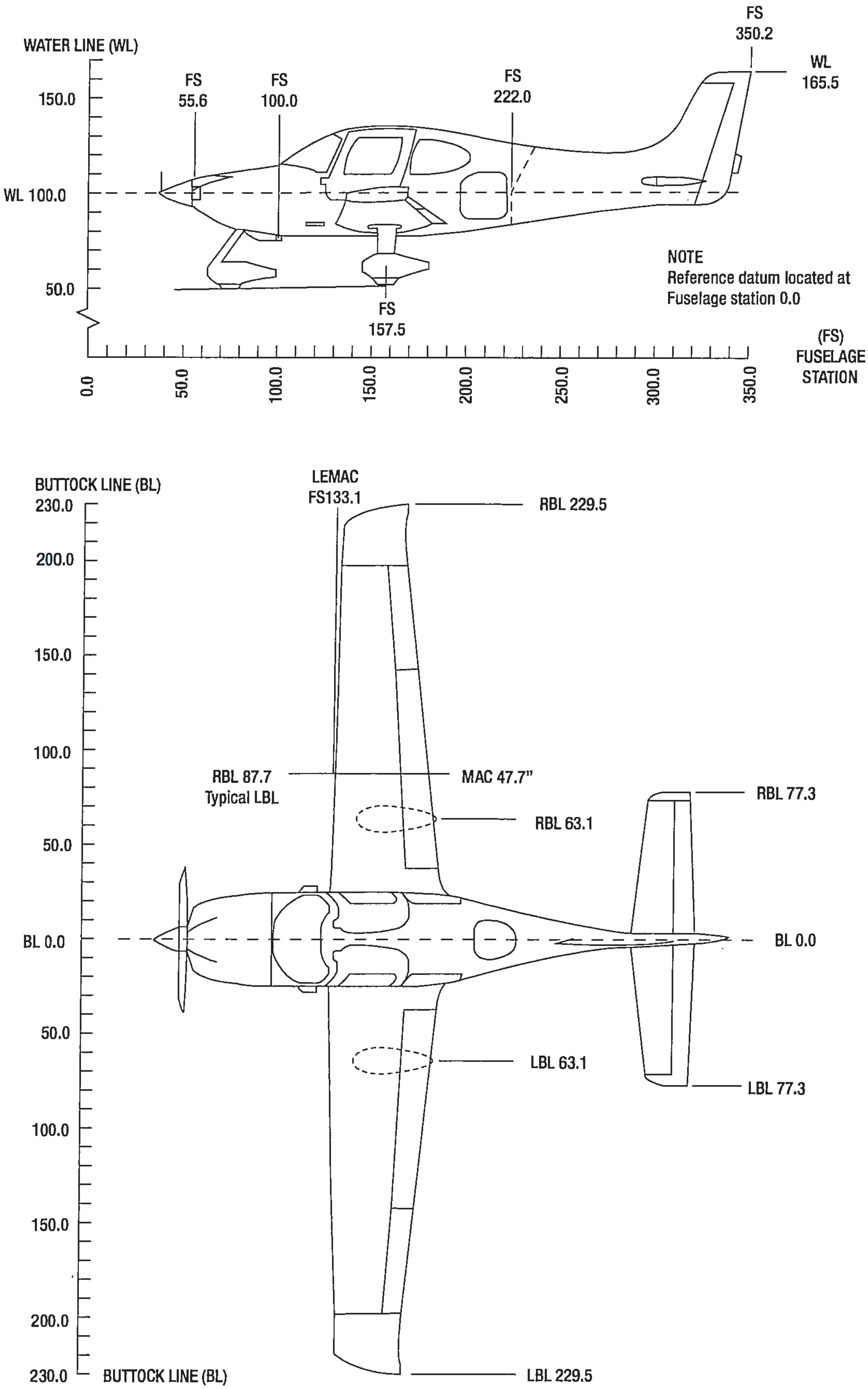


Figure 5-11. Station numbers and location identification on aircraft.

ALLOWANCES AND TOLERANCES

When a given dimension on a print shows an allowable variation, the plus (+) figure indicates the maximum, and the minus (-) figure the minimum allowable variation. The sum of the plus and minus allowance figures is called tolerance. For example, using 0.225 + 0.002 5 - 0.000 5, the plus and minus figures indicate the part will be acceptable if it is not more than 0.0025 larger than the 0.225 given dimension, or not more than 0.000 5 smaller than the 0.225 dimension. Tolerance in this example is 0.003 0 (0.002 5 max plus 0.000 5 min).

If the plus and minus allowances are the same, you will find them presented as 0.224 ± 0.002 5. The tolerance would then be 0.005 0. Allowance can be indicated in either fractional or decimal form. When very accurate dimensions are necessary, decimal allowances are used. Fractional allowances are sufficient when precise tolerances are not required. Standard tolerances of -0.010 or -1⁄32 may be given in the title block of many drawings, to apply throughout the drawing.

FINISH MARKS

Finish marks are used to indicate the surface that must be machine finished. Such finished surfaces have a better appearance and allow a closer fit with adjoining parts. During the finishing process, the required limits and tolerances must be observed. Do not confuse machined finishes with those of paint, enamel, chromium plating, and similar coating.

SCALE

Some drawings are made exactly the same size as the drawn part; they have a scale of 1:1. Other scales may be used. However, when drawings are made on a computer, drawing sizes may be easily increased (zoom in) or decreased (zoom out). Some electronic printers have the same capability. Furthermore, when a 1:1 copy of a print is made, the copy size may differ slightly from that of the original. For accurate information, refer to the dimensions shown on the drawing.

APPLICATION

When shown near the title block, application may refer to the aircraft, assembly, sub-assembly or next installation on which the part would be used.

METHODS OF ILLUSTRATION

APPLIED GEOMETRY

Geometry is the branch of mathematics that deals with lines, angles, figures and certain assumed properties in space. Applied geometry, as used in drawing, makes use of these properties to accurately and correctly represent objects graphically. In the past, draftsmen utilized a variety of instruments with various scales, shapes and curves to make their drawings. Today, computer software graphics programs showing drawings provide nearly any scale, shape and curve imaginable, outdating the need for additional instruments. A number of methods are used to illustrate objects graphically. The most common are orthographic projections, pictorial drawings, diagrams, and flowcharts.

ORTHOGRAPHIC PROJECTION DRAWINGS

In order to show the exact size and shape of all the parts of complex objects, a number of views are necessary. This is the system used in orthographic projection. In orthographic projection, there are six possible views of an object, because all objects have six sides—front, top, bottom, rear, right side, and left side. ***Figure 5-12(A)*** shows an object placed in a transparent box, hinged at the edges. The projections on the sides of the box are the views as seen looking straight at the object through each side. If the outlines of the object are drawn on each surface and the box opened as shown in ***Figure 5-12(B)*** , then laid flat as shown in ***Figure 5-12(C)*** , the result is a six-view orthographic projection.

It is seldom necessary to show all six views to portray an object clearly; therefore, only those views necessary to illustrate the required characteristics of the object are drawn. One-, two-, and three-view drawings are the most common. Regardless of the number of views used, the arrangement is generally as shown in ***Figure 5-12,*** with the front view as principal view. If the right side view is shown, it will be to the right of the front view. If the left side view is shown, it will be to the left of the front view. The top and bottom views, if included, will be shown in their respective positions relative to the front view.

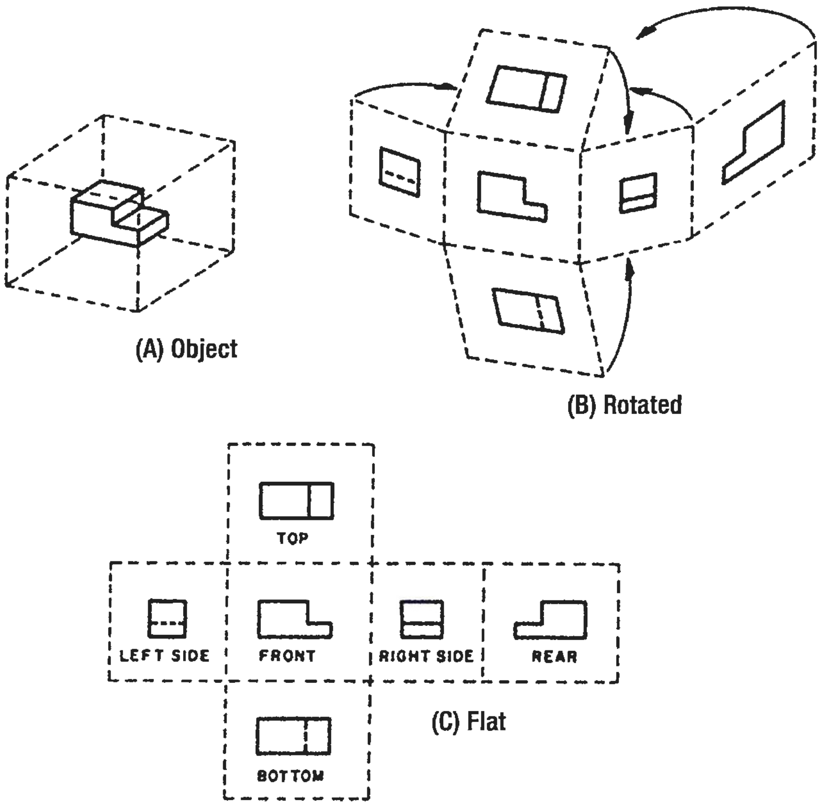


Figure 5-12. Orthographic projection.

One-view drawings are commonly used for objects of uniform thickness such as gaskets, shims, and plates. A dimensional note gives the thickness as shown in ***Figure 5-13.*** One-view drawings are also commonly used for cylindrical, spherical, or square parts if all the necessary dimensions can be properly shown in one view.

When space is limited and two views must be shown, symmetrical objects are often represented by half views, as illustrated in ***Figure 5-14.***

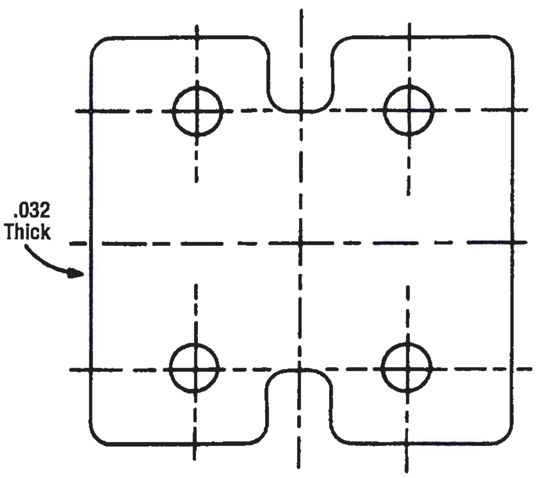


Figure 5-13. One view drawing.

Aircraft drawings seldom show more than two principal or complete views of an object. Instead, there will be usually one complete view and one or more detail views or sectional views.

DETAIL VIEW

A detail view shows only a part of the object but in greater detail and to a larger scale than the principal view. The part that is shown in detail elsewhere on the drawing is usually encircled by a heavy line on the principal view. ***Figure 5-15*** is an example of the use of detail views.

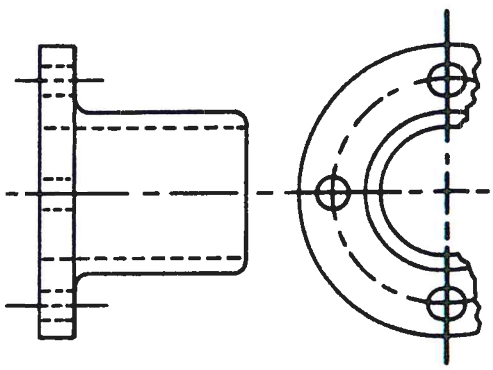


Figure 5-14. Symmetrical object with exterior half view.

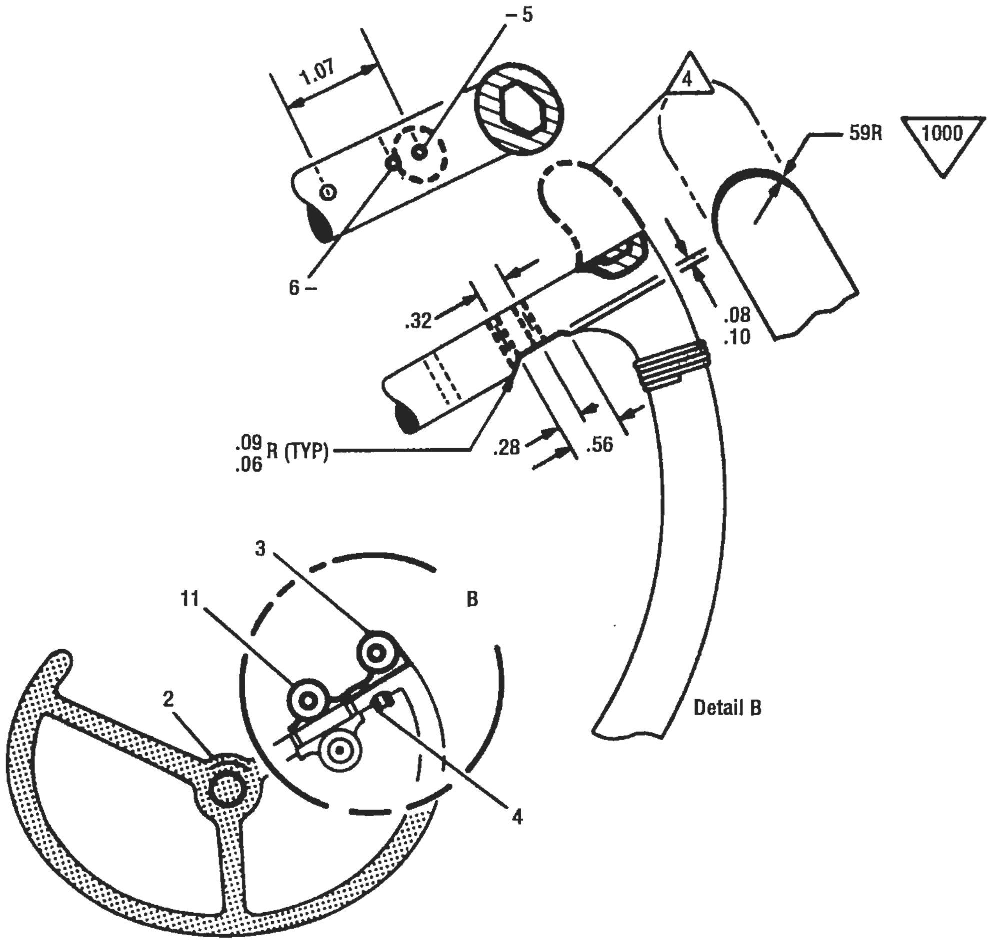


Figure 5-15. Detail view.

The principal view shows the complete control wheel, while the detail view is an enlarged drawing of a portion of the control wheel.

PICTORIAL DRAWINGS

A pictorial drawing is similar to a photograph. It shows an object as it appears to the eye, but it is not satisfactory for showing complex forms and shapes. Pictorial drawings are useful in showing the general appearance of an object and are used extensively with orthographic projection drawings. Pictorial drawings are used in maintenance, overhaul, and part numbers. Three types of pictorial drawings are used frequently by aircraft engineers and technicians: (1) perspective, (2) isometric, and (3) oblique. (***Figure 5-16***)

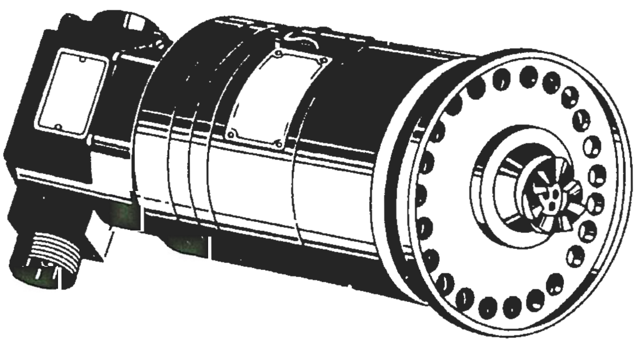


Figure 5-16. Pictorial drawing.

PERSPECTIVE DRAWINGS
A perspective view shows an object as it appears to an observer. It most closely resembles the way an object would look in a photograph. Because of perspective, some of the lines of an object are not parallel and therefore the actual angles and dimensions are not accurate. (***Figure 5-17(A)***)

ISOMETRIC DRAWINGS
An isometric view uses a combination of views of an orthographic projection and tilts the object forward so that portions of all three views can be seen in one view. This provides the observer with a three-dimensional view of the object. Unlike a perspective drawing where lines converge and dimensions are not true, lines in an isometric drawing are parallel and dimensioned as they are in an orthographic projection. (***Figure 5-17(B)***)

OBLIQUE DRAWINGS
An oblique view is similar to an isometric view except for one distinct difference. In an oblique drawing, two of the three drawing axes are always at right angles to each other. (***Figure 5-17(C)***)

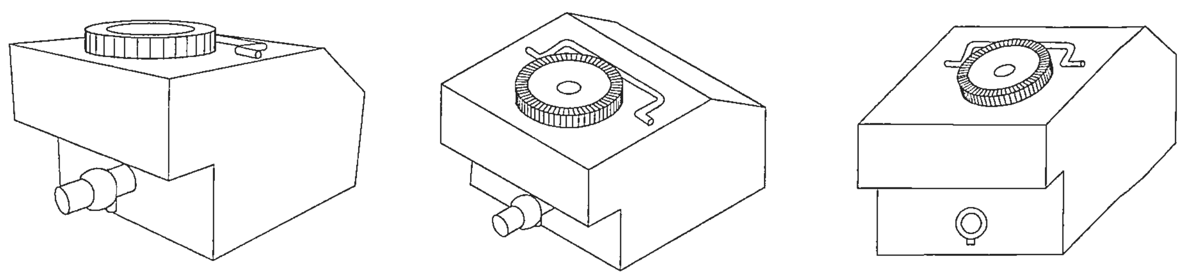
EXPLODED VIEW DRAWINGS
An exploded view drawing is a pictorial drawing of two or more parts that fit together as an assembly. The view shows the individual parts and their relative position to the other parts before they are assembled.

DIAGRAMS
A diagram may be defined as a graphic representation of an assembly or system, indicating the various parts and expressing the methods or principles of operation. There are many types of diagrams; however, those with which the aviation mechanic will be concerned during the performance of his or her job may be grouped into four classes or types: (1) installation, (2) schematic, (3) block, and (4) wiring diagrams.

INSTALLATION DIAGRAMS
Figure 5-18 is an example of an installation diagram. This is a diagram of the installation of the flight guidance control components of an aircraft. It identifies each of the components in the systems and shows their location in the aircraft. Each number (1, 2, 3, and 4) on the detail shows the location of the individual flight guidance system components within the cockpit of the aircraft. Installation diagrams are used extensively in aircraft maintenance and repair manuals, and are invaluable in identifying and locating components and understanding the operation of various systems.

SCHEMATIC DIAGRAMS
Schematic diagrams do not indicate the location of individual components in the aircraft, but locate components with respect to each other within the system. ***Figure 5-19*** illustrates a schematic diagram of an aircraft hydraulic system. The hydraulic pressure gauge is not necessarily located above the landing gear selector valve in the aircraft. It is, however, connected to the pressure line that leads to the selector valve. Schematic diagrams of this type are used mainly in troubleshooting. Note that each line is coded for ease of reading and tracing the flow. Each component is identified by name, and its location within the system can be ascertained by noting the lines that lead into and out of the unit.

Schematic diagrams and installation diagrams are used extensively in aircraft manuals.



(A) (B) (C)

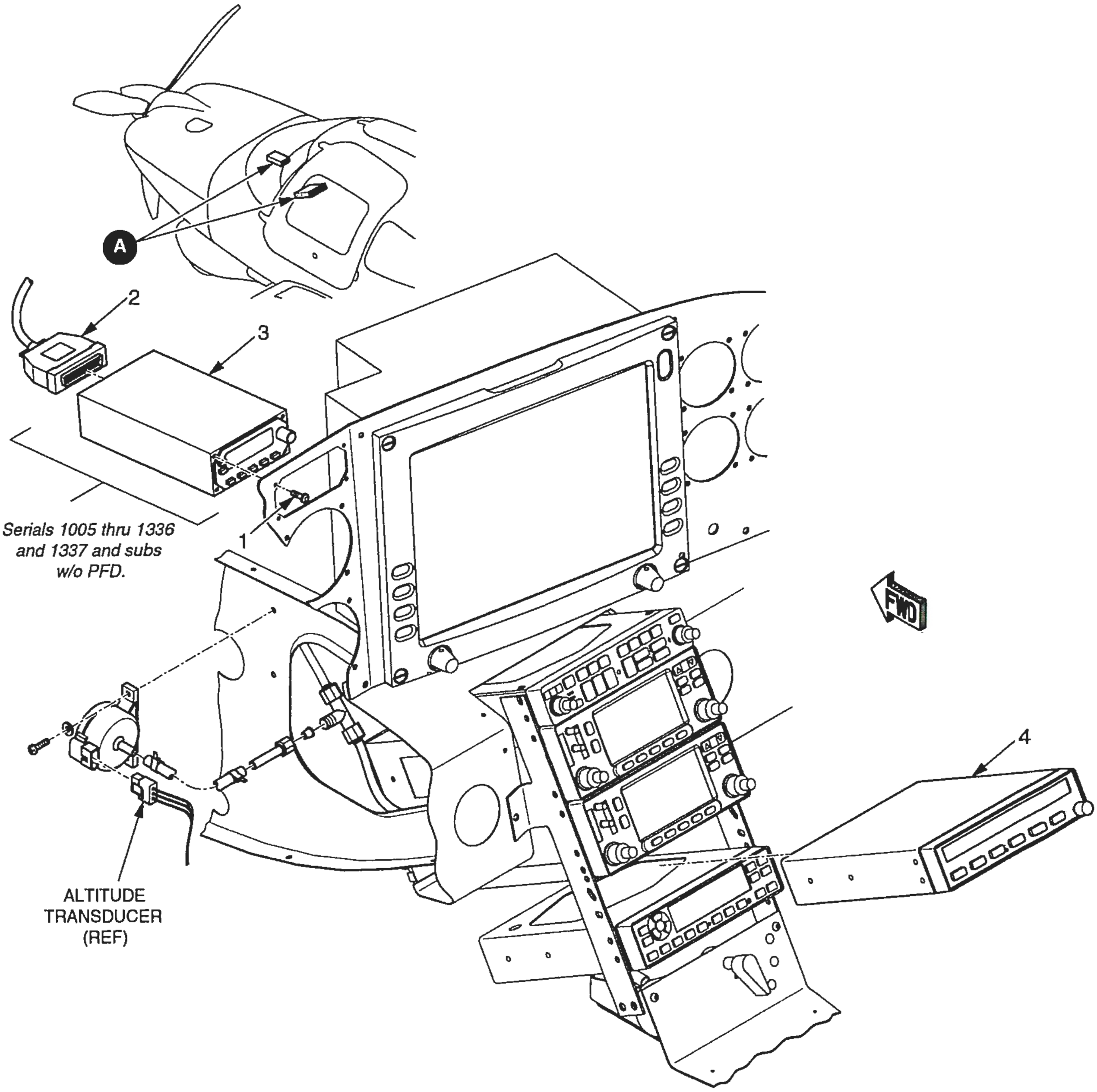
Figure 5-17. (A) Perspective, (B) isometric, and (C) oblique drawings.

BLOCK DIAGRAMS

Block diagrams are used to show a simplified relationship of a more complex system of components. Individual components are drawn as a rectangle (block) with lines connecting it to other components (blocks) that it interfaces with during operation. (*Figure 5-20*)

WIRING DIAGRAMS (SCHEMATICS)

Wiring diagrams show the electrical wiring and circuitry, coded for identification, of all the electrical appliances and devices used on aircraft. These diagrams, even for relatively simple circuits, can be quite complicated. For technicians involved with electrical repairs and installations, a thorough knowledge of wiring diagrams and electrical schematics is essential. (*Figure 5-21*)



LEGEND
1. Screw
2. Cable Connector
3. Altitude/Vertical Speed Selector
4. Flight Guidance Program/Computer

Figure 5-18. Example of installation diagram (flight guidance components).

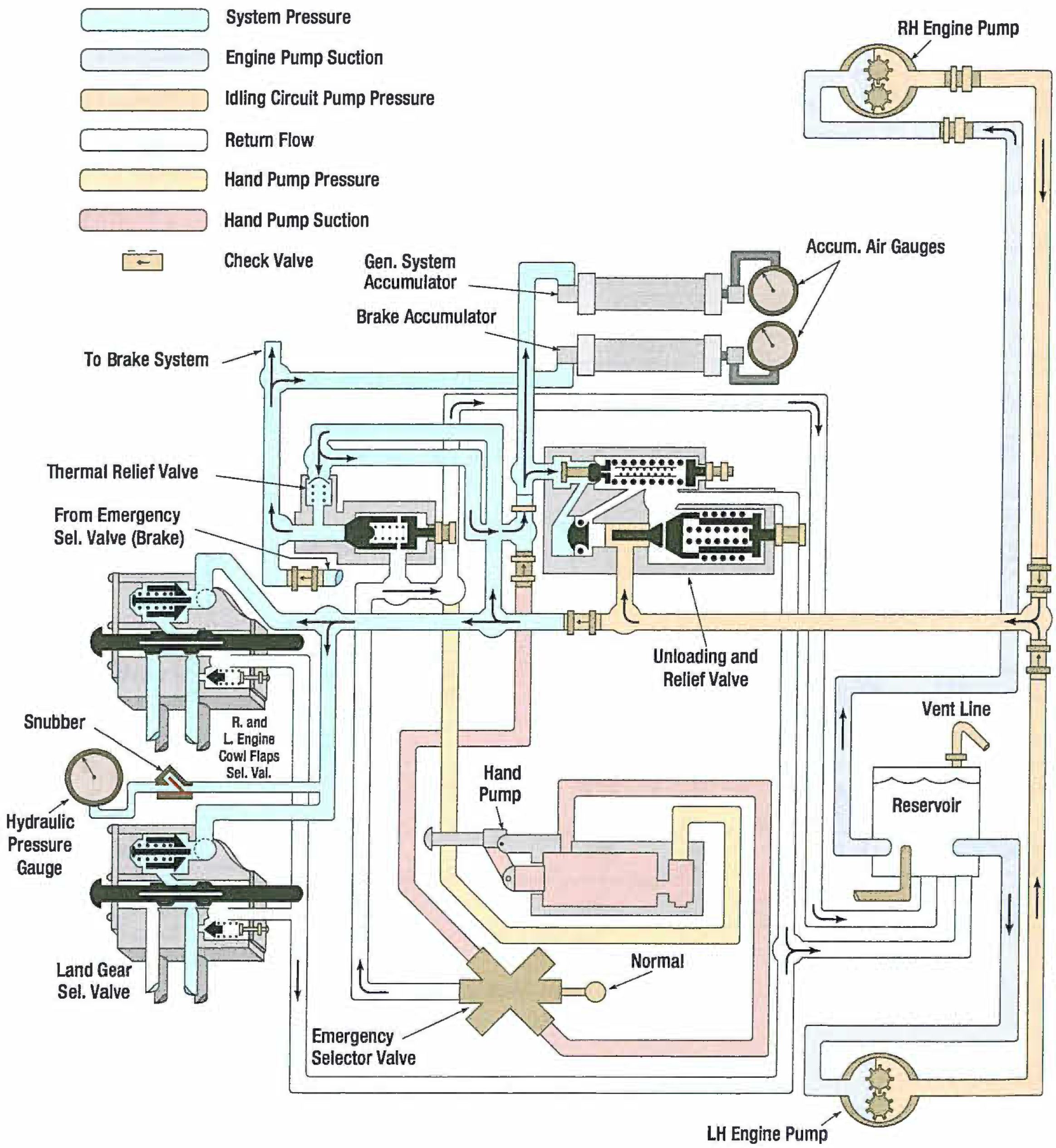


Figure 5-19. Aircraft hydraulic system schematic.

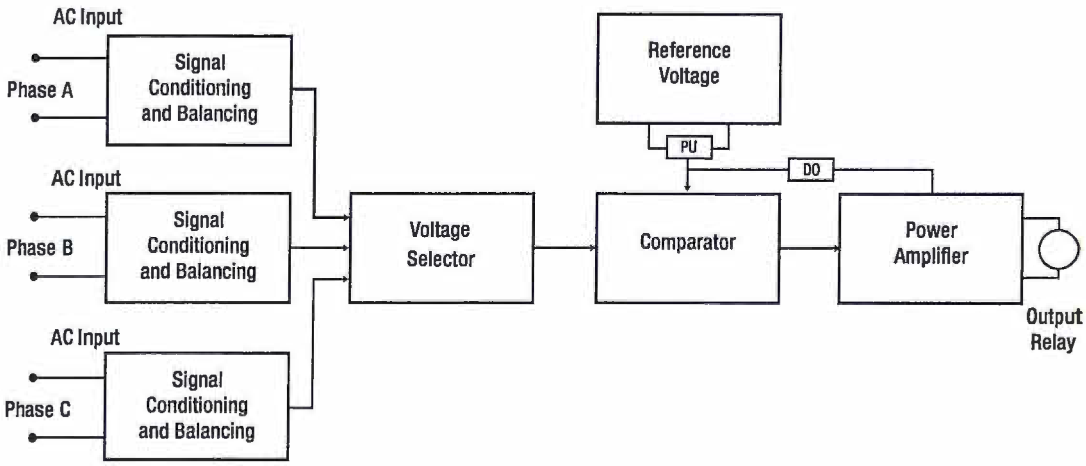


Figure 5-20. Block diagram.

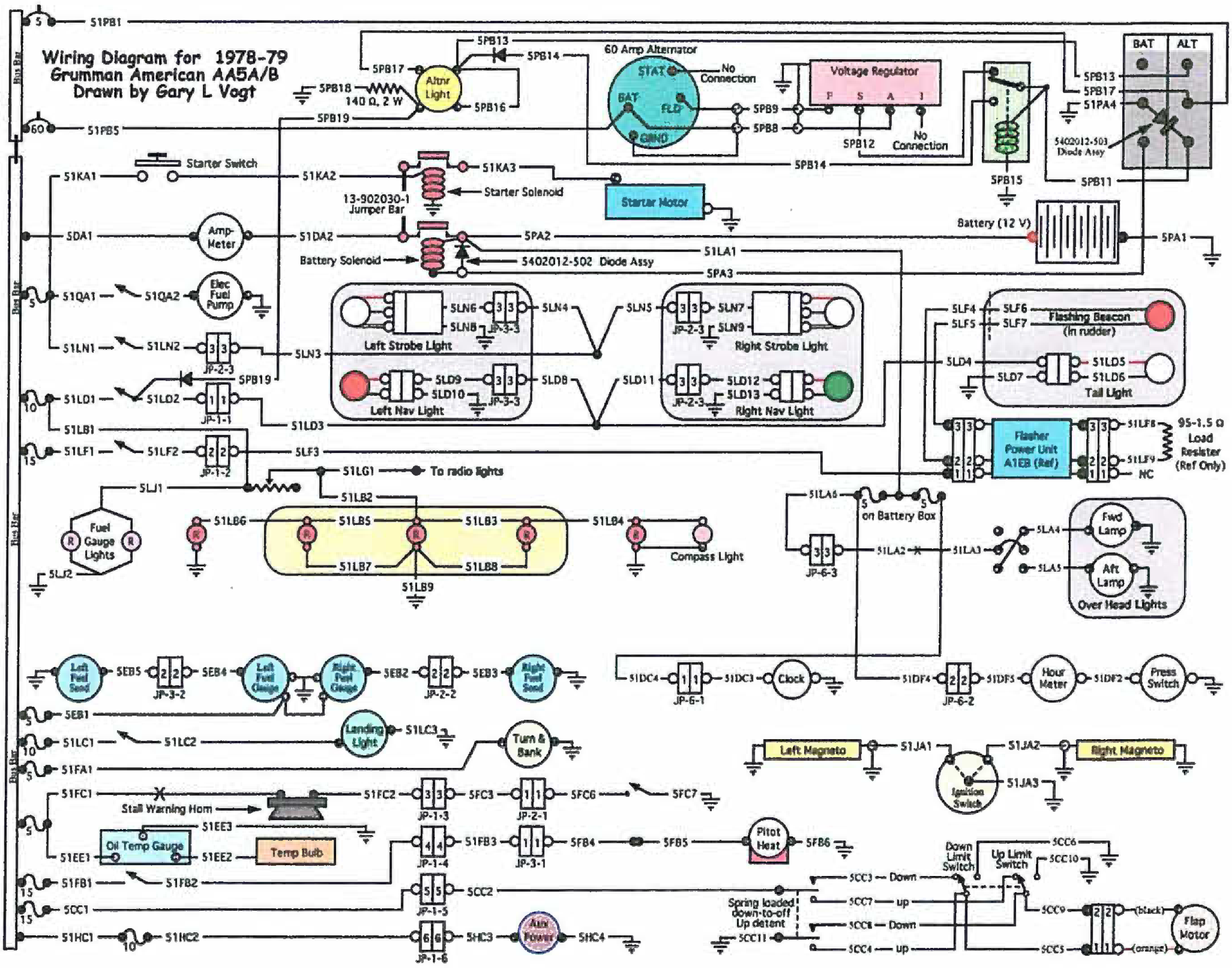


Figure 5-21. Block diagram.

FLOWCHARTS

Flowcharts are used to illustrate a particular sequence, or flow of events.

TROUBLESHOOTING FLOWCHART

Troubleshooting flowcharts are frequently used for the detection of faulty components. They often consist of a series of yes or no questions. If the answer to a question is yes, one course of action is followed. If the answer is no, a different course of action is followed. In this simple manner, a logical solution to a particular problem may be achieved. Another type of flowchart, developed specifically for analysis of digitally controlled components and systems, is the logic flowchart.

LOGIC FLOWCHART

A logic flowchart uses standardized symbols to indicate specific types of logic gates and their relationship to other digital devices in a system. Since digital systems make use of binary mathematics consisting of 1s and 0s, voltage or no voltage, a light pulse or no light pulse, and so forth, logic flowcharts consist of individual components that take an input and provide an output which is either the same as the input or opposite. By analyzing the input or multiple inputs, it is possible to determine the digital output or outputs. (***Figure 5-22***)

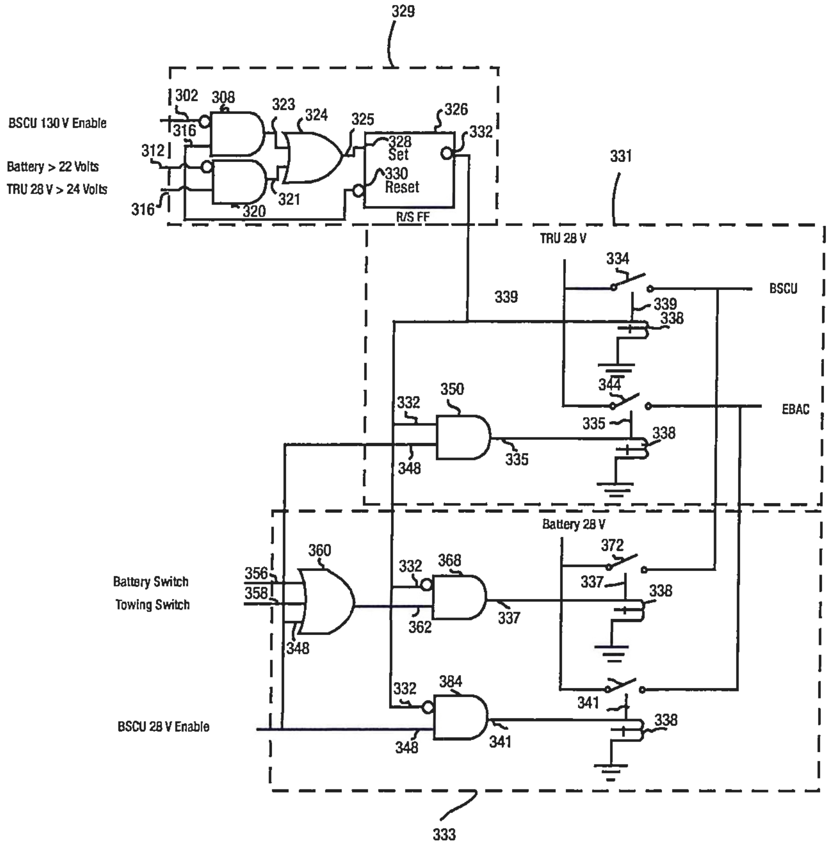


Figure 5-22. Logic flowchart.

LINES AND THEIR MEANINGS

Every drawing is composed of lines. Lines mark the boundaries, edges, and intersection of surfaces. Lines are used to show dimensions and hidden surfaces and to indicate centers. Obviously, if the same kind of line is used to show all of these variations, a drawing becomes a meaningless collection of lines. For this reason, various kinds of standardized lines are used on aircraft drawings.

These are illustrated in ***Figure 5-23***, and their correct uses are shown in ***Figure 5-24***.

Most drawings use three widths, or intensities, of lines: thin, medium, or thick. These lines may vary somewhat on different drawings, but there will always be a noticeable difference between a thin and a thick line, with the width of the medium line somewhere between the two.

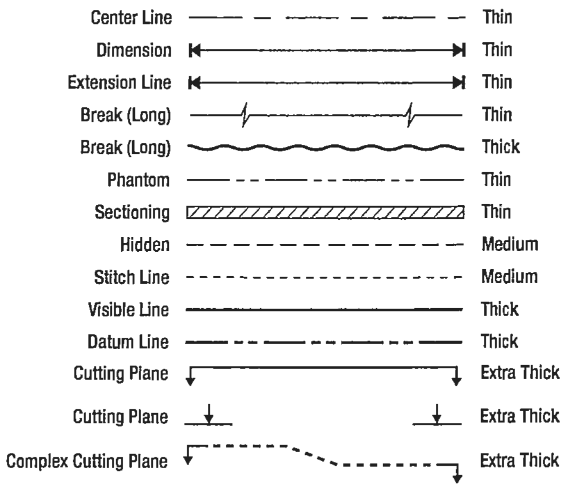


Figure 5-23. The meaning of lines.

CENTERLINES

Centerlines are made up of alternate long and short dashes. They indicate the center of an object or part of an object. Where centerlines cross, the short dashes intersect symmetrically. In the case of very small circles, the centerlines may be shown unbroken.

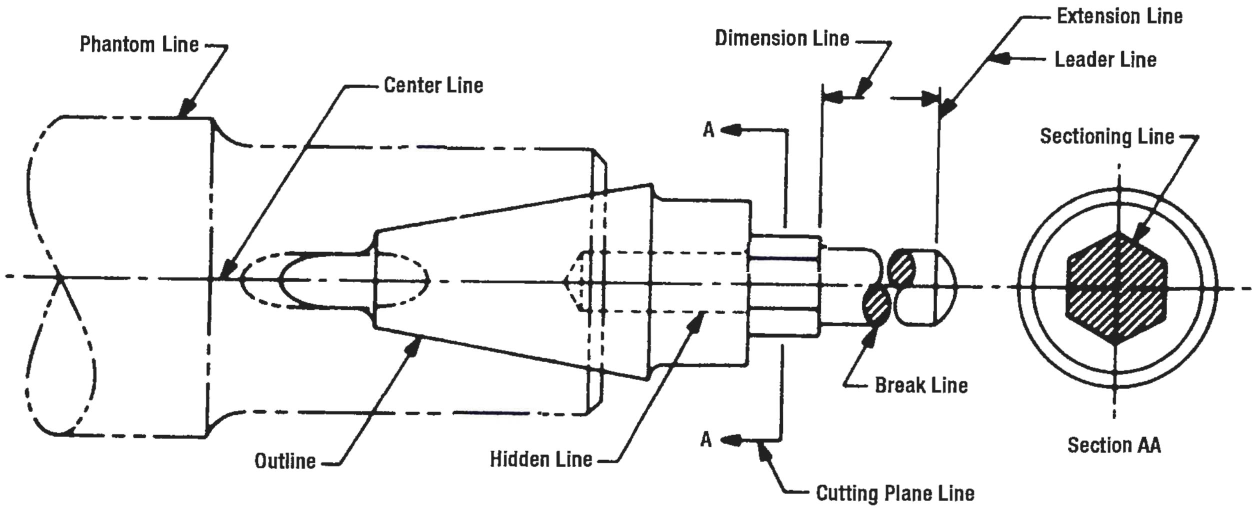


Figure 5-24. Correct use of lines.

DIMENSION LINES

A dimension line is a light solid line, broken at the midpoint for insertion of measurement indications, and having opposite pointing arrowheads at each end to show origin and termination of a measurement. They are generally parallel to the line for which the dimension is given, and are usually placed outside the outline of the object and between views if more than one view is shown.

All dimensions and lettering are placed so that they will read from left to right. The dimension of an angle is indicated by placing the degree of the angle in its arc. The dimensions of circular parts are always given in terms of the diameter of the circle and are usually marked with the letter D or the abbreviation DIA following the dimension. The dimension of an arc is given in terms of its radius and is marked with the letter R following the dimension. Parallel dimensions are placed so that the longest dimension is farthest from the outline and the shortest dimension is closest to the outline of the object. On a drawing showing several views, the dimensions will be placed upon each view to show its details to the best advantage.

In dimensioning distances between holes in an object, dimensions are usually given from center to center rather than from outside to outside of the holes. When a number of holes of various sizes are shown, the desired diameters are given on a leader followed by notes indicating the machining operations for each hole. If a part is to have three holes of equal size, equally spaced, this information is explicitly stated. For precision work, sizes are given in decimals. Diameters and depths are given for counterbored holes. For countersunk holes, the angle of countersinking and the diameters are given. Study the examples shown in ***Figure 5-25***.

The dimensions given for tolerances signifies the amount of clearance allowable between moving parts. A positive allowance is indicated for a part that is to slide or revolve upon another part. A negative allowance is one given for a force fit.

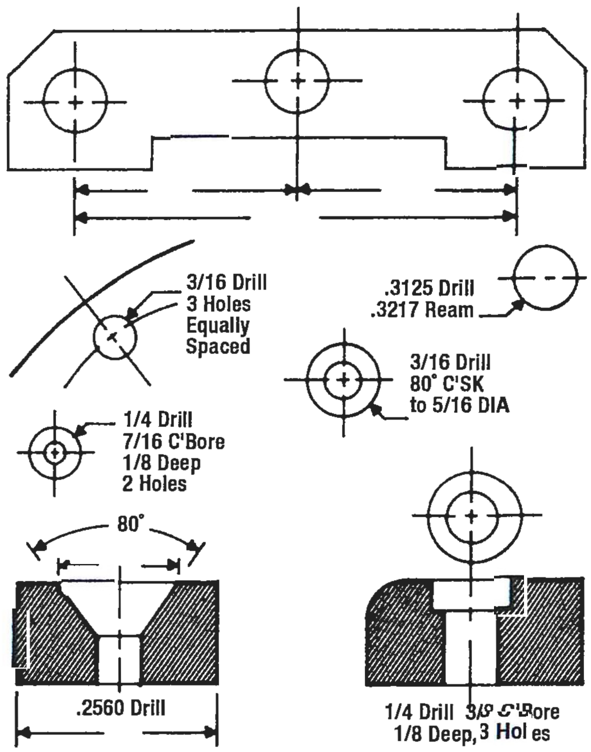


Figure 5-25. Dimensioning holes.

Whenever possible, the tolerance and allowances for desired fits conform to those set up in the American Standard for Tolerances, Allowances, and Gauges for Metal Fits. The classes of fits specified in the standard may be indicated on assembly drawings.

EXTENSION LINES

Extensions are used to extend the line showing the side or edge of a figure for the purpose of placing a dimension to that side or edge. They are very narrow and have a short break where they extend from the object and extend a short distance past the arrow of the dimensioning line.

SECTIONING LINES

Sectioning lines indicate the exposed surfaces of an object in sectional view. They are generally thin full lines but may vary with the kind of material shown in section. The example ***Figure 5-23*** indicates cast iron. Other examples are shown in ***Figure 5-26***.

PHANTOM LINES

Phantom lines, composed of one long and two short evenly spaced dashes, indicate the alternate position of parts of the object or the relative position of a missing part.

BREAK LINES

Break lines indicate that a portion of the object is not shown on the drawing. Short breaks are made by solid, freehand lines. For long breaks, solid ruled lines with zigzags are used. Shafts, rods, tubes, and other such parts which have a portion of their length broken out have the ends of the break drawn as indicated in ***Figure 5-24***.

LEADER LINES

Leader lines are solid lines with one arrowhead and indicate a part or portion to which a note, number, or other reference applies.

HIDDEN LINES

Hidden lines indicate invisible edges or contours. Hidden lines consist of short dashes evenly spaced and are frequently referred to as dash lines.

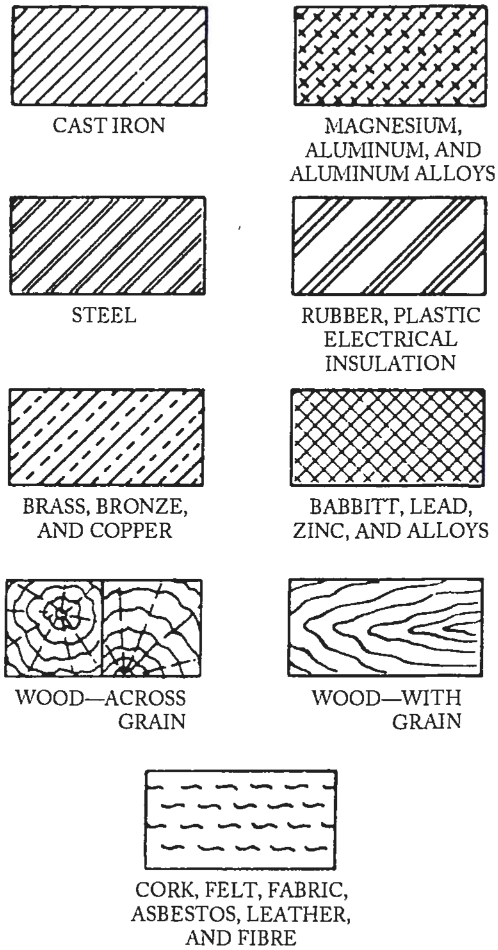


Figure 5-26. Standard material symbols.

OUTLINE OR VISIBLE LINES

The outline or visible line is used for all lines on the drawing representing visible lines on the object.

STITCH LINES

Stitch lines indicate stitching or sewing lines and consist of a series of evenly spaced dashes.

CUTTING PLANE AND VIEWING PLANE LINES

Cutting plane lines indicate the plane in which a sectional view of the object is taken. In ***Figure 5-24***, plane line A-A indicates the plane in which section A-A is taken. Viewing plane lines indicate the plane from which a surface is viewed.

DRAWING SYMBOLS

The drawings for a component are composed largely of symbols and conventions representing its shape and material. Symbols are the shorthand of drawing. They graphically portray the characteristics of a component with a minimal amount of drawing.

MATERIAL SYMBOLS

Section line symbols show the kind of material from which the part is to be constructed. The material may not be indicated symbolically if its exact specification is shown elsewhere on the drawing.

In this case, the more easily drawn symbol for cast iron is used for the sectioning, and the material specification is listed in the bill of materials or indicated in a note. ***Figure 5-26*** illustrates a few standard material symbols.

SHAPE SYMBOLS

Symbols can be used to excellent advantage when needed to show the shape of an object. Typical shape symbols used on aircraft drawings are shown in ***Figure 5-27.*** Shape symbols are usually shown on a drawing as a revolved or removed section.

ELECTRICAL SYMBOLS

Electrical symbols represent various electrical devices rather than an actual drawing of the units. Having learned what the various symbols indicate, it becomes relatively simple to look at an electrical diagram and determine what each unit is, what function it serves, and how it is connected in the system. (***Figure 5-28***)

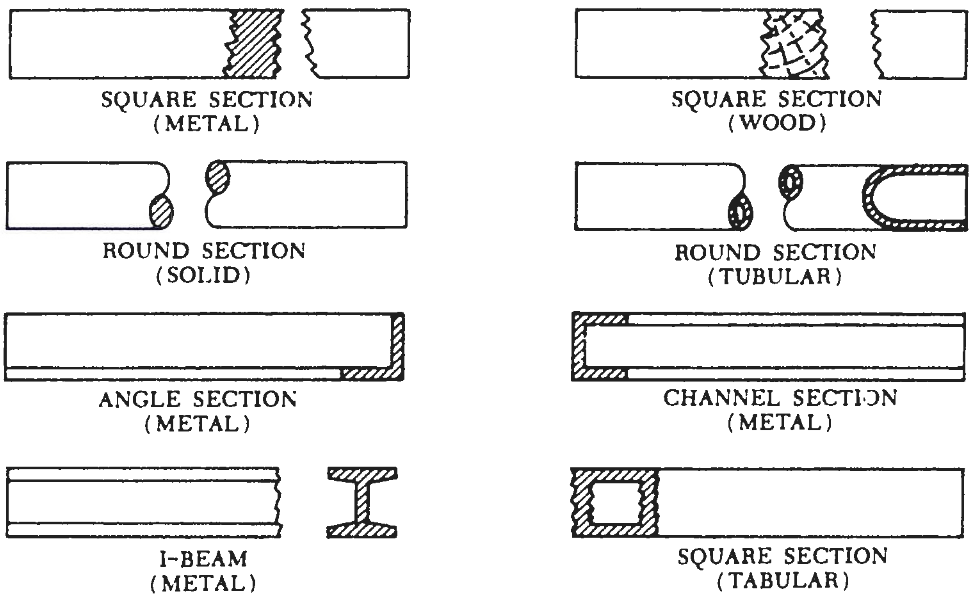


Figure 5-27. Shape symbols.

READING AND INTERPRETING DRAWINGS

Aircraft technicians do not necessarily need to be accomplished in making drawings. However, they must have a working knowledge of the information that is to be conveyed to them. They most frequently encounter drawings for construction and assembly of new aircraft and components, during modifications, and for making repairs.

A drawing cannot be read all at once any more than a whole page of print can be read at a glance. Both must be read a line at a time. To read a drawing effectively, follow a systematic procedure.

Upon opening a drawing, read the drawing number and the description of the article. Next, check the model affected, the latest change letter, and the next assembly

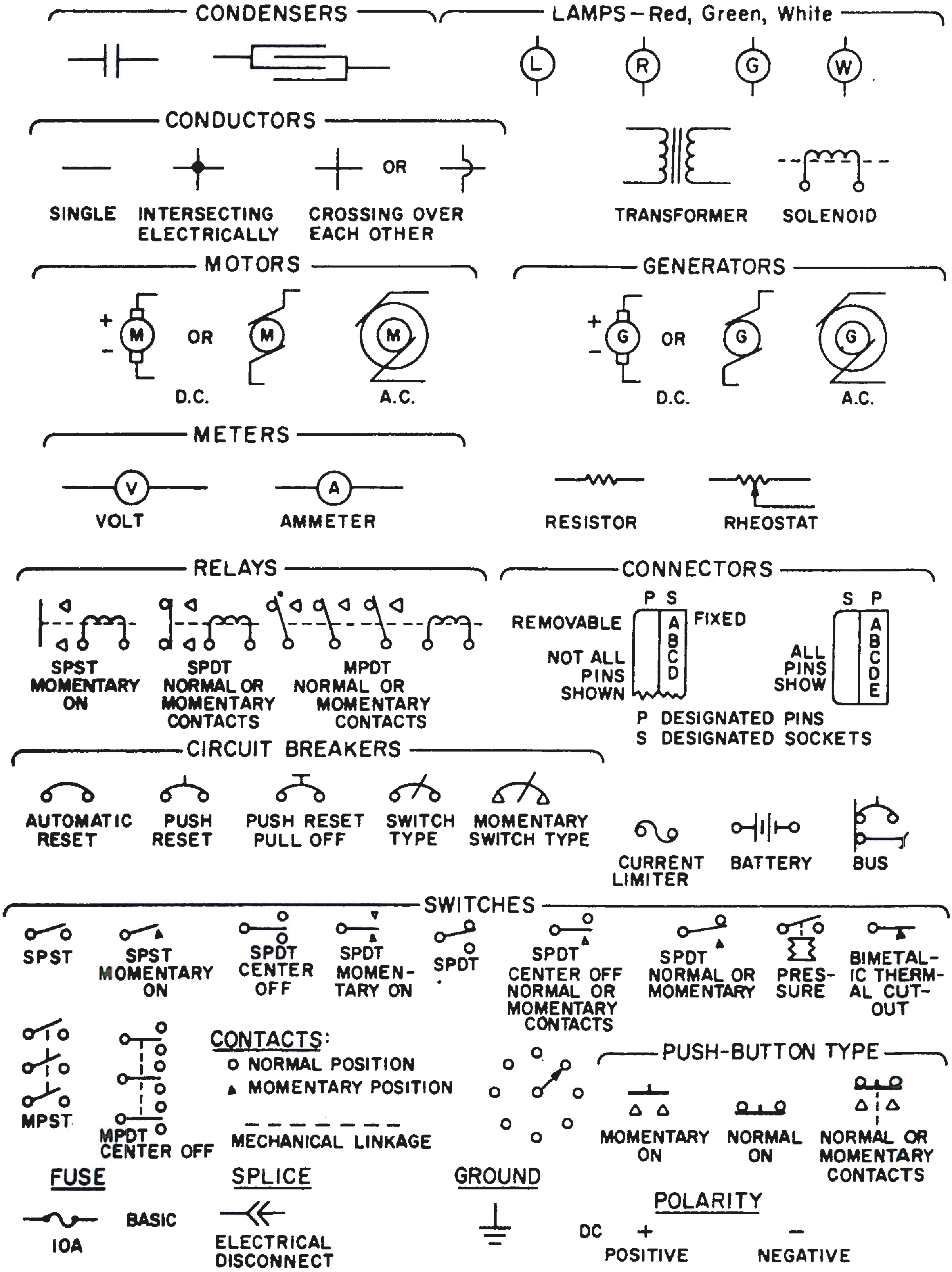


Figure 5-28. Electrical symbols.

listed. Having determined that the drawing is the correct one, proceed to read the illustration(s).

In reading a multi-view drawing, first get a general idea of the shape of the object by scanning all the views; then select one view for a more careful study. By referring back and forth to the adjacent view, it will be possible to determine what each line represents.

Each line on a view represents a change in the direction of a surface but another view must be consulted to determine what the change is. For example, a circle on one view may mean either a hole or a protruding boss, as in the top view of the object in ***Figure 5-29***. Looking at the top view, we see two circles; however, the other view must be consulted to determine what each circle represents.

A glance at the other view tells us that the smaller circle represents a hole, and the larger circle represents a protruding boss. In the same way, the top view must be consulted to determine the shape of the hole and the protruding boss.

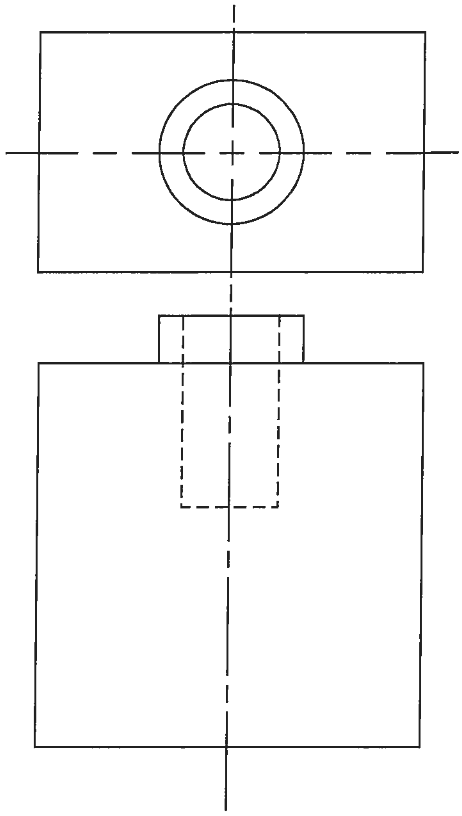


Figure 5-29. Reading views.

It can be seen from this example that one cannot read a print by looking at a single view when more than one view is given. Two views will not always describe an object and when three views are given, all three must be consulted to be sure the shape has been read correctly.

After determining the shape of an object, determine its size. Information on dimensions and tolerances is given so that certain design requirements may be met. Dimensions are indicated by figures either with or without the inch mark. If no inch mark is used, the dimension is in inches. It is customary to give part dimensions and an overall dimension that gives the greatest length of the part. If the overall dimension is missing, it can be determined by adding the separate part dimensions.

Drawings may be dimensioned in decimals or fractions. This is especially true in reference to tolerances. Instead of using plus and minus signs for tolerances, many figures give the complete dimension for both tolerances. For example, if a dimension is 2 inches with a plus or minus tolerance of 0.01, the drawing would show the total dimensions as:

2.01
1.99

A print tolerance (usually found in the title block) is a general tolerance that can be applied to parts where the dimensions are noncritical. Where a tolerance is not shown on a dimension line, the print tolerance applies. To complete the reading of a drawing, read the general notes and the contents of the material block, check and find the various changes incorporated, and read the special information given in or near views and sections.

DRAWING SKETCHES

A sketch is a simple rough drawing that is made rapidly and without much detail. Sketches may take many forms—from a simple pictorial presentation to a multi-view orthographic projection. Just as aircraft technicians need not be highly skilled in making drawings, they need not be accomplished artists. However, in many situations, they will need to prepare a drawing to present an idea for a new design, a modification, or a repair method. The medium of sketching is an excellent way of accomplishing this. The rules and conventional practices for making mechanical drawings are followed to the extent that all views needed to portray an object accurately are shown in their proper relationship. It is also necessary to observe the rules for correct line use (*Figures 2-23 and 2-24*) and dimensioning.

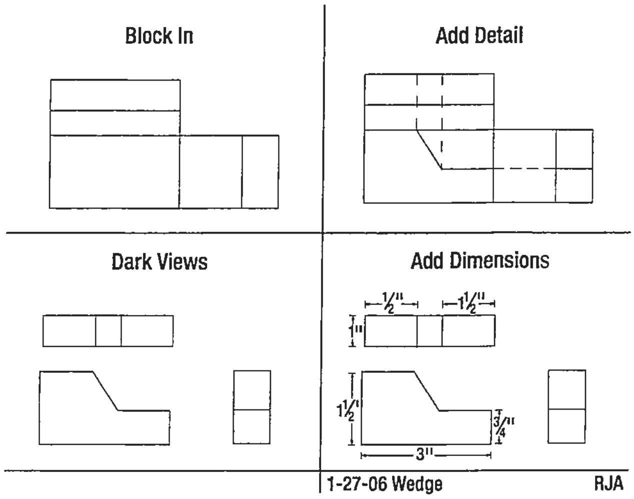


Figure 5-30. Steps in sketching.

SKETCHING TECHNIQUES

To make a sketch, first determine what views are necessary to portray the object; then block in the views, using light construction lines. Next, complete the details, darken the object outline, and sketch extension and dimension lines. Complete the drawing by adding notes, dimensions, title, date, and when necessary, the sketcher's name. The steps in making a sketch of an object are illustrated in ***Figure 5-30***.

BASIC SHAPES

Depending on the complexity of the sketch, basic shapes such as circles and rectangles may be drawn in freehand or by use of templates. If the sketch is quite complicated or the technician is required to make frequent sketches, use of a variety of templates and other drafting tools is highly recommended.

REPAIR SKETCHES

A sketch is frequently drawn for repairs or for use in manufacturing a replacement part. Such a sketch must provide all necessary information to those persons who must make the repair or manufacture the part. The degree to which a sketch is complete will depend on its intended use. Obviously, a sketch used only to represent an object pictorially need not be dimensioned. If a part is to be manufactured from the sketch, it should show all the necessary construction details.

CARE OF DRAFTING INSTRUMENTS

Good drawing instruments are expensive precision tools. Reasonable care given to them during their use and storage will prolong their service life.

T-squares, triangles, and scales should not be used or placed where their surfaces or edges may be damaged. Use a drawing board only for its intended purpose and not in a manner that will mar the working surface.

Compasses, dividers, and pens will provide better results with less annoyance, if they are correctly shaped and sharpened and are not damaged by careless handling.

Store drawing instruments in a place where they are not likely to be damaged by contact with other tools or equipment. Protect compass and divider points by inserting them into a piece of soft rubber or similar material. Never store ink pens without first cleaning and drying them thoroughly.

GRAPHS AND CHARTS

Graphs and charts are frequently used to convey information graphically or information given certain conditions. They often utilize values shown on the x and y axes that can be projected up and across to arrive at a specific result. Also, when data is entered into a computer database, software programs can create a variety of different bar graphs, pie charts, and so forth, to graphically represent that data.

READING AND INTERPRETING GRAPHS AND CHARTS

When interpreting information shown on graphs and charts, it's extremely important that all the notes and legend information be carefully understood in order to eliminate any misinterpretation of the information.

NOMOGRAMS

A nomogram is a graph that usually consists of three sets of data. Knowledge of any two sets of data enables the interpreter to obtain the value for the third unknown corresponding value. One type of nomogram consists of three parallel scales graduated for different variables so that when a straight edge connects any two values, the third can be read directly. Other types may use values on the x and y axes of a graph with the third corresponding value determined by the intersection of the x and y values with one of a series of curved lines.

Figure 5-31 is an example of a nomogram that shows the relationship between aviation fuels, specific weight, and temperature.

Density Variation of Aviation Fuel

Based on Average Specific Gravity

Fuel	Average Specific Gravity ar 15 °C (59 °F)
Aviation Kerosene Jet A and Jet A1	.812
Jet B (JP-4)	.785
AV Gas Grade 100/130	.703

Note: The fuel quantity indicator is calibrated for correct indication when using Aviation Kerosene Jet A and Jet A1. When using other fuels, multiply the indicated fuel quantity in pounds by .99 for Jet B (JP-4) or by .98 for Aviation Gasoline (100/130) to obtain actual fuel quantity in pounds.

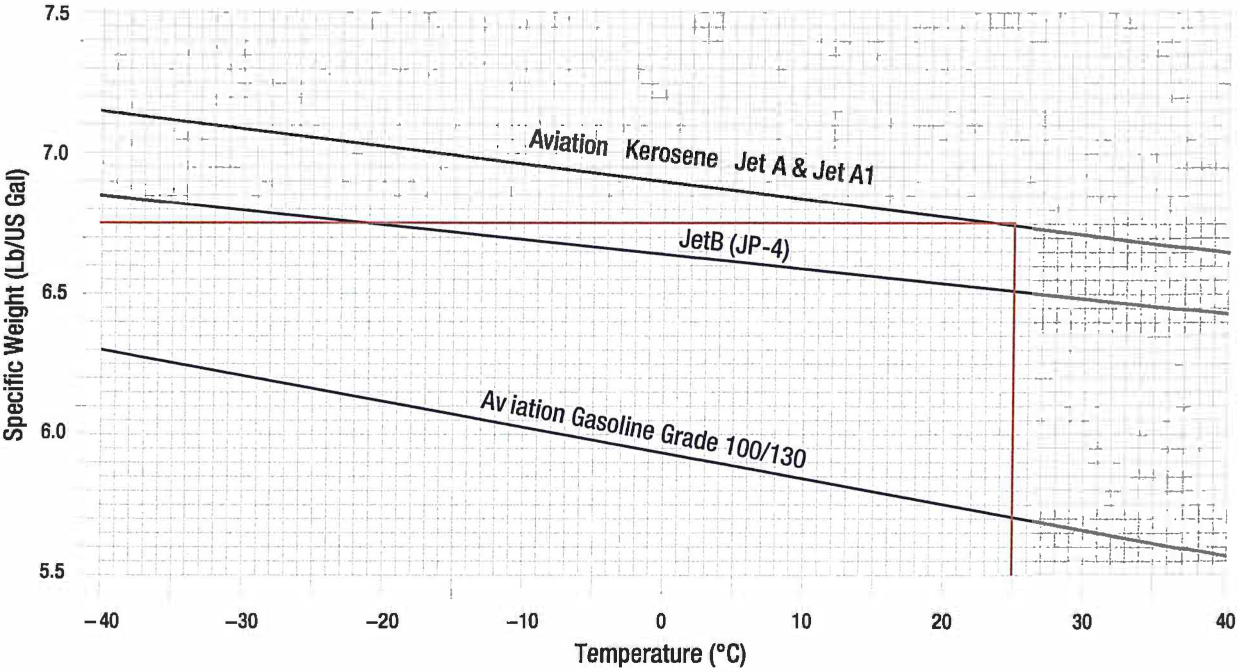


Figure 5-31. Nomogram.

MICROFILM AND MICROFICHE

The practice of recording drawings, parts catalogs, and maintenance and overhaul manuals on microfilms was utilized extensively in the past. Microfilm is available as regular 16 mm or 35 mm film. Since 35 mm film is larger, it provides a better reproduction of drawings. Microfiche is a card with pages laid out in a grid format. Microfilm and microfiche require use of special devices for both reading and printing the information.

Most modern aircraft manufacturers have replaced microfilm and microfiche with digital storage methods utilizing CDs, DVDs and other data storage devices. A great deal of service and repair information for older aircraft has been transferred to digital storage devices. However, there may still be a need to access information using the old methods. A well-equipped shop should have available, both the old microfilm and microfiche equipment, as well as new computer equipment.

DIGITAL IMAGES

Though not a drawing, a digital image created by a digital camera can be extremely helpful to aviation maintenance technicians in evaluating and sharing information concerning the airworthiness or other information about aircraft. Digital images can be rapidly transmitted over the World Wide Web as attachments to e-mail messages. Images of structural fatigue cracks, failed parts, or other flaws, as well as desired design and paint schemes, are just a few examples of the types of digital images that might be shared by any number of users over the Internet.

Figure 5-32 is a digital image of impact damage to a composite structure taken with a simple digital camera. To provide information about the extent of the damage, a measurement scale, or other object, such as a coin, can be placed near the area of concern before the picture is taken. Also, within the text of the e-mail, the technician should state the exact location of the damage, referenced to fuselage station, wing station, and so forth.

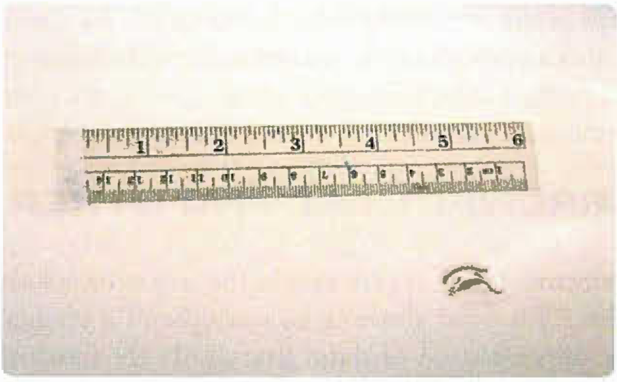


Figure 5-32. Digital image of impact damage.

ATA 100 AND iSPEC 2200

In an effort to standardize the format for the way in which maintenance information is presented in aircraft maintenance manuals, the Air Transport Association of America (ATA) issued specifications for Manufacturers Technical Data. The original specification was called ATA Spec 100. It prescribes classification of maintenance data subjects by standardized numbered chapters. Within each chapter, a standardized sub-system numbering system is used to organize the details of the major topic covered by a particular chapter. Manufacturers arrange their maintenance manuals to fall under this numbering system. Technicians, therefore, need not learn a new system of organizing data for each manufacturer.

The following illustrates the organization of an ATA 100 chapter. In this case, the chapter subject is air conditioning. Air conditioning is always presented in Chapter 21 under the ATA 100 spec. It doesn't matter whether it's in a Boeing manual, or Airbus manual, Bombardier or Gulfstream, Chapter 21 in the maintenance manuals will always deal with air conditioning. Additionally, standardized subtopic categories are numbered as shown and are always organized as such. (***Figure 5-33***)

Further division of the subtopic subject matter occurs by changing the right-most digit of the subtopic number pair. Then, after the subtopic category, another dash number occurs. This is the page number. Page blocks are reserved for subject matter as shown in ***Figure 5-34.***

CHAPTER 21 - AIR CONDITIONING	
21 - 00	General
21 - 10	Compression
21 - 20	Distribution
21 - 30	Pressurization Control
21 - 40	Heating
21 - 50	Cooling
21 - 60	Temperature Control
21 - 70	Moisture/Air Contaminate Control

Figure 5-33. Standard ATA Spec 100 sub-topic numbering.

PAGE TOPIC	PAGE BLOCK RESERVED
Description and Operation	1 - 100
Troubleshooting	101 - 200
Maintenance Practices	201 - 300
Servicing	301 - 400
Removal and Installation	401 - 500
Adjustment/Test	501 - 600
Inspection Test	601 - 700
Cleaning/Painting	701 - 800
Approved Repairs	801 - 900

Figure 5-34. ATA Spec page blocks.

Thus, 21-30-06 represents Page 06 of Description and Operation information on Pressurization Control of air conditioning systems.

Over the years, Spec 100 has been continuously revised and updated. Eventually, ATA Spec 2100 was developed for electronic documentation. These two specifications evolved into one document called ATA iSpec 2200. This is the latest organization standard. As a result of this standardization, maintenance technicians can always find information regarding a particular system in the same section of an aircraft maintenance manual, regardless of manufacturer. ***Figure 5-35***, shows the system titles of ATA Spec 100/i2200 with subsystems deleted in the interest of brevity. Consult any aircraft maintenance manuals for a complete description of the subsystems used in them. Note that the first 4 chapters are reserved for airline use.

Keep in mind that not all aircraft will have all these systems installed. Small and simple aircraft have far fewer systems than larger more complex aircraft.

AERONAUTICAL AND OTHER STANDARDS

Numerous standards are used in the aerospace industry. The ATA spec above is an example of a standard for organization of data. Standards for hardware manufacturing are common. They ensure that aircraft will perform as designed when hardware is replaced. Standards of all kinds are designed to provide the framework for compatible technology and procedures worldwide.

Most countries have government or quasi-government institutions that develop standards in various industries. These organizations play a vital role in facilitating business as well as technology. International standards are now in great development due to transportation and communication having made the world a "smaller place". Economies are intermingled and countries with formerly independent standards are under pressure to adapt to universal world-wide standards for doing things. EASA itself is an example of a movement towards the benefits of standardization in certification and workmanship.

ISO

The International Organization for Standardization (ISO) is one of the world's largest developers of global standards. It is an institution comprised of the national standards organizations from 156 member countries around the world. Most countries are ISO members. ISO works through technical committees made up of expert representatives from business, trade associations, government, academia, consumer and other groups.

Consensus is gathered from all committee members to adopt a set of standards. Public review before adoption is part of a protocol that tries to ensure all interested parties can contribute. ISO published standards are voluntary however, members comply because they recognize the benefits to industry and trade from established standards.

ISO standards contribute to making the development, manufacturing and supply of products and services more efficient, safer and cleaner. They make trade between countries easier and fairer. They provide governments with a technical base for health, safety and environmental legislation. They aid in transferring technology to

System Titles of ATA SPEC 100/i2200 with Subsystems Deleted			
05	TIME LIMITS/MAINTENANCE CHECKS	49	AIRBORNE AUXILIARY POWER
06	DIMENSIONS & AREAS	51	STRUCTURES
07	LIFTING & SHORING	52	DOORS
08	LEVELING & WEIGHING	53	FUSELAGE
09	TOWING & TAXING	54	NACELLES/PYLONS
10	PARKING, MOORING, STORAGE & RETURN TO SERVICE	55	STABILIZERS
11	PLACARDS AND MARKINGS	56	WINDOWS
12	SERVICING	57	WINGS
18	VIBRATION AND NOISE ANALYSIS (HELICOPTER ONLY)	61	PROPELLERS
22	AUTO FLIGHT	65	ROTORS
23	COMMUNICATIONS	71	POWER PLANT
24	ELECTRICAL POWER	72	(T) TURBINE/TURBOPROP
25	EQUIPMENT/FURNISHINGS	72	(R) ENGINE RECIPROCATING
26	FIRE PROTECTION	73	ENGINE FUEL AND CONTROL
27	FLIGHT CONTROLS	74	IGNITION
28	FUEL	75	BLEED AIR
29	HYDRAULIC POWER	76	ENGINE CONTROLS
30	ICE AND RAIN PROTECTION	77	ENGINE INDICATING
31	INDICATING/RECORDING SYSTEMS	78	ENGINE EXHAUST
32	LANDING GEAR	79	ENGINE OIL
33	LIGHTS	80	STARTING
34	NAVIGATION	81	TURBINES (RECIPROCATING ENGINE)
35	OXYGEN	82	WATER INJECTION
36	PNEUMATIC	83	REMOTE GEAR BOXES
37	VACUUM/PRESSURE	84	PROPULSION AUGMENTATION
38	WATER/WASTE	85	FUEL CELL SYSTEMS
39	ELECTRICAL/ELECTRONIC PANELS	91	CHARTS
40	MULTIPURPOSE COMPONENTS		

Figure 5-35. ATA maintenance manual chapter subject numbering system.

developing countries. ISO standards also serve to safeguard consumers, and users in general, of products and services, as well as to make their lives simpler.

The EASA aviation maintenance professional is exposed to a great deal of the standardization work of the ISO. Other standards are also of day to day concern for EASA technicians. Many hardware standards in aviation are rooted in widespread usage by the United States military and their adoption by US aircraft manufacturers. AN, MS, NAS and MIL specifications hardware were all developed this way:

AN (Army/Navy)

The AN system is one of the most widely used standards in aircraft hardware. It was developed, together with the MS system, by the US military to ensure quality and uniformity. Items manufactured to this standard are not limited to the military and are found in all classifications of aircraft.

MS (Military Standard)

This standard was developed by the military and found its way into all aspects of aviation. The MS and MIL (military) standard incorporate most of the same hardware as the AN system. Cross referencing may allow the substitution of MS hardware for AN hardware (and visa versa). Caution must be exercised to ensure any hardware substituted is indeed a proper replacement with all important characteristics of the original hardware intact.

NAS (National Aerospace Standard)
This standard is based on approval of military hardware for the civilian aerospace industry.

BS (British Standards)
These are controlled by the British Standards Institution (BSI). The BSI represents the United Kingdom on matters pertaining to ISO. It is a national standards institute that has standards for hardware, codes of practice, and much more. The wide proliferation of British influence in aviation makes this a common standard.

Question: 5-1
List the 4 basic types of drawings.
1.
2.
3.
4.

Question: 5-2
A ________________ drawing shows an object as it appears to an observer.

Question: 5-3
________________ diagrams are used mainly in troubleshooting.

Question: 5-4
List 8 pieces of information always contained in the title block of a drawing.

1.
2.
3.
4.
5.
6.
7.
8.

Question: 5-5
A line indicates that a portion of the object is not shown on the drawing.

Question: 5-6
A ________________ line is composed of one long and two short evenly spaced dashes.

Question: 5-7
An ________________ view uses a combination of views of an orthographic projection and tilts the object forward so that portions of all three views can be seen in one view.

Question: 5-8
The process in which a computer is used in the design and drafting process is known as ________________.

ANSWERS

Answer: 5-1
detailed
assembly
installation
sectional view.

Answer: 5-2
pictorial.

Answer: 5-3
schematic.

Answer: 5-4
drawing number
name of part
scale
date
firm name
name of draftsman
name of checker
name of person approving drawing

Answer: 5-5
break line.

Answer: 5-6
phantom.

Answer: 5-7
isometric.

Answer: 5-8
CAD; Computer Aided Drafting.

MAINTENANCE PRACTICES

FITS AND CLEARANCES

SUB-MODULE 06

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 06 FITS AND CLEARANCES Knowledge Requirements		
7.6 - Fits and Clearances Drill sizes for bolt holes, classes of fits; Common system of fits and clearances; Schedule of fits and clearances for aircraft and engines; Limits for bow, twist and wear; Standard methods for checking shafts, bearings and other parts.	2	1

Level 1
A familiarization with the principal elements of the subject.

Objectives:
(a) The applicant should be familiar with the basic elements of the subject.
(b) The applicant should be able to give a simple description of the whole subject, using common words and examples.
(c) The applicant should be able to use typical terms.

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

FITS AND CLEARANCES

DRILL SIZES FOR HOLES

The size of hole to be drilled depends upon the purpose of that hole. A hole drilled for a rivet with a specific diameter would differ from those drilled to take a screw thread, or the plain shank of a bolt, of the same diameter. Similarly, the size of a hole which is to accommodate a shaft will depend on the size of the shaft and on the manner in which the hole/shaft combination is to be used. Additionally, if the hole is to be reamed, then it must be drilled slightly smaller than its nominal size, to allow for the metal removed by the reamer.

Drill sizes (as discussed in the Tools topic) are fixed and can be found on charts that list each standard drill size, together with other columns such as clearance and tapping sizes. These charts may also include equivalent sizes displayed in metric, fractional, letter and in the number/letter system.

CLASSES AND STANDARDS OF FITS AND CLEARANCES

CLASSES OF FIT

The relationship between the bolt hole and the bolt, for example, determines the classification of fit. Three basic classes of fit are:

- Clearance Fit - A clearance fit is one having limits of size defined such that a clearance always results when mating parts are assembled.
- Interference Fit - An interference fit is one having limits of size so prescribed that an interference always results when mating parts are assembled.
- Transition Fit - A transition fit is one having limits of size so prescribed that either a clearance or an interference may result when mating parts are assembled. (***Figure 6-1***)

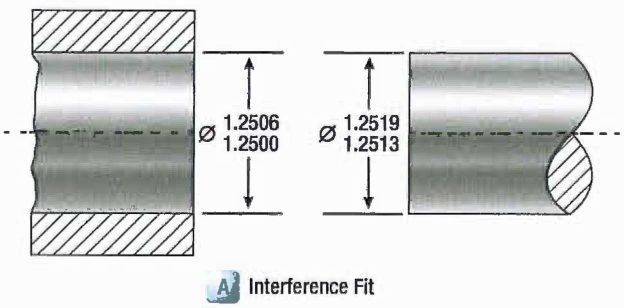
STANDARDS OF FITS AND CLEARANCES

To ensure consistent specifications, various standard fits have been devised around the world. The British Standards System (BS 1916-1 & 2:1953 and 3:1963) devised by the British Standards Institute (BSI) has a comprehensive system designed to cater for all classes of work.

The system provides for 21 types of holes designated by capital letters A,B,C,D, etc., and 21 types of shaft designated by small letters:- a,b,c,d, etc., from nominal diameters of 0.04 inch up to 19.69 inches. Each type of hole or shaft is provided with 16 grades of accuracy designated by numbers 1-16.

The ISO 286 standard established by the International Organization for Standardization
(ISO) is very similar to that of the BS, except that the system provides for 28 types for holes and shafts with 20 grades of accuracy.

In the United States, The American National Standards Institute (ANSI) has also developed standards. The ANSI standards for metric fits and clearances follows the ISO standard. For Imperial based units (inches), it uses symbols such as RCx for running and sliding fits and FNx for force and shrink fits.



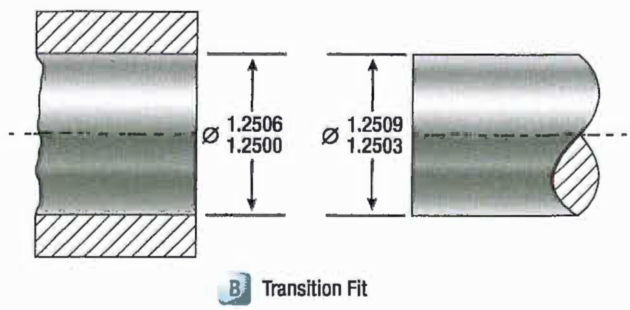


Figure 6-1. Interference and transition fit examples.

NEWALL SYSTEM

In the early Newall hole-based system of limits, the holes are classified as Class A and Class B fits. Class A holes are manufactured to a closer tolerance than are Class B holes. ***Figure 6-2*** shows how the shafts are classified, using the letters F, P, D, X, Y, and Z.

Class of Fit	Type of Fit	Remarks
Interference F	Force	Mechanical pressure is required for assembly and, once assembled, no dismantling is likely to be required.
D	Driving	These are a little less tight than Force Fit and one part can be driven into the other.
Transition P	Push	Slight manual effort is required to assemble the parts. Suitable for detachable or locating parts but not for moving parts.
Clearance X, Y, Z	Running	Suitable for various types of moving parts. Class Z provides the finest fit.

Figure 6-2. Newall system of fits.

BRITISH STANDARDS BS 4500 SYSTEM

The British Institute has now produce a British Standard Specification 4500. This is a system of limits based on standard sized holes and the various fits are obtained by using shafts of varying sizes. This permits the use of standard hole manufacturing tools i.e. drills, reamers, etc. The varying shaft sizes are easily obtained by normal manufacturing processes.

It can be seen that in an Interference Fit, the upper and lower limits of the shaft are greater than the corresponding limits of the hole and, thus, force is necessary to achieve the fit.

In the Transition Fit, the differences in the upper and lower limits of both items are negligible so that only light effort is required to insert the shaft into the hole. The upper and lower limits of the shaft, in a Clearance Fit, are always less than those of the hole, so that the shaft moves easily within the hole.

The following BS 4500 definitions are used to interpret ***Figure 6-3*** which illustrates the difference between a clearance, transition and interference fit.

Figure 6-4 illustrates BS4500 fits in table format.

BS 4500 Definitions:

- The 'upper limit' is the largest size allowed.
- The 'lower limit' is the smallest size allowed.
- The 'tolerance' is the difference between the upper and lower limit.

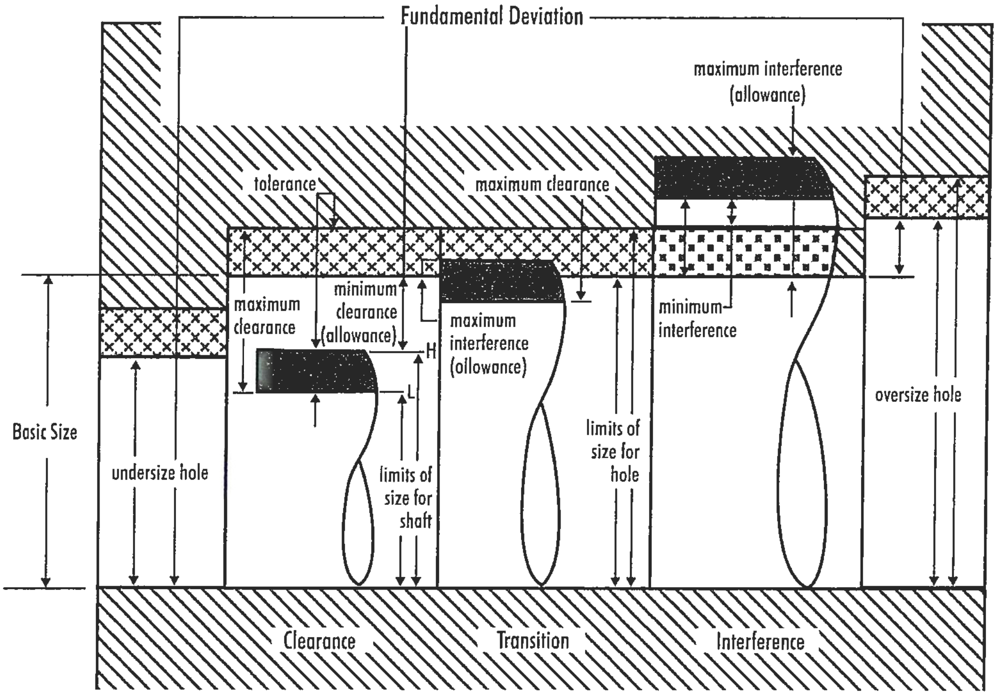


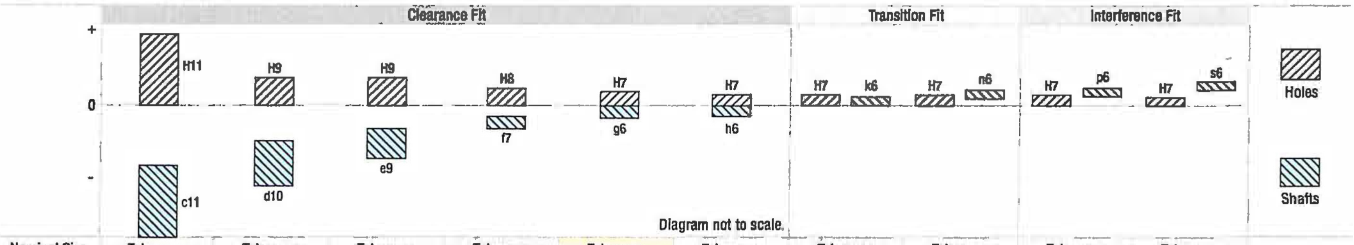
Figure 6-3. Disposition of limits and tolerances (Basic hole).

Recreated by
Aircraft Technical Book Company

BRITISH STANDARD

SELECTED ISO FITS—HOLE BASIS

Data Sheet
4500A



Nominal Size		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance		Tolerance			
Over	To	H11	c11	H9	d10	H9	e8	H8	f7	H7	g6	H7	h6	H7	k6	H7	n6	H7	p6	H7	s6	Over	To
mm	mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	0.001 mm	mm	mm
-	3	60 0	-60 -120	25 0	-20 -60	25 0	-14 -39	14 0	-6 -16	10 0	-2 -8	10 0	-6 0	10 0	6 0	10 0	10 4	10 0	12 6	10 0	20 14	-	3
3	6	75 0	-70 -145	30 0	-30 -78	30 0	-20 -50	18 0	-10 -22	12 0	-4 -12	12 0	-8 0	12 0	9 1	12 0	16 8	12 0	20 12	12 0	27 19	3	6
6	10	90 0	-80 -170	36 0	-40 -98	36 0	-25 -61	22 0	-13 -28	15 0	-5 -14	15 0	-9 0	15 0	10 1	15 0	19 10	15 0	24 15	15 0	32 23	6	10
10	18	110 0	-95 -205	43 0	-50 -120	43 0	-32 -75	27 0	-16 -34	18 0	-6 -17	18 0	-11 0	18 0	12 1	18 0	23 12	18 0	29 18	18 0	39 28	10	18
18	30	130 0	-110 -240	52 0	-65 -149	52 0	-40 -92	33 0	-20 -41	21 0	-7 -20	21 0	-13 0	21 0	15 2	21 0	28 15	21 0	35 22	21 0	48 35	18	30
30	40	160 0	-120 -280	62	-80	62	-50	39	-25	25	-9	25	-16	25	18	25	33	25	42	25	59	30	40
40	50	160 0	-130 -290	0	-180	0	-112	0	-50	0	-25	0	0	0	2	0	17	0	26	0	7	40	50
50	65	190 0	-140 -330	74	-100	74	-60	46	-30	30	-10	30	-19	30	21	30	39	30	51	30 0	72 53	50	65
65	80	190 0	-150 -340	0	-220	0	-134	0	-60	0	-29	0	0	0	2	0	20	0	32	30 0	78 59	65	80
80	100	220 0	-170 -390	87	-120	87	-72	54	-36	35	-12	35	-22	35	25	35	45	35	59	35 0	93 91	80	100
100	120	220 0	-180 -400	0	-260	0	-159	0	-71	0	-34	0	0	0	3	0	23	0	37	35 0	101 79	100	120
120	140	250 0	-200 -450	100	-145	100	-84	63	-43	40	-14	40	-25	40	28	40	52	40	68	40 0	117 92	120	140
140	160	250 0	-210 -460																	40 0	125 100	140	160
160	180	250 0	-230 -480	0	-305	0	-185	0	-83	0	-39	0	0	0	3	0	27	0	43	40 0	133 108	160	180
180	200	290 0	-240 -530	115	-170	115	-100	72	-50	46	-15	46	-29	46	33	46	60	46	79	46 0	151 122	180	200
200	225	290 0	-260 -550																	46 0	159 130	200	225
225	250	290 0	-280 -570	0	-355	0	-215	0	-96	0	-44	0	0	0	4	0	31	0	50	46 0	169 140	225	250
250	280	320 0	-300 -620	130	-190	130	-110	81	-56	52	-17	52	-32	52	36	52	66	52	88	52 0	190 158	250	280
280	315	320 0	-330 -650	0	-400	0	-240	0	-108	0	-49	0	0	0	4	0	34	0	56	52 0	202 170	280	315
315	355	360 0	-360 -720	140	-210	140	-125	89	-62	57	-18	57	-36	57	40	57	73	57	98	57 0	226 190	315	355
355	400	360 0	-400 -760	0	-440	0	-265	0	-119	0	-54	0	0	0	4	0	37	0	62	57 0	244 208	355	400
400	450	400 0	-440 -840	155	-230	155	-135	97	-68	63	-20	63	-40	63	45	63	80	63	108	63 0	272 232	400	450
450	500	400 0	-480 -880	0	-480	0	-290	0	-131	0	-60	0	0	0	5	0	40	0	68	63 0	292 252	450	500
		Slack Fit		Loose Fit		Easy Fit		Normal Fit		Close Fit		Slide Fit		Push Fit		Drive Fit		Press Fit		Force Fit			

Figure 6-4. Selected ISO Fits (BS-4500) - Hole Basis.

Where variation either side of the nominal dimension can occur, the tolerance is called bilateral. Where one tolerance is zero, the tolerance is said to be unilateral.

- *Deviation*: the difference between a size and the corresponding basic or nominal size.
- *Fit*: the working condition between a mating shaft and hole.
- *Clearance*: shaft always smaller than the hole - allows movement.
- *Transition*: may provide either clearance or interference - keys and keyways.
- *Interference*: shaft always bigger than the hole.
- *International Tolerance Grade (IT)*: numbers which for a particular IT number has the same relative level of accuracy but vary depending upon the nominal or basic size.
- *Hole Basis*: a system of fits relating to basic or nominal hole size. Fundamental deviation is "H".
- *Shaft Basis*: a system of fits relating to basic or nominal shaft size. Fundamental deviation is "h".

Deviations for holes are indicated by capital letters and deviations for shafts by lower case. Although there are 18 defined tolerance grade bands for each size group, only IT6 to IT11 are used for preferred fits (smaller grade numbers indicate a smaller tolerance zones).

Tolerance position letters' are used, capitals for hole (internal) dimensions and lower case for shaft (external) dimensions and these indicate the 'fundamental deviation' which locates the tolerance zone relative to the basic or nominal size.

Example: A 20 mm nominal diameter journal/shaft is to have a clearance, but close accurate running fit. Within what size tolerances should the parts be manufactured?

Use the 'basic hole system'.

Solution: A H8/f7 fit is suitable. From the British Standards chart, for a 20 mm diameter nominal size the H8 limits are +0.033 and -0.000mm and the f7 limits are -0.020 and -0.041mm.

Hence the hole diameter should be between 20.000 and 20.033 mm and the shaft diameter should be between 19.959 and 19.980 mm.

BS 4500 Basic Hole System

1. Hole will be machined with a standard sized tool.
2. Determine type of fit necessary. Use fit table or otherwise determine allowance.
3. Apply tolerances using hole size as basic dimension (*Figure 6-5*).

BS 4500 BASIC SHAFT SYSTEM

The BS 4500 basic shaft system is less commonly used than the basic hole system. It is usually used when many parts will fit on a standard shaft. Shaft size is basic dimension. (*Figure 6-6*)

BASIC HOLE METHOD - METRIC

The 18 International Tolerances (IT) grades vary according to the basic size. H indicates a tolerance for hole base, F is for shaft base. (*Figure 6-7*)

BS 4500 also defines the following types of fit:

- Easy running - H7/e8
- Normal running - H7/f7
- Slide-H7/g6
- Location - H7/h6
- Push-H7/k6
- Light press - H7/p6
- Heavy press - H7/s6

DIMENSIONS, ALLOWANCES AND TOLERANCES

In hand and machine fitting the term fitting means putting parts together so that they touch or join with each other in such a way that either one part will turn inside another; one will slide upon another; or that the parts will hold tightly together so that they cannot move upon each other.

To achieve the particular type of fit required, the parts may be machined, filed, ground lapped or scraped. Examples of fitted parts are shafts fitted to a bearing,

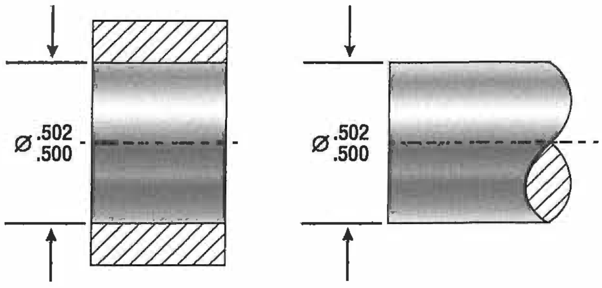


Figure 6-5. Basic hole fit.

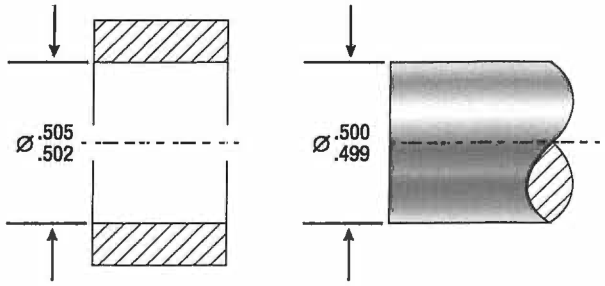


Figure 6-6. Basic shaft fit.

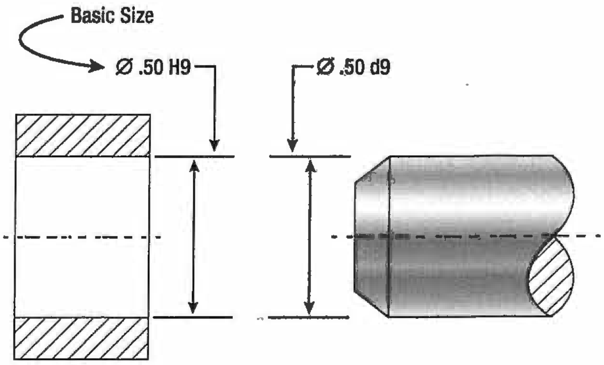


Figure 6-7. Basic hole method (Metric).

a piston running in a cylinder, a propeller splined to its shaft or a bolt fitting into a nut.

Most fitting was at one time carried out by hand and required great skill and judgment. With the use of high developed machine tools capable of producing precision work of accuracy and uniformity, hand fitting has become superseded. It still has a part to play, however, in teaching basic skills and in many cases where individual work is required.

DIMENSIONS

Mass production has long been the basis of the approach to the most economic methods of manufacturing and the complete replacement of a defective item is common practice in the maintenance of aircraft and aerospace components.

For this reason, *limits* are imposed on the manufacturing processes, to ensure that, if any two mating parts are manufactured to the dimensions as stated on the relevant drawings, then the parts will assemble without need of further major adjustments and in the least time possible.

The limits are based on the allowances and tolerances imposed on the dimensions of the manufactured parts. These dimensions will be given the accuracy required by the designer of the respective parts. The basic size of dimension is given with tolerances expressed as a plus/minus range.

ALLOWANCES

An allowance is a difference in dimension that is necessary to give a particular 'class of fit' between two parts, for example, a shaft required to locate within a corresponding hole in a component. To assist in the economy of manufacture, either the hole or the shaft is made as accurately as possible to the nominal size and an allowance is applied to the associated item. Note that the term 'shaft' also includes bolts and pins.

If the shaft is constant and the hole varies in size, then the system used is said to be 'shaft-based'. If the hole is constant and the shaft varies in size, then the system is 'hole based'. The hole-based system is the one in more general use. The item dimensioned to include the allowance also has high and low limits and therefore a tolerance. The correct allowance would be the difference between the high limit of the shaft and the low limit of the hole.

TOLERANCES

Tolerance is the total amount of variation in the size of a part or feature on a part. To find the tolerance of a part or feature subtract the smallest size from the largest size. For example: given a dimension of 2.5 +/- 0.05, the largest size would be 2.55, the smallest size would be 2.45. Therefore the tolerance is 0.10 (2.55 - 2.45).

UNILATERAL AND BILATERAL TOLERANCES

Bilateral tolerance is when there is an amount of dimension variation above and below the design size. Unilateral tolerance is when the design size can only vary in one direction. (***Figure 6-8 and Figure 6-9***)

Example: +/-0.05

Which means the feature or parts can be as small as 3.70 or as large as 3.80. Unilateral tolerance is the amount of variation in one direction either above or below the design size.

Example: +0.05/-0.00

Which means the feature or parts can be as small as 3.75 or as large as 3.8.

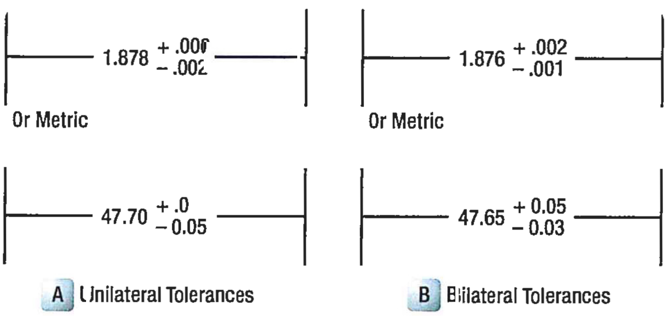


Figure 6-8. Unilateral and Bilateral Tolerances.

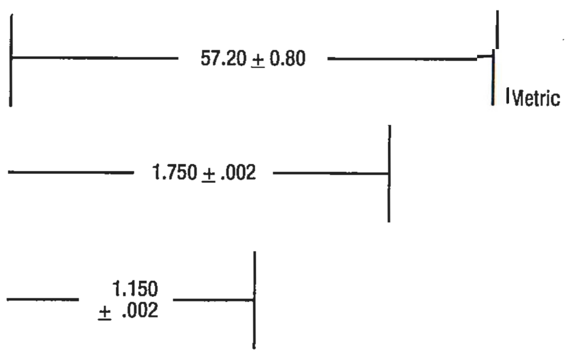


Figure 6-9. Equal Bilateral Tolerances.

Example: With sheet material, such as patch plates used in certain repairs, the dimensions quoted in the repair scheme usually have a tolerance in one direction only, the nominal size being the lower limit. In effect the patch plate must never be below the nominal size, although it can be slightly over in accordance with the repair scheme in the manual.

BASELINE AND CONTINUED TOLERANCES

Baseline tolerances do not "stack-up." Continued (or "chained") tolerances "stack up " and are cumulative.

OVALITY, BOW AND TWIST

SCHEDULE OF FITS AND CLEARANCES

Wear occurs at any time that there is motion between two parts. This motion can be intentional, such as when a shaft rotates in a plain (journal) bearing or when a roller moves back and forth over a track. Wear can also be accidental, where two parts that should be immovable chafe together.

If the parts are intended to move together, then the maintenance documentation will have a Schedule of Fits and Clearances, based on the limit system issued for each mechanism used on the aircraft.

If the parts are not intended to move together, it will depend upon inspection procedures to discover the problem and repair schemes will be initiated in an attempt to prevent recurrence.

The Schedule of Fits and Clearances contains tables which specify the limits on wear and other characteristics such as:

- Ovality (of a hole or shaft)
- Bow of a shaft
- Twist of a shaft.

LIMITS FOR WEAR

The four dimensions, typically covered in wear tables are:

- Dimension New
- Permissible Worn Dimension
- Clearance New
- Permissible Worn Clearance.

Dimension New relates to the size of the part when new, and will show the relevant tolerances.

Permissible Worn Dimension refers to the size to which a part may wear before it must be rejected as unserviceable. Parts, which are not worn beyond this size, can be used again, providing a suitable mating part is chosen to keep the clearance within the permissible figure. This will frequently involve choosing a new part to mate with the worn part.

Clearance New is the desired clearance in limit form. Interference fits are quoted as negative clearances. Permissible Worn Clearance refers to the maximum allowable clearance when reassembling the component.

LIMITS FOR OVALITY

This usually occurs as a result of the surface wearing through friction or linear movement. Ovality can apply equally to holes and shafts (refer to ***Figure 6-10***).

Holes may be tested for ovality, using such instruments as Go/No-Go gauges, internal micrometers, or calipers, as were previously discussed in the Tools topic of this course.

Shafts may be checked for wear by measuring them using micrometer, however, roundness cannot be measured by taking numerous measurements of diameter at different points round the circumference. Certain shapes appear to be round when measured in this manner although in fact they may not be. Testing roundness of a shaft may be achieved by placing the shaft to be tested on a block and

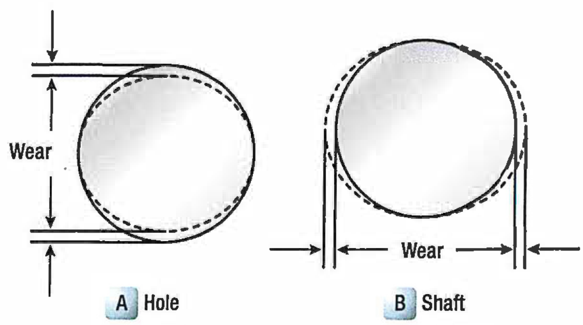


Figure 6-10. Ovality of a Hole (A) or a Shaft (B).

FITS AND CLEARANCES

rotating it under a scribing block or a dial indicator (this same method may be used to checking shafts for bow).

Two or more diameters of a shaft have a common axis and it is important that they shall be true with one another, they are said to be concentric. Concentricity may be tested by placing the shaft in Vee Blocks or between centers and rotating it under a dial indicator. It is important to test for ovality of a shaft, before testing it for bow, as the results may be suspect if bow is done first. Bow in a shaft can be determined in a workshop by utilizing V blocks, a surface gauge and a dial indicator (in conjunction with a surface table).

LIMITS FOR BOW

When dealing with shafts and tubes, it is vital that not only are the ends square with each other, but that the centerline of the complete shaft or tube is straight. If the center line of the shaft is not straight, then the item is bowed. When the shaft or tube is rotating, especially at a high speed in a bowed state, there is the risk of vibration which can lead to mechanical failures, loosening of fasteners and (most critical of all) fatigue.

All cylindrical items, both tubular and solid, can be given a limit to the amount of bow permitted. For example a drive shaft, which rotates about 1 500 rpm, may have a limit of 0.25 mm (0.01 in) bow over the length of the shaft. This ensures that, within the limits of production, the drive shafts are effectively straight, giving the least possible vibration.

To measure the amount of bow in a structural member (for example, a strut) a straight edge and a set of feelers can be used, providing no protruding fittings prevent the straight edge being applied directly along the surface of the member. The straight edge should be placed along the entire length of the member parallel to its axis, then by inserting feeler gauges at the point of maximum clearance the amount of bow can be calculated.

CLEARANCE MEASURED BY FEELER GAUGES

Over the length of a member in general a maximum bow of 1 in 600 is normally acceptable unless otherwise stated in the repair manual. During normal servicing or overhauling of aircraft components, dimensional checks may be carried out with the aid of various types of precision measuring instruments for example; micrometer, vernier caliper, and dial indicator. Wear limits may be found in the appropriate repair or overhaul manual.

LIMITS FOR TWIST

Twist is the result of applied torsion on circular or square-sectioned shafts. If the twist disappears, as a result of removing the force, then the shaft will have been loaded below its elastic limit. If the shaft remains twisted, after removal of the load, then it has been loaded above its elastic limit.

The action of a shaft (of whatever section) carrying a torque load is to twist in proportion to the torque applied. The result of cyclic loading of shafts is that, at certain times, the shafts have to be checked for permanent twist. If the shaft has a square section, it can be checked for twist on a surface table using a dial indicator mounted on a surface gauge.

Solid or tubular shafts that have to be checked for twist will possibly have witness marks or lines engraved or etched at each end of the shaft. The shafts can be checked, by mounting the shaft in V blocks and then locating these marks in the horizontal position. It is possible to measure the amount of twist, to which a shaft is subjected, whilst in operation or rotation, by the use of strain gauges. These emit varying amounts of electric current when under strain, giving an indication (on a calibrated instrument) of the load being applied.

The designer of the aircraft or equipment will set all limits, with regards to the distortion of parts and set them down in the relevant manuals. The methods used to measure the distortion will either be standard procedures, such as using a dial indicator and surface table etc., or will have a special procedure included in the manuals.

Question: 6-1
The size of hole to be drilled depends upon the ________________ of that hole.

Question: 6-2
An ________________ is a difference in dimension that is necessary to give a particular 'class of fit' between two parts.

Question: 6-3
If the center line of a shaft is not straight, then the item is said to be ________________.

Question: 6-4
A ________________ type fit is one having prescribed size limits that either a clearance or interference may result when the parts are assembled.

Question: 6-5
According to the ________________ system of classifying fits, a ________________ type fit is when mechanical pressure is required for assembly and that once assembled, no dismantling is expected.

Question: 6-6
To check for roundness of a shaft, place the shaft in a V block and measure with a ________________ or a ________________.

ANSWERS

Answer: 6-1
purpose.

Answer: 6-2
allowance.

Answer: 6-3
bowed.

Answer: 6-4
transition

Answer: 6-5
Newall, force

Answer: 6-6
Dial Test Indicator, scribing block

MAINTENANCE PRACTICES

ELECTRICAL WIRING INTERCONNECTION SYSTEM (EWIS)

SUB-MODULE 07

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 07 ELECTRICAL WIRING INTERCONNECTION SYSTEM (EWIS) Knowledge Requirements		
7.7 - Electrical Wiring Interconnection System (EWIS) Continuity, insulation and bonding techniques and testing; Use of crimp tools: hand and hydraulic operated; Testing of crimp joints; Connector pin removal and insertion; Co-axial cables: testing and installation precautions; Identification of wire types, their inspection criteria and damage tolerance. Wiring protection techniques: Cable looming and loom support, cable clamps, protective sleeving techniques including heat shrink wrapping, shielding. EWIS installations, inspection, repair, maintenance and cleanliness standards.	3	3

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

ELECTRICAL WIRING INTERCONNECT SYSTEM (EWIS)

An EWIS is any wire, wiring device, or combination of these, including termination devices, installed in any area of the aircraft for the purpose of transmitting electrical energy between two or more intended termination points. EWIS does not include electrical equipment or avionics qualified to acceptable environmental conditions and testing procedures, portable electrical devices not part of airplane's an type design, or fiber optics. EWIS includes the following:

1. Wires and cables.
2. Bus bars.
3. The termination point on electrical devices, including those on relays, interrupters, switches, contactors, terminal blocks and circuit breakers, and other circuit protection devices.
4. Connectors, including feed-through connectors.
5. Connector accessories.
6. Electrical grounding and bonding devices and their associated connections.
7. Electrical splices.
8. Materials used to provide additional protection for wires, including wire insulation, wire sleeving, and conduits that have electrical termination for the purpose of bonding.
9. Shields or braids.
10. Clamps and other devices used to route and support the wire bundle.
11. Cable tie devices.
12. Labels or other means of identification.
13. Pressure seals.
14. EWIS components inside shelves, panels, racks, junction boxes, distribution panels, and back-planes of equipment racks, including, but not limited to, circuit board back-planes, wire integration units, and external wiring of equipment.

These EWIS wires and associated components are treated as an airplane system.

INSULATION

Two fundamental properties of insulation materials are insulation resistance and dielectric strength. These are entirely different and distinct properties.

Insulation resistance is the resistance to current leakage through and over the surface of insulation materials. Insulation resistance can be measured with a megohmmeter insulation tester without damaging the insulation, and data so obtained serves as a useful guide in determining the general condition of the insulation. (***Figure 7-1***) However, the data obtained in this manner may not give a true picture of the condition of the insulation. Clean, dry insulation having cracks or other faults might show a high value of insulation resistance but would not be suitable for use. Therefore, a thorough visual inspection must also be made.

Dielectric strength is the ability of the insulator to withstand potential difference and is usually expressed in terms of the voltage at which the insulation fails because of the electrostatic stress. Maximum dielectric strength values can be measured by raising the voltage of a test sample until the insulation breaks down.

The type of conductor insulation material varies with the type of installation. Characteristics should be chosen based on environment, such as abrasion resistance, arc resistance, corrosion resistance, cut-through strength, dielectric strength, flame resistant, mechanical strength, smoke emission, fluid resistance, and heat distortion. Such types of insulation materials (for example, PVC/nylon) are no longer used for new aircraft designs, but might still be installed on older aircraft. Insulation materials for new aircraft designs are made of Tefzel®, Teflon®/Kapton®/Teflon® and PTFE/Polyimide/PTFE. The development of better and safer insulation materials is ongoing.

Figure 7-1. An insulation tester.

Since electrical wire may be installed in areas where inspection is infrequent over extended periods of time, it is necessary to give special consideration to heat-aging characteristics in the selection of wire. Resistance to heat is of primary importance in the selection of wire for aircraft use, as it is the basic factor in wire rating. Where wire may be required to operate at higher temperatures due either to high ambient temperatures, high current loading, or a combination of the two, selection should be made on the basis of satisfactory performance under the most severe operating conditions.

BONDING AND GROUNDING

One of the more important factors in the design and maintenance of aircraft electrical systems is proper bonding and grounding. Inadequate bonding or grounding can lead to unreliable operation of systems, electromagnetic interference (EMI), electrostatic discharge damage to sensitive electronics, personnel shock hazard, or damage from lightning strike.

GROUNDING

Grounding is the process of electrically connecting conductive objects to either a conductive structure or some other conductive return path for the purpose of safely completing either a normal or fault circuit. (*Figure 7-2*)

If wires carrying return currents from different types of sources, such as signals of DC and AC generators, are connected to the same ground point or have a common connection in the return paths, an interaction of the currents occurs. Mixing return currents from various sources should be avoided because noise is coupled from one source to another and can be a major problem for digital systems. To minimize the interaction between various return currents, different types of ground should be identified and used. As a minimum, the design should use three ground types: (1) AC returns, (2) DC returns, and (3) all others.

Figure 7-2. Ground wires.

For distributed power systems, the power return point for an alternative power source would be separated. For example, in a two-AC generator (one on the right side and the other on the left side) system, if the right AC generator were supplying backup power to equipment located in the left side, (left equipment rack) the backup AC ground return should be labeled "AC Right." The return currents for the left generator should be connected to a ground point labeled "AC Left."

The design of the ground return circuit should be given as much attention as the other leads of a circuit. A requirement for proper ground connections is that they maintain an impedance that is essentially constant. Ground return circuits should have a current rating and voltage drop adequate for satisfactory operation of the connected electrical and electronic equipment. EMI problems that can be caused by a system's power wire can be reduced substantially by locating the associated ground return near the origin of the power wiring (e.g., circuit breaker panel) and routing the power wire and its ground return in a twisted pair. Special care should be exercised to ensure replacement on ground return leads. The use of numbered insulated wire leads instead of bare grounding jumpers may aid in this respect. In general, equipment items should have an external ground connection, even when internally grounded. Direct connections to a magnesium structure must not be used for ground return because they may create a fire hazard.

Power ground connections for generators, transformer rectifiers, batteries, external power receptacles, and other heavy-current loads must be attached to individual grounding brackets that are attached to aircraft structure with a proper metal-to-metal bonding attachment. This attachment and the surrounding structure must provide adequate conductivity to accommodate normal and fault currents of the system without creating excessive voltage drop or damage to the structure. At least three fasteners, located in a triangular or rectangular pattern, must be used to secure such brackets in order to minimize susceptibility to loosening under vibration. If the structure is fabricated of a material, such as carbon fiber composite

(CFC), that has a higher resistivity than aluminum or copper, it is necessary to provide an alternative ground path(s) for power return current. Special attention should be considered for composite aircraft.

Power return or fault current ground connections within flammable vapor areas must be avoided. If they must be made, make sure these connections do not arc, spark, or overheat under all possible current flow or mechanical failure conditions, including induced lightning strikes.

Criteria for inspection and maintenance to ensure continued airworthiness throughout the expected life of the aircraft should be established. Power return fault currents are normally the highest currents flowing in a structure. These can be the full generator current capacity. If full generator fault current flows through a localized region of the carbon fiber structure, major heating and failure can occur. CFC and other similar low-resistive materials must not be used in power return paths. Additional voltage drops in the return path can cause voltage regulation problems. Likewise, repeated localized material heating by current surges can cause material degradation. Both problems may occur without warning and cause no repeatable failures or anomalies.

The use of common ground connections for more than one circuit or function should be avoided except where it can be shown that related malfunctions that could affect more than one circuit do not result in a hazardous condition. Even when the loss of multiple systems does not, in itself, create a hazard, the effect of such failure can be quite distracting to the crew.

BONDING

Bonding is the electrical connecting of two or more conducting objects not otherwise adequately connected. The following bonding requirements must be considered:

- Equipment bonding—low-impedance paths to aircraft structure are normally required for electronic equipment to provide radio frequency return circuits and for most electrical equipment to facilitate reduction in EMI. The cases of components that produce electromagnetic energy should be grounded to structure. To ensure proper operation of electronic equipment, it is particularly important to conform to the system's installation specification when interconnections, bonding, and grounding are being accomplished.
- Metallic surface bonding—all conducting objects on the exterior of the airframe must be electrically connected to the airframe through mechanical joints, conductive hinges, or bond straps capable of conducting static charges and lightning strikes. Exceptions may be necessary for some objects, such as antenna elements, whose function requires them to be electrically isolated from the airframe. Such items should be provided with an alternative means to conduct static charges and/or lightning currents, as appropriate.
- Static bonds—all isolated conducting parts inside and outside the aircraft, having an area greater than 3 square inches and a linear dimension over 3 inches, that are subjected to appreciable electrostatic charging due to precipitation, fluid, or air in motion, should have a mechanically secure electrical connection to the aircraft structure of sufficient conductivity to dissipate possible static charges. A resistance of less than 1 ohm when clean and dry generally ensures such dissipation on larger objects. Higher resistances are permissible in connecting smaller objects to airframe structure.

Testing of Bonds and Grounds

The resistance of all bond and ground connections should be tested after connections are made before re-finishing. The resistance of each connection should normally not exceed 0.003 ohm. A high quality test instrument, an AN/USM-21A or equivalent, is required to accurately measure the very low resistance values.

Bonding Jumper Installation

Bonding jumpers should be made as short as practicable, and installed in such a manner that the resistance of each connection does not exceed .003 ohm. The jumper should not interfere with the operation of movable aircraft elements, such as surface controls, nor should normal movement of these elements result in damage to the bonding jumper. (***Figure 7-3***)

- Bonding connections—to ensure a low-resistance connection, nonconducting finishes, such as paint and anodizing films, should be removed from the attachment surface to be contacted by the bonding terminal. Electrical wiring should not be grounded directly to magnesium parts.
- Corrosion protection—one of the more frequent causes of failures in electrical system bonding and grounding is corrosion. The areas around completed

connections should be post-finished quickly with a suitable finish coating.

- Corrosion prevention—electrolytic action may rapidly corrode a bonding connection if suitable precautions are not taken. Aluminum alloy jumpers are recommended for most cases; however, copper jumpers should be used to bond together parts made of stainless steel, cadmium plated steel, copper, brass, or bronze. Where contact between dissimilar metals cannot be avoided, the choice of jumper and hardware should be such that corrosion is minimized; the part likely to corrode should be the jumper or associated hardware.
- Bonding jumper attachment—the use of solder to attach bonding jumpers should be avoided. Tubular members should be bonded by means of clamps to which the jumper is attached. Proper choice of clamp material should minimize the probability of corrosion.
- Ground return connection—when bonding jumpers carry substantial ground return current, the current rating of the jumper should be determined to be adequate, and a negligible voltage drop is produced. (***Figure 7-4***)

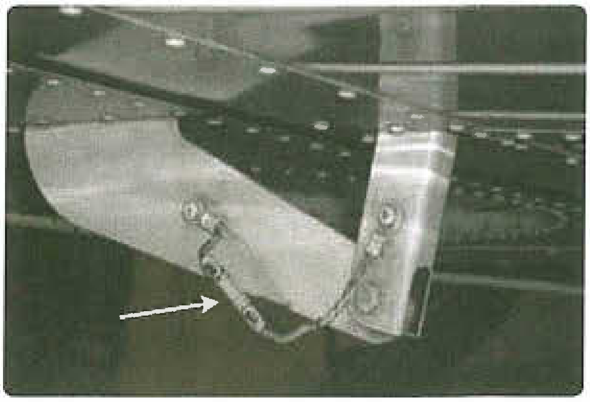
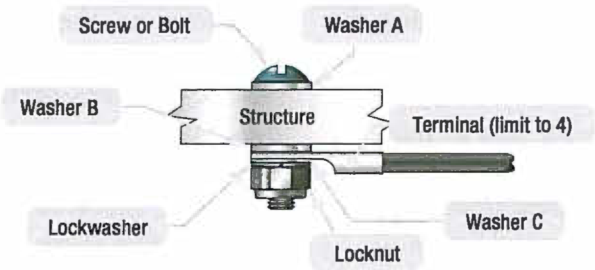


Figure 7-3. Bonding jumpers.



Structure	Screw or Bolt and Nut Plate	Locknut	Washer A	Washer B	Washer C
Aluminum Terminal and Jumper					
Aluminum alloys	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel or aluminum	None	Cadmium-plated steel or aluminum
Magnesium alloys	Cadmium-plated steel	Cadmium-plated steel	Magnesium-alloy	None or magnesium alloy	Cadmium-plated steel or aluminum
Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel or aluminum
Corrosion-resisting steel	Corrosion-resisting steel or Cadmium-plated steel	Cadmium-plated steel	Corrosion-resisting steel	Cadmium-plated steel	Cadmium-plated steel or aluminum
Tinned Copper Terminal and Jumper					
Aluminum alloys	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Aluminum alloys[2]	Cadmium-plated steel
Magnesium alloys[1]					
Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	Cadmium-plated steel	none	Cadmium-plated steel
Corrosion-resisting steel	Corrosion-resisting steel or cadmium-plated steel	Cadmium-plated steel	Corrosion-resisting steel	none	Cadmium-plated steel

[1] Avoid connecting copper to magnesium.

[2] Use washers with a conductive finish treated to prevent corrosion, such as AN960JD10L.

Figure 7-4. Bolt and nut bonding or grounding to flat surface.

WIRE TERMINATION

STRIPPING WIRE

Before wire can be assembled to connectors, terminals, splices, etc., the insulation must be stripped from connecting ends to expose the bare conductor. Copper wire can be stripped in a number of ways depending on the size and insulation. Aluminum wire must be stripped using extreme care, since individual strands break very easily after being nicked. The following general precautions are recommended when stripping any type of wire:

1. When using any type of wire stripper, hold the wire so that it is perpendicular to cutting blades.
2. Adjust automatic stripping tools carefully; follow the manufacturer's instructions to avoid nicking, cutting, or otherwise damaging strands. This is especially important for aluminum wires and for copper wires smaller than No. 10. Examine stripped wires for damage. Cut off and re-strip (if length is sufficient), or reject and replace any wires having more than the allowable number of nicked or broken strands listed in the manufacturer's instructions.
3. Make sure insulation is clean-cut with no frayed or ragged edges. Trim, if necessary.
4. Make sure all insulation is removed from stripped area. Some types of wire are supplied with a transparent layer of insulation between the conductor and the primary insulation. If this is present, remove it.
5. When using hand-plier strippers to remove lengths of insulation longer than ¾ inch, it is easier to accomplish in two or more operations.
6. Re-twist copper strands by hand or with pliers, if necessary, to restore natural lay and tightness of strands.

A pair of hand held wire strippers is shown in ***Figure 7-5***. This tool is commonly used to strip most types of wire. The following general procedures describe the steps for stripping wire with a hand stripper.

1. Insert wire into exact center of correct cutting slot for wire size to be stripped. Each slot is marked with wire size.
2. Close handles together as far as they will go.
3. Release handles, allowing wire holder to return to the open position.
4. Remove stripped wire.

Terminals are attached to the ends of electrical wires to facilitate connection of the wires to terminal strips or items of equipment. (***Figure 7-6***) The tensile strength of the wire-to-terminal joint should be at least equivalent to the tensile strength of the wire itself, and its resistance negligible relative to the normal resistance of the wire.

The following should be considered in the selection of wire terminals: current rating, wire size (gauge) and insulation diameter, conductor material compatibility, stud size, insulation material compatibility, application environment, and solder versus solderless.

Pre-insulated crimp-type ring-tongue terminals are preferred. The strength, size, and supporting means of studs and binding posts, as well as the wire size, may be considered when determining the number of terminals to be attached to any one post. In high-temperature applications, the terminal temperature rating must be greater than the ambient temperature plus current related temperature rise. Use of nickel-plated terminals and of uninsulated terminals with high-temperature insulating sleeves should be considered. Terminal blocks should be provided with adequate electrical clearance or insulation strips between mounting hardware and conductive parts.

Figure 7-5. Wire strippers.

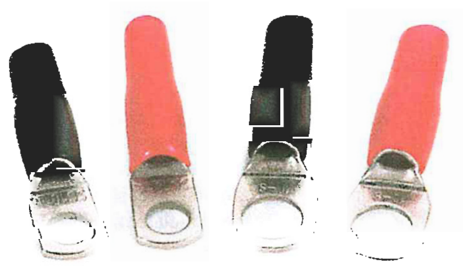


Figure 7-6. Ring-tongue terminals.

TERMINAL STRIPS

Wires are usually joined at terminal strips. (*Figure 7-7*) A terminal strip fitted with barriers may be used to prevent the terminals on adjacent studs from contacting each other. Studs should be anchored against rotation. When more than four terminals are to be connected together, a small metal bus should be mounted across two or more adjacent studs. In all cases, the current should be carried by the terminal contact surfaces and not by the stud itself. Defective studs should be replaced with studs of the same size and material since terminal strip studs of the smaller sizes may shear due to over-tightening the nut. The replacement stud should be securely mounted in the terminal strip and the terminal securing nut should be tight. Terminal strips should be mounted in such a manner that loose metallic objects cannot fall across the terminals or studs. It is good practice to provide at least one spare stud for future circuit expansion or in case a stud is broken.

Terminal strips that provide connection of radio and electronic systems to the aircraft electrical system should be inspected for loose connections, metallic objects that may have fallen across the terminal strip, dirt and grease accumulation, etc. These conditions can cause arcing, which may result in a fire or system failures.

TERMINAL LUGS

Wire terminal lugs should be used to connect wiring to terminal block studs or equipment terminal studs. No more than four terminal lugs, or three terminal lugs and a bus bar, should be connected to any one stud. The total number of terminal lugs per stud includes a common bus bar joining adjacent studs. Four terminal lugs plus a common bus bar are not permitted on one stud. Terminal lugs should be selected with a stud hole diameter that matches the diameter of the stud. However, when the terminal lugs attached to a stud vary in diameter, the greatest diameter should be placed on the bottom and the smallest diameter on top. Tightening terminal connections should not deform the terminal lugs or the studs. Terminal lugs should be positioned so that bending of the terminal lug is not required to remove the fastening screw or nut, and movement of the terminal lugs tends to tighten the connection.

COPPER WIRE TERMINALS

Solderless crimp-style, copper wire, terminal lugs may be used which conform to MIL-T-7928. Spacers or washers should not be used between the tongues of terminal lugs. (*Figure 7-8*)

ALUMINUM WIRE TERMINALS

The aluminum terminal lugs should be crimped to aluminum wire only. The tongue of the aluminum terminal lugs, or the total number of tongues of aluminum terminal lugs when stacked, should be sandwiched between two flat washers when terminated on terminal studs. Spacers or washers should not be used between the tongues of terminal lugs. Special attention should be given to aluminum wire and cable installations to guard against conditions that would result in excessive voltage drop and high resistance at junctions that may ultimately lead to failure of the junction.

Examples of such conditions are improper installation of terminals and washers, improper torsion (torquing of nuts), and inadequate terminal contact areas.

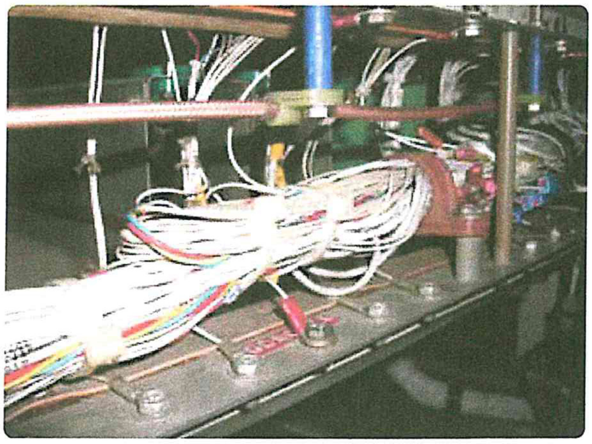


Figure 7-7. Terminal strip.

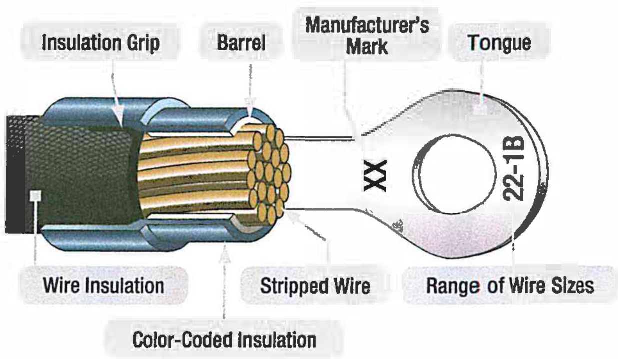


Figure 7-8. Wire terminal.

PRE-INSULATED SPLICES

Pre-insulated terminal lugs and splices must be installed using a high-quality crimping tool. Such tools are provided with positioners for the wire size and are adjusted for each wire size. It is essential that the crimp depth be appropriate for each wire size. If the crimp is too deep, it may break or cut individual strands. If the crimp is not deep enough, it may not be tight enough to retain the wire in the terminal or connector. Crimps that are not tight enough are also susceptible to high resistance due to corrosion buildup between the crimped terminal and the wire. (***Figure 7-9***)

CRIMPING TOOLS

Hand, portable, and stationary power tools are available for crimping terminal lugs. These tools crimp the barrel to the conductor, and simultaneously form the insulation support to the wire insulation. ***Figure 7-10*** illustrates typical manually operated crimping tools. The wire is simply inserted properly into the crimp terminal and then placed into the proper location for its size in the crimper. Squeezing the handles together applies the proper force to the assemble for an airworthy crimp. Be sure the wire and insulation are inserted correctly in the terminal and that the terminal end is inserted correctly into the crimp tool.

Hydraulic crimping tools may also be used, especially when dealing with large wire sizes and cable. A hand operated hydraulic crimping tool is shown in (***Figure 7-11***). It has a four-position upper die and a common lower die for crimping terminal wire sizes 9, 6, 4, and 2. To operate, open the tool by pressing the latch. Pull back the nest lock and turn the thumb lock until the required die appears and the lock springs into place. Position the wire terminal assembly in the die and close the head. Rotate the reservoir handle clockwise to close the hydraulic fluid pressure return port. When the handle moves, hydraulic fluid is then pumped and the die begins to close. A sudden decrease in effort indicates that the crimping is complete. Rotate the reservoir handle anti-clockwise to release the hydraulic pressure and open the die.

EMERGENCY SPLICING REPAIRS

Broken wires can be repaired by means of crimped splices, by using terminal lugs from which the tongue has been cut off, or by soldering together and potting broken strands. These repairs are applicable to copper wire. Damaged aluminum wire must not be temporarily spliced. These repairs are for temporary emergency use only and should be replaced as soon as possible with permanent repairs. Since some manufacturers prohibit splicing, the applicable manufacturer's instructions should always be consulted.

INSPECTION AND TESTING OF CRIMPED JOINTS

Properly crimped joints should be very strong. The wire and insulation should not slip or move when a tension load is applied. The tensile strength of the wire-to-terminal joint should be at least equivalent to the tensile strength of the wire itself. Resistance of wire-to-terminal joint should be negligible, relative to the normal resistance of the wire. The correct combination of wire, terminal end, and proper crimping with the depth mark in the correct location should all be evident. Both the conductor and insulator must be correctly inserted in the terminal end fitting. Only conductor material should be in the crimp barrel. Neither the conductor or insulator should appear damaged in any way with insulator material gripped by the insulation crimp so that the conductor is not visible.

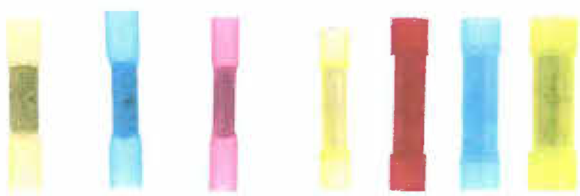


Figure 7-9. Terminal splices.

Figure 7-10. Crimping pliers.

Figure 7-11. Hand operated hydraulic crimping tool.

Actual testing of crimps is not usually performed on an installation made with the proper crimping tool. Crimping tools should be inspected annually and on condition if excessive play is detected. Crimps made with the tool can be checked using go/no-go gauges supplied by the tool manufacturer. Tensile strength and voltage carrying capability of crimps made with a specific crimping tool can be tested in the shop. Example voltage and tensile strength values for testing of crimped connections on a range of wire sizes are given in ***Figure 7-12***.

Wire Size	Test Current	Voltage Drop (Max) Millivolts	(Min.) Pull-Apart Load (lbs.)
26	3	8	7
24	4.5	8	10
22	9	7	15
20	11	6	19
18	16	5	38
16	22	7	50
14	32	6	70
12	41	5	110
10	55	5	150
8	73	5	225
6	101	5	300
4	135	5	400

Figure 7-12. Crimped joint test table.

JUNCTION BOXES

Junction boxes are used for collecting, organizing, and distributing circuits to the appropriate harnesses that are attached to the equipment. (***Figure 7-13***) Junction boxes are also used to conveniently house miscellaneous components, such as relays and diodes. Junction boxes that are used in high-temperature areas should be made of stainless steel.

Replacement junction boxes should be fabricated using the same material as the original or from a fire-resistant, nonabsorbent material, such as aluminum, or an acceptable plastic material. Where fireproofing is necessary, stainless steel junction box is recommended. Rigid construction prevents oil-canning of the box that could result in internal short circuits. In all cases, drain holes should be provided in the lowest portion of the box. Cases of electrical power equipment must be insulated from metallic structures to avoid ground fault related fires.

The junction box arrangement should permit easy access to any installed items of equipment, terminals, and wires. Where marginal clearances are unavoidable, an insulating material should be inserted between current carrying parts and any grounded surface. It is not good practice to mount equipment on the covers or doors of junction boxes, since inspection for internal clearance is impossible when the door or cover is in the closed position.

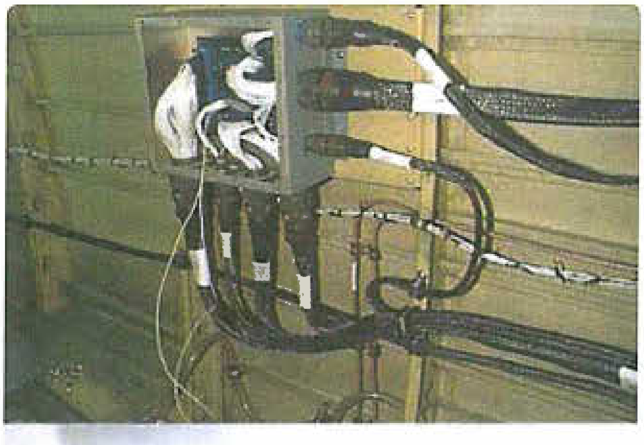


Figure 7-13. Junction boxes.

Junction boxes should be securely mounted to the aircraft structure in such a manner that the contents are readily accessible for inspection. When possible, the open side should face downward or at an angle so that loose metallic objects, such as washers or nuts, tend to fall out of the junction box rather than wedge between terminals.

Junction box layouts should take into consideration the necessity for adequate wiring space and possible future additions. Electrical wire bundles should be laced or clamped inside the box so that cables do not touch other components, prevent ready access, or obscure markings or labels. Cables at entrance openings should be protected against chafing by using grommets or other suitable means.

AN/MS CONNECTORS

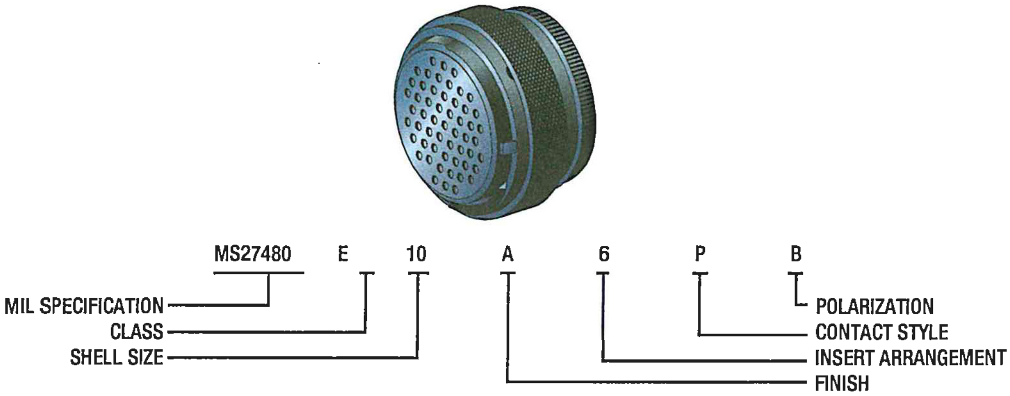
Connectors (plugs and receptacles) facilitate maintenance when frequent disconnection is required. There is a multitude of types of connectors. The connector types that use crimped contacts are generally used on aircraft. Some of the more common types are the round cannon type, the rectangular, and the module blocks. Environmentally resistant connectors should be used in applications subject to fluids, vibration, heat, mechanical shock, and/or corrosive elements.

When HIRF/lightning protection is required, special attention should be given to the terminations of individual or overall shields. The number and complexity of wiring systems have resulted in an increased use of electrical connectors. (***Figure 7-14***) The proper choice and application of connectors is a significant part of the aircraft wiring system. Connectors must be kept to a minimum, selected, and installed to provide the maximum degree of safety and reliability to the aircraft. For the installation of any particular connector assembly, the specification of the manufacturer or the appropriate governing agency must be followed.

TYPES OF CONNECTOR

Connectors must be identified by an original identification number derived from MIL Specification (MS) or Original Equipment Manufacturer (OEM) specification. ***Figure 7-15*** provides information about MS style connectors.

Figure 7-14. Electrical connectors.



MS27472	Wall mount receptacle
MS27473	Straight plug
MS27474	Jam nut receptacle
MS27475	Hermetic wall mount receptacle
MS27476	Hermetic box mount receptacle
MS27477	Hermetic jam nut receptacle
MS27478	Hermetic solder mount receptacle
MS27479	Wall mount receptacle (note 1)
MS27480	Straight plug (note 1)
MS27481	Jam nut receptacle (note 1)
MS27482	Hermetic wall mount receptacle (note 1)
MS27483	Hermetic jam nut receptacle (note 1)
MS27484	Straight plug, EMI grounding
MS27497	Wall receptacle, back panel mounting
MS27499	Box mounting receptacle
MS27500	90° Plug (note 1)
MS27503	Hermetic solder mount receptacle (note 1)
MS27504	Box mount receptacle (note 1)
MS27508	Box mount receptacle, back panel mounting
MS27513	Box mount receptacle, long grommet
MS27664	Wall mount receptacle, back panel mounting (note 1)
MS27667	Thru-bulkhead receptacle

NOTE

1. Active	Supersedes
MS27472	MS27479
MS27473	MS27480
MS27474	MS27481
MS27475	MS27482
MS27477	MS27483
MS27473 with MS27507 elbow	MS27500
MS27478	MS27503
MS27499	MS27504
MS27497	MS27664

CLASS
- E Environment-resisting box and thru-bulkhead mounting types only (see class T)
- P Potting—includes potting form and short rear grommet
- T Environment-resisting wall and jam-nut mounting receptacle and plug types: thread and teeth for accessory attachment
- Y Hermetically sealed

FINISH
- A Silver to light iridescent yellow color cadmium plate over nickel (conductive) –65 °C to +150 °C (inactive for new design)
- B Olive drab cadmium plate over suitable underplate (conductive), –65 °C to 175 °C
- C Anodic (nonconductive), –65 °C to + 175 °C
- D Fused tin, carbon steel(conductive), –65 °C to +150 °C
- E Corrosion resistant steel (cres), passivated (conductive), –65 °C to +200 °C
- F Electroless nickel coating (conductive), –65 °C to +200 °C
- N Hermetic seal or environment resisting cres (conductive plating), –65 °C to +200 °C

CONTACT STYLE
- A Without pin contacts
- B Without socket contacts
- C Feed through
- P Pin contact—including hermetics with solder cups
- S Socket contacts—including hermetics with solder cups
- X Pin contacts with eyelet (hermetic)
- Z Socket contacts with eyelet (hermetic)

POLARIZATION
- A, B Normal—no letter required
- C, or D Abnormal

Figure 7-15. MS connector information sheet.

Environment-resistant connectors are used in applications where they are probably subjected to fluids, vibration, heat, mechanical shock, corrosive elements, etc. Firewall class connectors incorporating these same features should, in addition, be able to prevent the penetration of the fire through the aircraft firewall connector opening and continue to function without failure for a specified period of time when exposed to fire. Hermetic connectors provide a pressure seal for maintaining pressurized areas. When EMI/RFI protection is required, special attention should be given to the termination of individual and overall shields. Backshell adapters designed for shield termination, connectors with conductive finishes, and EMI grounding fingers are available for this purpose.

Rectangular connectors are typically used in applications where a very large number of circuits are accommodated in a single mated pair. (***Figure 7-16***) They are available with a great variety of contacts, which can include a mix of standard, coaxial, and large power types. Coupling is accomplished by various means. Smaller types are secured with screws which hold their flanges together. Larger ones have integral guide pins that ensure correct alignment, or jackscrews that both align and lock the connectors. Rack and panel connectors use integral or rack-mounted pins for alignment and box mounting hardware for couplings.

Module blocks are types of junctions that accept crimped contacts similar to those on connectors. Some use internal busing to provide a variety of circuit arrangements. They are useful where a number of wires are connected for power or signal distribution. When used as grounding modules, they save and reduce hardware installation on the aircraft. Standardized modules are available with wire end grommet seals for environmental applications and are track mounted. Function module blocks are used to provide an easily wired package for environment-resistant mounting of small resistors, diodes, filters, and suppression networks. In-line terminal junctions are sometimes used in lieu of a connector when only a few wires are terminated and when the ability to disconnect the wires is desired. The in-line terminal junction is environment resistant. The terminal junction splice is small and may be tied to the surface of a wire bundle when approved by the OEM.

VOLTAGE AND CURRENT RATING

Selected connectors must be rated for continuous operation under the maximum combination of ambient temperature and circuit current load. Hermetic connectors and connectors used in circuit applications involving high-inrush currents should be derated. It is good engineering practice to conduct preliminary testing in any situation where the connector is to operate with most or all of its contacts at maximum rated current load. When wiring is operating with a high conductor temperature near its rated temperature, connector contact sizes should be suitably rated for the circuit load. This may require an increase in wire size. Voltage derating is required when connectors are used at high altitude in non-pressurized areas.

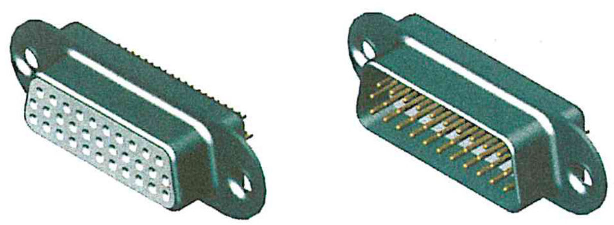


Figure 7-16. Rectangular connectors.

SPARE CONTACTS FOR FUTURE WIRING

To accommodate future wiring additions, spare contacts are normally provided. Locating the unwired contacts along the outer part of the connector facilitates future access. A good practice is to provide two spares on connectors with 25 or fewer contacts; 4 spares on connectors with 26 to 100 contacts; and 6 spares on connectors with more than 100 contacts. Spare contacts are not normally provided on receptacles of components that are unlikely to have added wiring. Connectors must have all available contact cavities filled with wired or unwired contacts. Unwired contacts should be provided with a plastic grommet sealing plug.

WIRE INSTALLATION INTO THE CONNECTOR

Wires that perform the same function in redundant systems must be routed through separate connectors. On systems critical to flight safety, system operation wiring should be routed through separate connectors from the wiring used for system failure warning. It is also good practice to route a system's indication wiring in separate connectors from its failure warning circuits to the extent practicable. These steps can reduce an aircraft's susceptibility to incidents that might result from connector failures.

CONNECTOR PIN REMOVAL AND INSERTION

There is a wide variety of electrical connectors used in aircraft electrical/avionics systems. This section describes a type of plastic removal/insertion tools used to remove or insert the pins of some connectors. Plastic insertion and extraction tools are used to prevent damage to contact retaining clips and insert materials. They are color-coded for contact size, i.e. Red, size 20; Blue, 16 and Yellow 12 and 22. In composite tools the extractor is always White. (***Figure 7-17***)

Figure 7-17. Typical pins and associated insertion tools.

Insertion

Figure 7-18 illustrates an insertion extraction tool and a wire connector. To install a wire into a connector, load the wire and pre-installed contact tip into the tool. (***Figure 7-19A***) The contact should protrude from the end. Squeeze the wire hard into the tool at the tip, between the thumb and forefinger, and at the same time, quickly pull the protruding wire with the other hand away from the tool. (***Figure 7-19B***)

The wire will now have snapped into place. Pull it back through the tool until the tip seats on the back end of the crimp barrel. (***Figure 7-19C***) Holding the connector with the rear seal facing you slowly push the contact straight into the connector seal. (***Figure 7-19D***) A firm stop will be evident when the contact positively seats in the connector. (***Figure 7-19E***)

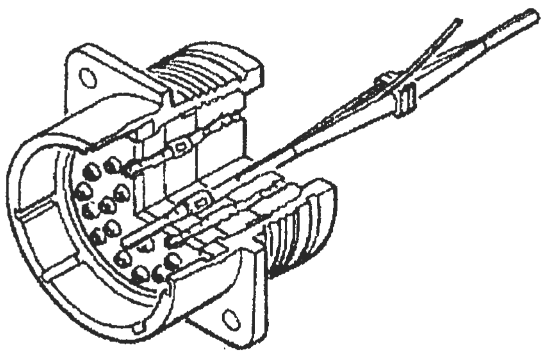


Figure 7-18. Use of plastic insertion tool.

Removal

With the rear of the connector facing you, lay the wire of the contact to be removed along the slot of the removal half (White) of the tool, leaving about 4" from the end of the tool to the rear of the connector. (***Figure 7-20A***) Squeeze the wire hard into the tool between the thumb and forefinger and at the same time quickly pull the connector away from the tool with the other hand. (***Figure 7-20B***) The wire will now have snapped into place. Slide the tool down over the wire and into the rear seal and push it slowly into the connector until a positive resistance is felt. At this time the contact retaining clip is in the unlock position. (***Figure 7-20C***) Press the wire of the contact to be removed against the serrations of the plastic tool and pull both the tool and the contact-wire assembly out of the connector. (***Figure 7-20D***)

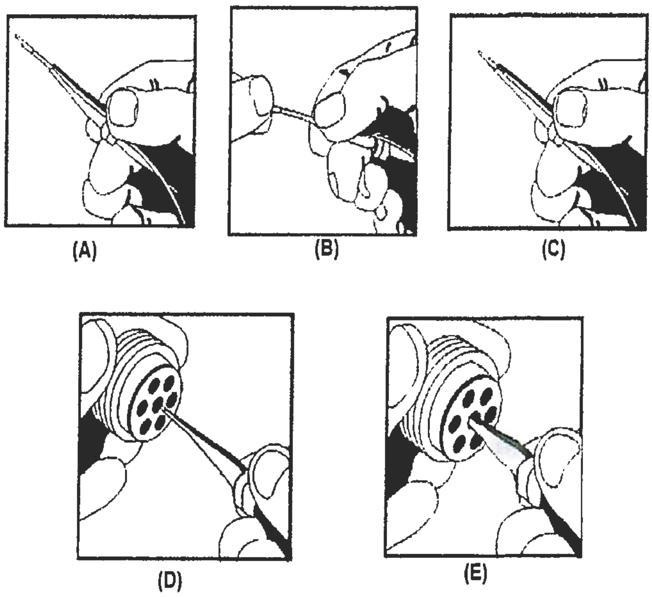


Figure 7-19. Inserting a wire into a connector.

ADJACENT LOCATIONS

Mating of adjacent connectors should not be possible. In order to ensure this, adjacent connector pairs must be different in shell size, coupling means, insert arrangement, or keying arrangement. When such means are impractical, wires should be routed and clamped so that incorrectly mated pairs cannot reach each other. Reliance on markings or color stripes is not recommended as they are likely to deteriorate with age. (*Figure 7-21*)

SEALING

Connectors must be of a type that excludes moisture entry through the use of peripheral and interfacial seals that are compressed when the connector is mated. Moisture entry through the rear of the connector must be avoided by correctly matching the wire's outside diameter with the connector's rear grommet sealing range. It is recommended that no more than one wire be terminated in any crimp style contact.

The use of heat-shrinkable tubing to build up the wire diameter, or the application of potting to the wire entry area as additional means of providing a rear compatibility with the rear grommet is recommended.

These extra means have inherent penalties and should be considered only where other means cannot be used. Unwired spare contacts should have a correctly sized plastic plug installed.

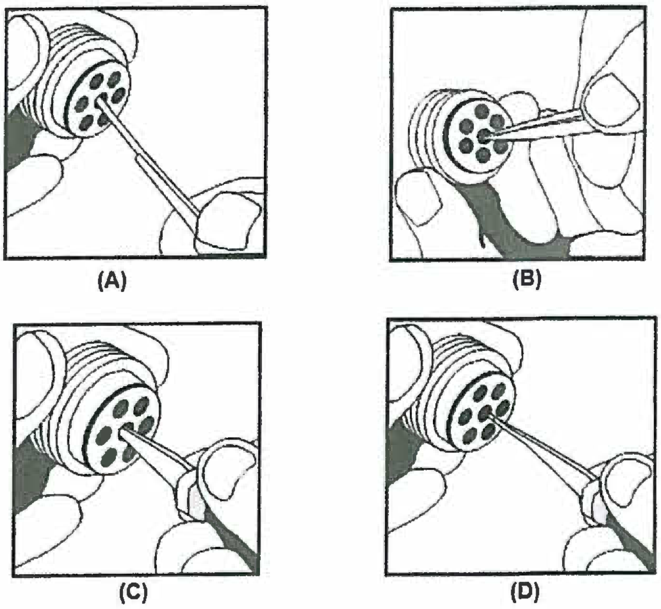


Figure 7-20. Extracting a wire out of a connector.


Figure 7-21. Connector arrangement to avoid wrong connection.

DRAINAGE

Connectors must be installed in a manner that ensures moisture and fluids drain out of and not into the connector when unmated. Wiring must be routed so that moisture accumulated on the bundle drains away from connectors. When connectors must be mounted in a vertical position, as through a shelf or floor, the connectors must be potted or environmentally sealed. In this situation, it is better to have the receptacle faced downward so that it is less susceptible to collecting moisture when unmated.

WIRE SUPPORT

A rear accessory back shell must be used on connectors that are not enclosed. Connectors with very small size wiring, or subject to frequent maintenance activity, or located in high vibration areas must be provided with a strain-relief-type back shell. The wire bundle should be protected from mechanical damage with suitable cushion material where it is secured by the clamp. Connectors that are potted or have molded rear adapters do not normally use a separate strain relief accessory. Strain relief clamps should not impart tension on wires between the clamp and contact. (*Figure 7-22*) Sufficient wire length must be provided at connectors to ensure a proper drip loop and that there is no strain on termination after a complete replacement of the connector and its contacts.

Figure 7-22. Backshells with strain relief.

COAXIAL CABLE

All wiring needs to be protected from damage. However, coaxial and triaxial cables are particularly vulnerable to certain types of damage. Personnel should exercise care while handling or working around coaxial. (***Figure 7-23***)

Coaxial damage can occur when clamped too tightly, or when they are bent sharply (normally at or near connectors). Damage can also be incurred during unrelated maintenance actions around the coaxial cable. Coaxial cable can be severely damaged on the inside without any evidence of damage on the outside. Coaxial cables with solid center conductors should not be used. Stranded center coaxial cables can be used as a direct replacement for solid center coaxial cables. Different types of coaxial cable connectors are illustrated in ***Figure 7-24.***

Coaxial cable precautions include:

- Never kink coaxial cable.
- Never drop anything on coaxial cable.
- Never step on coaxial cable.
- Never bend coaxial cable sharply.
- Never loop coaxial cable tighter than the allowable bend radius.
- Never pull on coaxial cable except in a straight line.
- Never use coaxial cable for a handle, lean on it, or hang things on it (or any other wire).

Coaxial cable is used to protect the inner conductor from the effects of electromagnetic radiation. It consists of a conductor wrapped with a dielectric or insulator. Around the insulator, wire braiding is used to channel off electromagnetic radiation to ground.

Figure 7-23. Coaxial cables.

The entire assembly is normally wrapped with an outer sheath for protection. (***Figure 7-25***)

TESTING COAXIAL CABLE

Simple coaxial cable testing can be done with an ohmmeter. It can be performed before the end terminals are installed to simply check the cable itself. Or, the check can be made with the end terminals installed so as to check the integrity of the entire cable assembly. There must always be low resistance, basically zero resistance, when the ohmmeter probes are touched to the inner conductor. However, there should always be infinite resistance when the probes are touched to the conductor and the shielding. In other words, the shielding and conductor should be electrically isolated at all times. Continuity is required throughout the shielding as well and there should be no resistance between the shielding and ground.

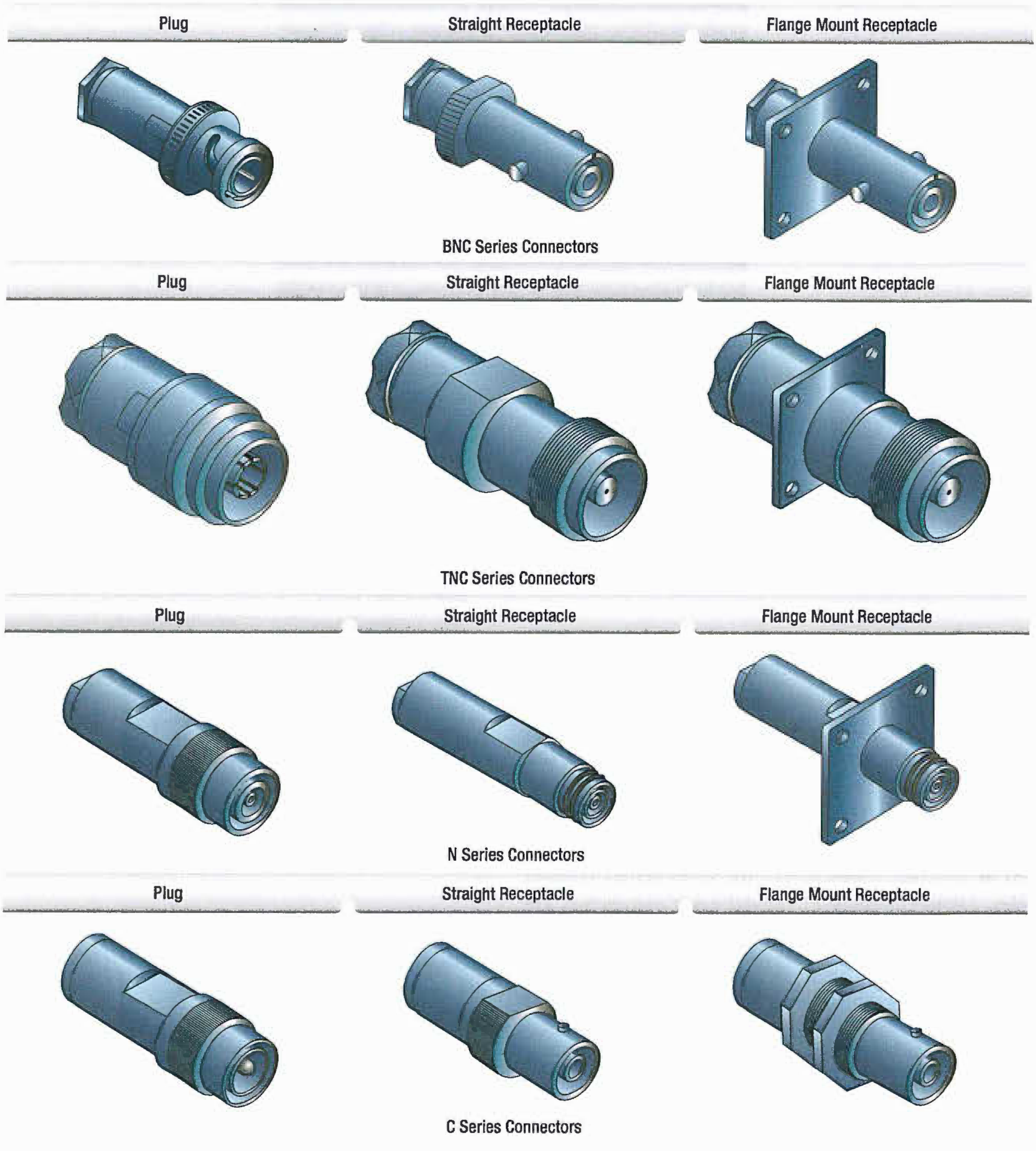


Figure 7-24. Coaxial cable connectors.

WIRE INSPECTION

Aircraft service imposes severe environmental stresses on electrical wire. To ensure satisfactory service, inspect wire annually for abrasions, defective insulation, condition of terminations, and potential corrosion.

Grounding connections for power, distribution equipment, and electromagnetic shielding must be given particular attention to ensure that electrical bonding resistance has not been significantly increased by the loosening of connections or corrosion.

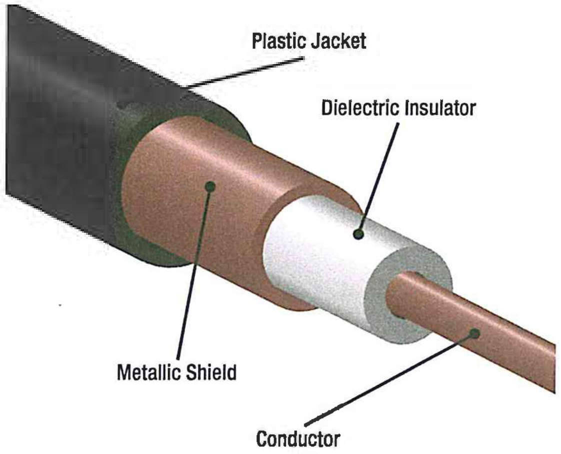


Figure 7-25. Sections of coaxial cable.

WIRE IDENTIFICATION

The proper identification of electrical wires and cables with their circuits and voltages is necessary to provide safety of operation, safety to maintenance personnel, and ease of maintenance. All wire used on aircraft must have its type identification imprinted along its length. It is common practice to follow this part number with the five digit/letter Commercial and Government Entity (CAGE) code identifying the wire manufacturer. You can identify the performance capabilities of existing installed wire you need to replace, and avoid the inadvertent use of a lower performance and unsuitable replacement wire.

PLACEMENT OF IDENTIFICATION MARKINGS

Identification markings should be placed at each end of the wire and at 15-inch maximum intervals along the length of the wire. Wires less than 3 inches in length need not be identified.

Wires 3 to 7 inches in length should be identified approximately at the center. Added identification marker sleeves should be located so that ties, clamps, or supporting devices need not be removed to read the identification. The wire identification code must be printed to read horizontally (from left to right) or vertically (from top to bottom).

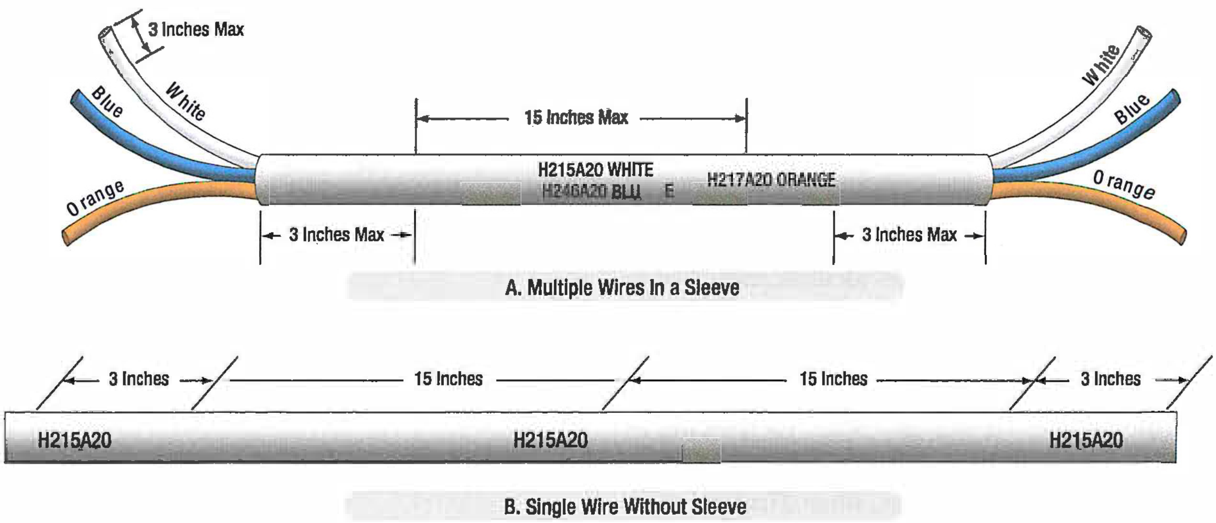


Figure 7-26. Wire markings.

The two methods of marking wire or cable are as follows:

1. Direct marking is accomplished by printing on the cable's outer covering. (***Figure 7-26*B**)
2. Indirect marking is accomplished by printing on a heat-shrinkable sleeve and installing the printed sleeve on the wire or cables outer covering. Indirectly-marked wire or cable should be identified with printed sleeves at each end and at intervals not longer than 6 feet. (***Figure 7-27***) The individual wires inside a cable should be identified within 3 inches of their termination. (***Figure 7-26A***)

TYPES OF WIRE MARKINGS

The preferred method is to mark directly on the wire without causing insulation degradation. Teflon-coated wires, shielded wiring, multi-conductor cable, and thermocouple wires usually require special sleeves to carry identification marks. There are some special wire marking machines available that can be used to stamp directly on the type wires mentioned above. Whatever method of marking is used, the marking should be legible and the color should contrast with the wire insulation or sleeve.

Several different methods can be used to mark directly on the wire: hot stamp marking, ink jet printers, and laser jet printers. (***Figure 7-28***) The hot stamp method can damage the insulation of a newer type of wire that utilizes thin insulators. Fracture of the insulation wall and penetration to the conductor of these materials by the stamping dies have occurred. Later in service, when these openings have been wetted by various fluids or moisture, serious arcing and surface tracking have damaged wire bundles.

Identification sleeves can be used if the direct marking on the wire is not possible. (***Figure 7-29***)

Flexible sleeving, either clear or opaque, is satisfactory for general use. When color-coded or striped component wire is used as part of a cable, the identification sleeve should specify which color is associated with each wire identification code. Identification sleeves are normally used for identifying the following types of wire or cable: unjacketed shielded wire, thermocouple wire, coaxial cable, multi-conductor cable, and high temperature wire. In most cases, identification tape can be used in place of sleeving. For sleeving exposed to high temperatures (over 400 °F), materials, such as silicone fiberglass, should be used. Polyolefin sleeving should be used in areas where resistance to solvent and synthetic hydraulic fluids is necessary. Sleeves may be secured in place with cable ties or by heat shrinking. The identification sleeving for various sizes of wire is shown in ***Figure 7-30.***

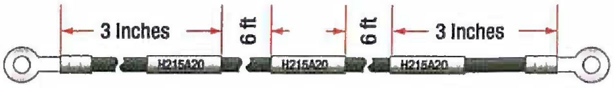


Figure 7-27. Spacing of printed identification marks (indirect marking).


Figure 7-28. Laser wire printer.


Figure 7-29. Alternate method of identifying wire bundles.

Wire Size		Sleeving Size	
AN #	AL #	No.	Nominal ID (inch)
24		12	0.085
22		11	0.095
20		10	0.106
18		9	0.118
16		8	0.113
14		7	0.148
12		6	0.166
10		4	0.208
8	8	2	0.263
6	6	0	0.330
4	4	3/8 inch	0.375
2	2	1/2 inch	0.500
1	1	1/2 inch	0.500
0	0	5/8 inch	0.625
00	00	5/8 inch	0.625
000	000	3/4 inch	0.750
0000	0000	3/4 inch	0.750

Figure 7-30. Recommended size of identification sleeving.

WIRE INSTALLATION, ROUTING, AND PROTECTION TECHNIQUES

OPEN WIRING

Interconnecting wire is used in point-to-point open harnesses, normally in the interior or pressurized fuselage, with each wire providing enough insulation to resist damage from handling and service exposure. Electrical wiring is often installed in aircraft without special enclosing means. This practice is known as open wiring and offers the advantages of ease of maintenance and reduced weight.

WIRE GROUPS AND BUNDLES AND ROUTING

Wires are often installed in bundles to create a more organized installation. These wire bundles are often called wire harnesses. Wire harnesses are often made in the factory or electrical shop on a jig board so that the wire bundles could be preformed to fit into the aircraft. (*Figure 7-31*)

As a result, each harness for a particular aircraft installation is identical in shape and length. The wiring harness could be covered by a shielding (metal braid) to avoid EMI. Grouping or bundling certain wires, such as electrically unprotected power wiring and wiring going to duplicate vital equipment, should be avoided. Wire bundles should generally be less than 75 wires, or 1½ to 2 inches in diameter where practicable. When several wires are grouped at junction boxes, terminal blocks, panels, etc., identity of the groups within a bundle can be retained.

Figure 7-31. Cable harness jig board.

SLACK IN WIRE BUNDLES

Wiring should be installed with sufficient slack so that bundles and individual wires are not under tension. Wires connected to movable or shock-mounted equipment should have sufficient length to allow full travel without tension on the bundle. Wiring at terminal lugs or connectors should have sufficient slack to allow two reterminations without replacement of wires.

This slack should be in addition to the drip loop and the allowance for movable equipment. Normally, wire groups or bundles should not exceed ½-inch deflection between support points. (***Figure 7-32***) This measurement may be exceeded if there is no possibility of the wire group or bundle touching a surface that may cause abrasion. Sufficient slack should be provided at each end to permit replacement of terminals and ease of maintenance; prevent mechanical strain on the wires, cables, junctions, and supports; permit free movement of shock- and vibration mounted equipment; and allow shifting of equipment, as necessary, to perform alignment, servicing, tuning, removal of dust covers, and changing of internal components while installed in aircraft.

TWISTING WIRES

When specified on the engineering drawing, or when accomplished as a local practice, parallel wires must sometimes be twisted. The following are the most common examples:

1. Wiring in the vicinity of magnetic compass or flux valve.
2. Three-phase distribution wiring.
3. Certain other wires (usually radio wiring) as specified on engineering drawings.

Twist the wires so they lie snugly against each other, making approximately the number of twists per foot as shown in ***Figure 7-33***. Always check wire insulation for damage after twisting. If the insulation is torn or frayed, replace the wire.

SPLICED CONNECTIONS IN WIRE BUNDLES

Splicing is permitted on wiring as long as it does not affect the reliability and the electromechanical characteristics of the wiring. Splicing of power wires, coaxial cables, multiplex bus, and large-gauge wire must have approved data. Splicing of electrical wire should be kept to a minimum and avoided entirely in locations subject to extreme vibrations.

Splicing of individual wires in a group or bundle should have engineering approval, and the splice(s) should be located to allow periodic inspection.

Many types of aircraft splice connectors are available for use when splicing individual wires.

Use of a self-insulated splice connector is preferred; however, a non-insulated splice connector may be used provided the splice is covered with plastic sleeving that is secured at both ends. Environmentally sealed splices that conform to MIL-T-7928 provide a reliable means of splicing in SWAMP areas. However, a non-insulated splice connector may be used, provided the splice is covered with dual-wall shrink sleeving of a suitable material.

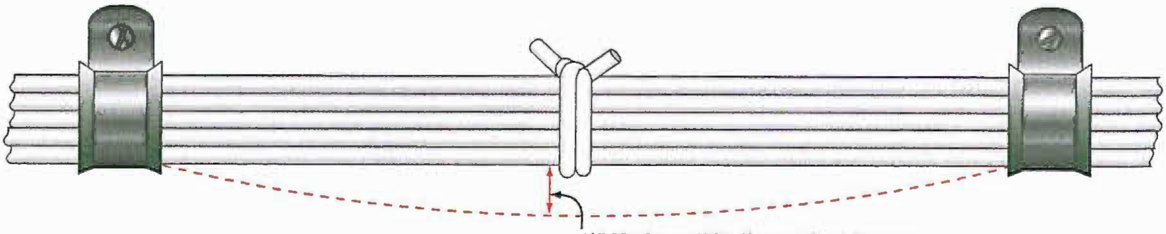


Figure 7-32. Slack between supports of a cable harness.

Gauge #	22	20	18	16	14	12	10	8	6	4
2 Wires	10	10	9	8	7½	7	6½	6	5	4
3 Wires	10	10	8½	7	6½	6	5½	5	4	3

Figure 7-33. Recommended number of wire twists per foot.

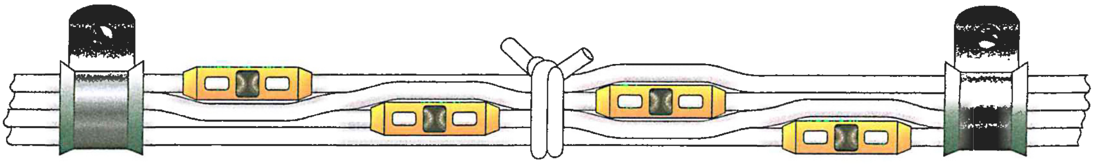


Figure 7-34. Staggered splices in wire bundle.

There should be no more than one splice in any one wire segment between any two connectors or other disconnect points. Exceptions include when attaching to the spare pigtail lead of a potted connector, when splicing multiple wires to a single wire, when adjusting wire size to fit connector contact crimp barrel size, and when required to make an approved repair.

Splices in bundles must be staggered to minimize any increase in the size of the bundle, preventing the bundle from fitting into its designated space or causing congestion that adversely affects maintenance. (***Figure 7-34***)

Splices should not be used within 12 inches of a termination device, except when attaching to the pigtail spare lead of a potted termination device, to splice multiple wires to a single wire, or to adjust the wire sizes so that they are compatible with the contact crimp barrel sizes.

BEND RADII

The minimum radius of bends in wire groups or bundles must not be less than 10 times the outside diameter of the largest wire or cable, except that at the terminal strips where wires break out at terminations or reverse direction in a bundle. Where the wire is suitably supported, the radius may be three times the diameter of the wire or cable. Where it is not practical to install wiring or cables within the radius requirements, the bend should be enclosed in insulating tubing. The radius for thermocouple wire should be done in accordance with the manufacturer's recommendation and shall be sufficient to avoid excess losses or damage to the cable. Ensure that RF cables (e.g., coaxial and triaxial) are bent at a radius of no less than six times the outside diameter of the cable.

PROTECTION AGAINST CHAFING

Wires and wire groups should be protected against chafing or abrasion in those locations where contact with sharp surfaces or other wires would damage the insulation, or chafing could occur against the airframe or other components. Damage to the insulation can cause short circuits, malfunction, or inadvertent operation of equipment.

PROTECTION AGAINST HIGH TEMPERATURE

Wiring must be routed away from high-temperature equipment and lines to prevent deterioration of insulation. Wires must be rated so the conductor temperature remains within the wire specification maximum when the ambient temperature and heat rise related to current-carrying capacity are taken into account. The residual heating effects caused by exposure to sunlight when aircraft are parked for extended periods should also be taken into account.

Wires, such as those used in fire detection, fire extinguishing, fuel shutoff, and fly-by-wire flight control systems that must operate during and after a fire, must be selected from types that are qualified to provide circuit integrity after exposure to fire for a specified period. Wire insulation deteriorates rapidly when subjected to high temperatures.

Separate wires from high-temperature equipment, such as resistors, exhaust stacks, heating ducts, to prevent insulation breakdown.

Insulate wires that must run through hot areas with a high-temperature insulation material, such as fiberglass or PTFE. Avoid high-temperature areas when using cables with soft plastic insulation, such as polyethylene, because these materials are subject to deterioration and deformation at elevated temperatures. Many coaxial cables have this type of insulation.

PROTECTION AGAINST SOLVENTS AND FLUIDS

An arcing fault between an electrical wire and a metallic flammable fluid line may puncture the line and result in a fire. Every effort must be made to avoid this hazard by physical separation of the wire from lines and equipment containing oxygen, oil, fuel, hydraulic fluid, or alcohol. Wiring must be routed above these lines and equipment with a minimum separation of 6 inches or more whenever possible. When such an arrangement is not practicable, wiring must be routed so that it does not run parallel to the fluid lines. A minimum of 2 inches must be maintained between wiring and such lines and equipment, except when the wiring is positively clamped to maintain at least 1/2-inch separation, or when it must be connected directly to the fluid-carrying equipment. Install clamps as shown in ***Figure 7-35***.

These clamps should not be used as a means of supporting the wire bundle. Additional clamps should be installed to support the wire bundle and the clamps fastened to the same structure used to support the fluid line(s) to prevent relative motion.

Wires, or groups of wires, should enter a junction box, or terminate at a piece of equipment in an upward direction where practicable. Ensure that a trap, or drip loop, is provided to prevent fluids or condensation from running into wire or cable ends that slope downward toward a connector, terminal block, panel, or junction block.

A drip loop is an area where the wire(s) are made to travel downward and then up to the connector. (***Figure 7-36***) Fluids and moisture will flow along the wires to the bottom of the loop and be trapped there to drip or evaporate without affecting electrical conductivity in the wire, junction, or connected device.

Where wires must be routed downwards to a junction box or electrical unit and a drip loop is not possible, the entrance should be sealed according to manufacturer's specifications to prevent moisture from entering the box/unit. Wires and cables installed in bilges and other locations where fluids collect must be routed as far from the lowest point as possible or otherwise be provided with a moisture-proof covering.

PROTECTION OF WIRES IN WHEEL WELL AREAS

Wires located on landing gear and in the wheel well area can be exposed to many hazardous conditions if not suitably protected. Where wire bundles pass flex points, there must not be any strain on attachments or excessive slack when parts are fully extended or retracted. The wiring and protective tubing must be inspected frequently and replaced at the first sign of wear.

Figure 7-35. Positive separation of wires and wire clamps.

Figure 7-36. Drip loop.

Wires should be routed so that fluids drain away from the connectors. When this is not practicable, connectors must be potted. Wiring which must be routed in wheel wells or other external areas must be given extra protection in the form of harness jacketing and connector strain relief. Conduits or flexible sleeving used to protect wiring must be equipped with drain holes to prevent entrapment of moisture.

The technician should check during inspections that wires and cables are adequately protected in wheel wells and other areas where they may be exposed to damage from impact of rocks, ice, mud, etc. (If rerouting of wires or cables is not practical, protective jacketing may be installed). This type of installation must be held to a minimum.

CLAMP INSTALLATION

Wires and wire bundles must be supported by clamps or plastic cable straps. (*Figure 7-37*) Clamps and other primary support devices must be constructed of materials that are compatible with their installation and environment, in terms of temperature, fluid resistance, exposure to ultraviolet (UV) light, and wire bundle mechanical loads. They should be spaced at intervals not exceeding 24 inches. Clamps on wire bundles should be selected so that they have a snug fit without pinching wires. (*Figures 7-38 through 7-40*)

Caution: The use of metal clamps on coaxial RF cables may cause problems, if clamp fit is such that RF cable's original cross section is distorted.

Clamps on wire bundles should not allow the bundle to move through the clamp when a slight axial pull is applied. Clamps on RF cables must fit without crushing and must be snug enough to prevent the cable from moving freely through the clamp, but may allow the cable to slide through the clamp when a light axial pull is applied. The cable or wire bundle may be wrapped with one or more turns of electrical tape when required to achieve this fit. Plastic clamps or cable ties must not be used where their failure could result in interference with movable controls, wire bundle contact with movable equipment, or chafing damage to essential or unprotected wiring. They must not be used on vertical runs where inadvertent slack migration could result in chafing or other damage. Clamps must be installed with their attachment hardware positioned above them, wherever practicable, so that they are unlikely to rotate as the result of wire bundle weight or wire bundle chafing. (*Figure 7-38*)

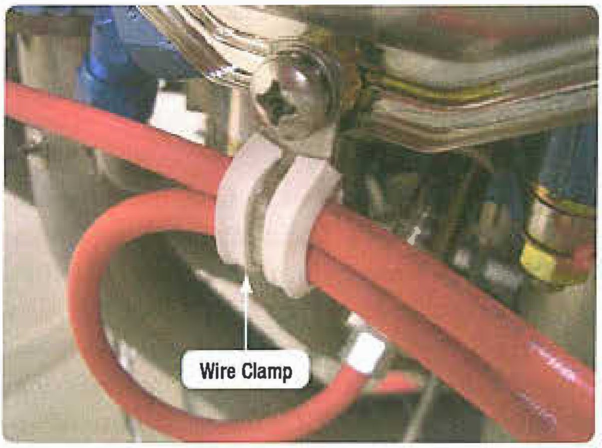


Figure 7-37. Wire clamps.

Clamps lined with nonmetallic material should be used to support the wire bundle along the run. Tying may be used between clamps, but should not be considered as a substitute for adequate clamping. Adhesive tapes are subject to age deterioration and, therefore, are not acceptable as a clamping means. (*Figure 7-39*)

The back of the clamp, whenever practical, should be rested against a structural member. (*Figure 7-40*) Stand-offs should be used to maintain clearance between the wires and the structure. Clamps must be installed in such a manner that the electrical wires do not come in contact with other parts of the aircraft when subjected to vibration.

Sufficient slack should be left between the last clamp and the electrical equipment to prevent strain at the terminal and to minimize adverse effects on shock-mounted equipment. Where wires or wire bundles pass through bulkheads or other structural members, a grommet or suitable clamp should be provided to prevent abrasion.

When a wire bundle is clamped into position, if there is less than ⅜ inch of clearance between the bulkhead cutout and the wire bundle, a suitable grommet should be installed as indicated in *Figure 7-41*. The grommet may be cut at a 45° angle to facilitate installation, provided it is cemented in place and the slot is located at the top of the cutout.

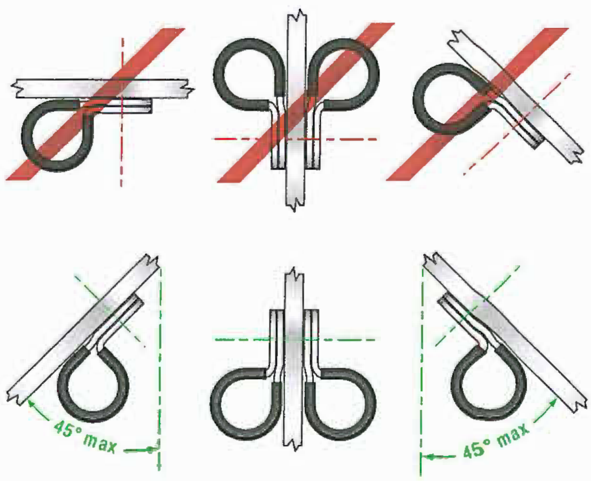


Figure 7-38. Safe angle for cable clamps.

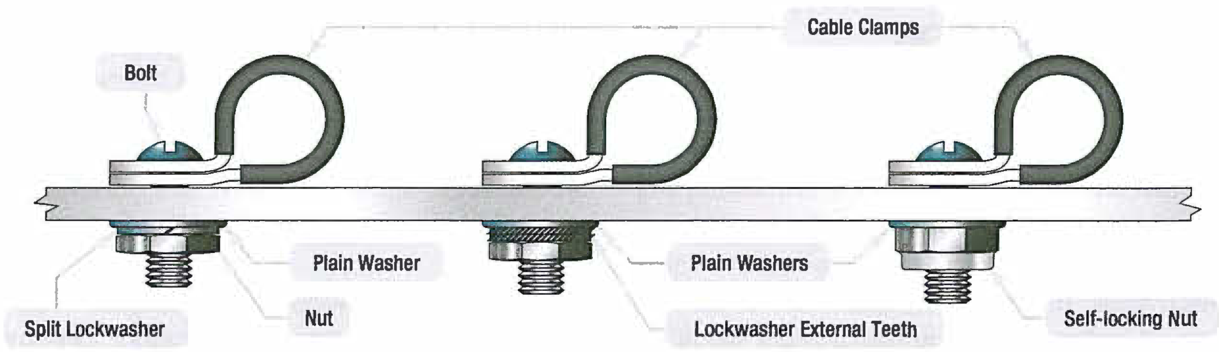


Figure 7-39. Typical mounting hardware for MS-21919 cable clamps.

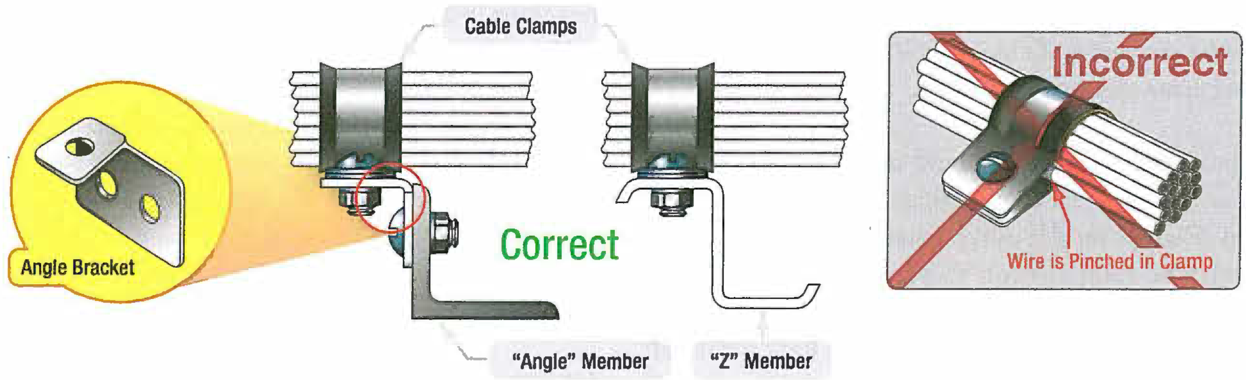


Figure 7-40. Installing cable clamp to structure.

WIRE AND CABLE CLAMP INSPECTION

Inspect wire and cable clamps for proper tightness. Where cables pass through structure or bulkheads, inspect for proper clamping and grommets. Inspect for sufficient slack between the last clamp and the electronic equipment to prevent strain at the cable terminals and to minimize adverse effects on shock-mounted equipment. Wires and cables are supported by suitable clamps, grommets, or other devices at intervals of not more than 24 inches, except when contained in troughs, ducts, or conduits. The supporting devices should be of a suitable size and type, with the wires and cables held securely in place without damage to the insulation.

Use metal stand-offs to maintain clearance between wires and structure. Tape or tubing is not acceptable as an alternative to stand-offs for maintaining clearance. Install phenolic blocks, plastic liners, or rubber grommets in holes, bulkheads, floors, or structural members where it is impossible to install off angle clamps to maintain wiring separation. In such cases, additional protection in the form of plastic or insulating tape may be used.

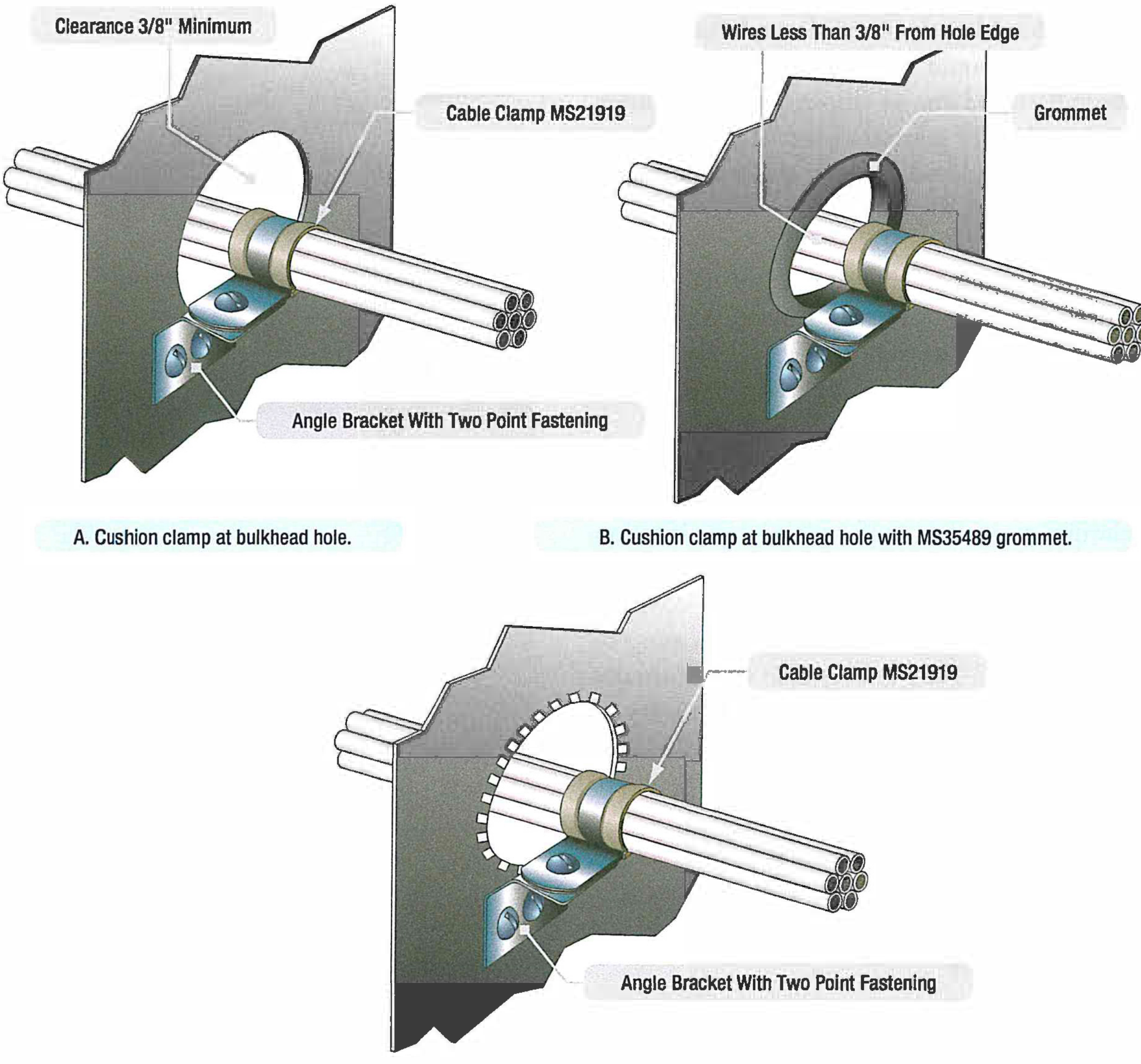
Properly secure clamp retaining bolts so the movement of wires and cables is restricted to the span between the points of support and not on soldered or mechanical connections at terminal posts or connectors.

MOVABLE CONTROLS WIRING PRECAUTIONS

Clamping of wires routed near movable flight controls must be attached with steel hardware and must be spaced so that failure of a single attachment point cannot result in interference with controls. The minimum separation between wiring and movable controls must be at least ½-inch (12.7 mm) when the bundle is displaced by light hand pressure in the direction of the controls.

CONDUIT

Conduit is manufactured in metallic and nonmetallic materials and in both rigid and flexible forms. Primarily, its purpose is for mechanical protection of cables or wires. Conduit size should be selected for a specific wire bundle application to allow for ease in maintenance, and possible future circuit expansion, by specifying the conduit inner diameter (ID) about 25 percent larger than the maximum diameter of the wire bundle.



A. Cushion clamp at bulkhead hole.

B. Cushion clamp at bulkhead hole with MS35489 grommet.

C. Cushion clamp at bulkhead hole with MS21266 grommet.

Figure 7-41. Clamping at a bulkhead hole.

Conduit problems can be avoided by following these guidelines:

- Do not locate conduit where passengers or maintenance personnel might use it as a handhold or footstep.
- Provide drain holes at the lowest point in a conduit run. Drilling burrs should be carefully removed.
- Support conduit to prevent chafing against structure and to avoid stressing its end fittings.

RIGID CONDUIT

Damaged conduit sections should be repaired to preclude injury to the wires or wire bundle that may consume as much as 80 percent of the tube area. Minimum acceptable tube bend radii for rigid conduit are shown in ***Figure 7-42***.

Nominal Tube OD (inches)	Minimum Bend Radius (Inches)
1/8	3/8
3/16	7/16
1/4	9/16
3/8	15/16
1/2	1 1/4
5/8	1 1/2
3/4	1 3/4
1	3
1 1/4	3 3/4
1 1/2	5
1 3/4	7
2	8

Figure 7-42. Minimum bend radii for rigid conduit.

Kinked or wrinkled bends in rigid conduits are not recommended and should be replaced. Tubing bends that have been flattened into an ellipse and have a minor diameter of less than 75 percent of the nominal tubing diameter should be replaced, because the tube area has been reduced by at least 10 percent.

Tubing that has been formed and cut to final length should be deburred to prevent wire insulation damage. When installing replacement tube sections with fittings at both ends, care should be taken to eliminate mechanical strain.

FLEXIBLE CONDUIT

Flexible aluminum conduit conforming to specification MIL-C-6136 is available in two types: Type I, bare flexible conduit, and Type II, rubber-covered flexible conduit. Flexible brass conduit conforming to specification MIL-C-7931 is available and normally used instead of flexible aluminum where necessary to minimize radio interference. Also available is a plastic flexible tubing. (Reference MIL-T-8191A.)

Flexible conduit may be used where it is impractical to use rigid conduit, such as areas that have motion between conduit ends or where complex bends are necessary. (***Figure 7-43***)

Figure 7-43. Flexible conduit.

Nominal ID of Conduit (inches)	Minimum Bending Radius Inside (Inches)
3/16	2 1/4
1/4	2 3/4
3/8	3 3/4
1/2	3 3/4
5/8	3 3/4
3/4	4 1/4
1	5 3/4
1 1/4	8
1 1/2	8 1/4
1 3/4	9
2	9 3/4
2 1/2	10

Figure 7-44. Minimum bending radii for flexible aluminum or brass conduit.

The use of transparent adhesive tape is recommended when cutting flexible tubing with a hacksaw to minimize fraying of the braid. The tape should be centered over the cutting reference mark with the saw cutting through the tape. After cutting the flexible conduit, the transparent tape should be removed, the frayed braid ends trimmed, burrs removed from inside the conduit, and coupling nut and ferrule installed. Minimum acceptable bending radii for flexible conduit are shown in ***Figure 7-44***.

HEAT SHRINK WRAPPING

In certain applications, heat shrinkable tubing may be an appropriate alternative to flexible conduit. Various types are available for different purposes such as identification and color coding, strain relief of wires and terminations, and cable jacketing and repair work. Each type has a dielectric rating and operating temperature range which must be considered before usage.

Heat shrink wrap comes in a variety of diameters so that it can be slipped over the wire(s) or cable yet, when heated, the wrap shrinks to a snug fit around them. Once the proper size and material of heat shrink wrap is selected and cut to length, position the tubing as required over the item to be covered. Use a hot-air gun or compressed air heater as the heat source. Apply the heat evenly over the full length of the wrap until it shrinks and conforms to the component being covered. Allow it to cool before handling.

Note that electric heat guns are not explosion proof and are not approved for use in hazardous locations. A pneumatic powered gun is preferred. Various reflectors or nozzles may be available to attach to the gun. Use caution to not overheat the wrap or the wires inside. Polyurethane coated wires, for example, release irritating gases when the temperature exceeds 315 °C.

WIRE SHIELDING

With the increase in number of highly sensitive electronic devices found on modern aircraft, it has become very important to ensure proper shielding for many electric circuits. Shielding is the process of applying a metallic covering to wiring and equipment to eliminate electromagnetic interference (EMI). EMI is caused when electromagnetic fields (radio waves) induce high frequency (HF) voltages in a wire or component. The induced voltage can cause system inaccuracies or even failure.

Use of shielding with 85 percent coverage or greater is recommended. Coaxial, triaxial, twinaxial, or quadraxial cables should be used, wherever appropriate, with their shields connected to ground at a single point or multiple points, depending upon the purpose of the shielding. (*Figure 7-45*) The airframe grounded structure may also be used as an EMI shield.

In conventional wiring systems, circuits are shielded individually, in pairs, triples, or quads depending on each circuit's shielding requirement called out for in the engineering documentation. A wire is normally shielded when it is anticipated that the circuit can be affected by another circuit in the wire harness. When the wires come close together, they can couple enough interference to cause a detrimental upset to attached circuitry. This effect is often called crosstalk. Wires must come close enough for their fields to interact, and they must be in an operating mode that produces the crosstalk effect. However, the potential for crosstalk is real, and the only way to prevent crosstalk is to shield the wire. (*Figure 7-46*)

Figure 7-45. Shielded wire harness for flight control.

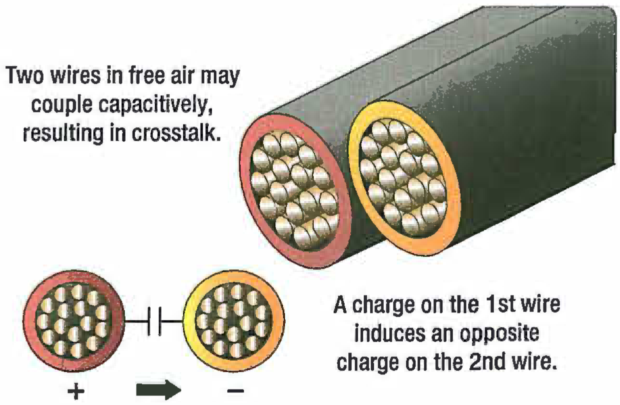


Figure 7-46. Crosstalk.

EWIS STANDARDS

Historically, wiring and associated components were installed without much thought given to aspects from the result of aging. A fit and forget mentality prevailed without much anticipation of insulation flashover, arcing, and other failures. Worse was the lack of recognition of the potential severity of incidents that could come from EWIS failures. Maintenance programs often did not address the aging aspects of wiring degradation and faults.

In the late 1980's, incidents and accidents due to wiring issues, along with the general increase in focus on the effects of aging on aircraft, resulted in numerous investigations by industry, civil aviation authorities and other government agencies. It was revealed that numerous factors contribute to degradation of aircraft wiring systems.

Some of these factors are:

- Design
- Maintenance
- Operation
- Training
- Repair
- Installation
- Environment
- Awareness
- Abuse
- Time

Since all of these factors contribute to degradation, a single action is not sufficient to correct the problem. Action on all fronts is needed. Design approval holders now follow stricter guidelines for certification and continued airworthiness instructions.

Operators are required to inspect EWIS frequently and provide better training to maintenance personnel. Technicians are charged with some new repair techniques and rededication to safe practices when repairing and inspecting EWIS. A cultural shift or awareness by the aviation maintenance community that electrical wiring interconnection systems are to be treated as important systems on aircraft is required.

During maintenance and repair work, many contributors to the degradation of EWIS are present. Chemical contamination from fluids, improper routing, clamping and terminations, FOD from maintenance actions (drill filings, etc.) and poor/improper repairs contribute to EWIS degradation. Heat and vibration also contribute. Moisture surely increases degradation as do malfunctions of adjacent systems in the general vicinity of the EWIS. (A bleed air duct leak, for example, may expose the EWIS to excessively high temperature.)

EWIS INSPECTION

Many simple corrections to EWIS can be made to ensure reduced degradation and provide a longer functional life. Inspection of installations, repairs, and general appearance go a long way towards solving EWIS problems. Following inspections with manufacturer specified procedures ensures that up to date EWIS concerns and procedures are addressed.

Three basic EWIS inspections exist. The first is a general visual inspection or GVI. The second is a stand-alone GVI and the third is a detailed inspection or DET. For general visual inspection, a mirror may be necessary to enhance visual access to all exposed surfaces in the inspection area. This level of inspection is made under normally available lighting conditions such as daylight, hangar lighting, flashlight, or droplight and may require removal or opening of access panels or doors.

Stands, ladders, or platforms may be required to gain proximity to the area being checked. A GVI includes a visual examination of an interior or exterior area, installation or assembly to detect obvious damage, failure, or irregularity.

A stand-alone GVI is an inspection of a particular area, installation or assembly that is not part of a general zonal inspection. In fact, even when a particular zone of an EWIS is inspected, a separate stand-alone GVI may be called for with its own paperwork to insure attention to the stand-alone item.

A DET or detailed inspection of a specific item or assembly may be specified in the manufacturers ICA or maintenance manual. Follow the instructions to accomplish this inspection.

EWIS inspection focus areas include:

- Clamping Points - Wire chafing is aggravated by loose clamps, damaged clamps, clamp cushion migration, or improper clamp installations.
- Connectors - Worn environmental seals, loose connectors, excessive corrosion, missing seal plugs, missing dummy contacts, or lack of strain relief on connector grommets can compromise connector integrity and allow contamination to enter the connector, leading to corrosion or grommet degradation. Drip loops should be maintained when connectors are below the level of the harness and tight bends at connectors should be avoided or corrected.
- Terminations - Terminal lugs and splices are susceptible to mechanical damage, corrosion, heat damage and chemical contamination. Also, the build up and nut torque on large-gauge wire studs is critical to their performance.
- Backshells - Wires may break at backshells, due to excessive flexing, lack of strain relief, or improper build-up. Loss of backshell bonding may also occur due to these and other factors.
- Damaged Sleeving and Conduits - Damage to sleeving and conduits, if not corrected, will often lead to wire damage.
- Grounding Points - Grounding points should be checked for security (i.e. tightness), condition of the termination, cleanliness, and corrosion. Any grounding points that are corroded or have lost their protective coating should be repaired.

Some EWIS inspection locations are listed below. Available data has shown that these areas should receive special attention in an operators EWIS inspection program:

- Wings - The wing leading and trailing edges are areas that experience difficult environments for EWIS installations. The wing leading and trailing edge EWIS is exposed on some aircraft models whenever the flaps or slats are extended. Other potential damage sources include slat torque shafts and bleed air ducts.
- Engine, Pylon, and Nacelle Area - These areas experience high vibration, heat, frequent maintenance, and are susceptible to chemical contamination.
- APU - Like the engine/nacelle area, the APU is susceptible to high vibration, heat, frequent maintenance, and chemical contamination.
- Landing Gear and Wheel Wells - This area is exposed to severe external environmental conditions in addition to vibration and chemical contamination.
- Electrical Panels and Line Replaceable Units (LRUs) - Panel EWIS is particularly prone to broken wires and damaged insulation when these high density areas are disturbed during troubleshooting activities, major modifications, and refurbishment. One repair facility has found that wire damage was minimized by tying EWIS to wooden dowels. This reduced wire disturbance during modification. It is also recommended to remove entire disconnect brackets, when possible, instead of removing individual receptacles.
- Batteries - Wires and EWIS hardware in the vicinity of all aircraft batteries should be inspected for corrosion and discoloration. Discolored wires should be inspected for serviceability. Corroded wires and/or EWIS hardware should be replaced.
- Power Feeders - Operators may find it advantageous to inspect splices and terminations for signs of overheating and security. If any signs of overheating are seen, the splice or termination should be replaced. This applies to galley power feeders, in addition to the main and APU generator power feeders. The desirability of periodically retorquing power feeder terminations should be evaluated.
- Under Galleys and Lavatories - Areas under the galleys, lavatories and other liquid containers are particularly susceptible to contamination from coffee, food, water, soft drinks and lavatory fluids, etc. Fluid drain provisions should be periodically inspected and repaired as necessary.
- Cargo Bay/Under Floor - Cargo can damage EWIS. Damage to EWIS under a cargo bay floor can occur due to maintenance activities in the area.
- Surfaces, Controls, and Doors - Moving or bending harnesses should be inspected at these locations.
- Access Panels - Harnesses near access panels may receive accidental damage and should have special emphasis inspections.

EWIS CLEANING REQUIREMENTS AND METHODS

An EWIS cleaning program encourages a protect and clean-as-you-go philosophy. Manufacturers and operators are required to identify non-destructive methods for cleaning dust, dirt, foreign object debris (FOD), lavatory fluid, and other contaminants produced by an aircraft environment from wiring systems. They must also specify wire replacement guidelines when an accumulation of contaminants, either on the surface and/or embedded in the wire bundle, cannot be safely removed. Follow manufacturer's and operator's guidance for maintaining a clean EWIS.

Question: 7-1
EWIS stands for ______________________.

Question: 7-2
The ________________ of all bond and ground connections should be tested after connections are made before re-finishing.

Question: 7-3
Wires are usually joined at ________________.

Question: 7-4
Connectors must be identified by an original identification number derived from MIL Specification (MS) or ________________ specification.

Question: 7-5
Wiring must be routed so that moisture accumulated on the bundle drains ________________ from connectors.

Question: 7-6
Identification markings are placed at each end of a wire and at ________________ maximum intervals along the length of the wire.

Question: 7-7
Normally, wire groups or bundles should not exceed __________ deflection between support points.

Question: 7-8
Wires and wire bundles must be supported by clamps or plastic cable straps at spaced intervals not exceeding ________________.

ANSWERS

Answer: 7-1
Electrical Wiring Interconnection System

Answer: 7-2
resistance.

Answer: 7-3
terminal strips.

Answer: 7-4
OEM (manufacturer's).

Answer: 7-5
away.

Answer: 7-6
15-inch.

Answer: 7-7
½-inch (1.27 cm).

Answer: 7-8
24 inches (.6 meter).

MAINTENANCE PRACTICES

RIVETING

SUB-MODULE 08

PART-66 SYLLABUS CERTIFICATION CATEGORY →	LEVELS B1	 B2
Sub-Module 08 RIVETING Knowledge Requirements		
7.8 - Riveting Riveted joints, rivet spacing and pitch; Tools used for riveting and dimpling; Inspection of riveted joints.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:

(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

RIVETS

SOLID SHANK RIVET

The solid shank rivet is the most common type of rivet used in aircraft construction. Used to join aircraft structures, solid shank rivets are one of the oldest and most reliable types of fastener. Widely used in the aircraft manufacturing industry, solid shank rivets are relatively low-cost, permanently installed fasteners. They are faster to install than bolts and nuts since they adapt well to automatic, high-speed installation tools. Rivets should not be used in thick materials or in tensile applications, as their tensile strengths are quite low relative to their shear strength. The longer the total grip length, the more difficult it becomes to lock the rivet.

Riveted joints are neither airtight nor watertight unless special seals or coatings are used. Since rivets are permanently installed, they must be removed by drilling them out, a laborious task.

DESCRIPTION

Before installation, the rivet consists of a smooth cylindrical shaft with a factory head on one end. The opposite end is called the bucktail. To secure two or more pieces of sheet metal together, the rivet is placed into a hole cut just a bit larger in diameter than the rivet itself. Once placed in this predrilled hole, the bucktail is upset or deformed by any of several methods from hand-held hammers to pneumatically driven squeezing tools. This action causes the rivet shank protruding through the sheet metal to form a shop head of approximately 1-½ times the diameter of the rivet and reduces the length to ½ times the diameter of the rivet. (***Figure 8-1***)

RIVET HEAD SHAPE

Solid rivets are available in several head shapes, but the universal and the 100° countersunk head are the most commonly used in aircraft structures. Universal head rivets were developed specifically for the aircraft industry and designed as a replacement for both the round and brazier head rivets.

These rivets replaced all protruding head rivets and are used primarily where the protruding head has no aerodynamic significant. They have a flat area on the head, a head diameter twice the shank diameter, and a head height approximately 42.5 percent of the shank diameter. (***Figure 8-1***)

Figure 8-1. Solid shank rivet styles.

The countersunk head angle can vary from 60° to 120°, but the 100° has been adopted as standard because this head style provides the best possible compromise between tension/shear strength and flushness requirements. This rivet is used where flushness is required because the rivet is flat-topped and undercut to allow the head to fit into a countersunk or dimpled hole. The countersunk rivet is primarily intended for use when aerodynamics smoothness is critical, such as on the external surface of a high-speed aircraft.

Typically, rivets are fabricated from aluminum alloys, such as 2017-T4, 2024-T4, 2117-T4, 7050, and 5056. Titanium, nickel-based alloys, such as Monel® (corrosion-resistant steel), mild steel or iron, and copper rivets are also used for rivets in certain cases.

Rivets are available in a wide variety of alloys, head shapes, and sizes and have a wide variety of uses in aircraft structure. Rivets that are satisfactory for one part of the aircraft are often unsatisfactory for another part. Therefore, it is important that an aircraft technician know the strength and driving properties of the various types of rivets and how to identify them, as well as how to drive or install them.

Solid rivets are classified by their head shape, by the material from which they are manufactured, and by their size. Identification codes used are derived from a combination of the Military Standard (MS) and National Aerospace Standard (NAS) systems, as well as an older classification system known as AN for Army/Navy. For example, the prefix MS identifies hardware that conforms to written military standards. A letter or letters following the head-shaped code identify the material or alloy from which the rivet was made. The alloy code is followed by two numbers separated by a dash. The first number is the numerator of a fraction, which specifies the shank diameter in thirty-seconds of an inch. The second number is the numerator of a fraction in sixteenths of an inch and identifies the length of the rivet. Rivet head shapes and their identifying code numbers are shown in ***Figure 8-2***.

The most frequently used repair rivet is the AD rivet because it can be installed in the received condition. Some rivet alloys, such as DD rivets (alloy 2024-T4), are too hard to drive in the received condition and must be annealed before they can be installed. Typically, these rivets are annealed and stored in a freezer to retard hardening, which has led to the nickname "ice box rivets." They are removed from the freezer just prior to use. Most DD rivets have been replaced by E-type rivets which can be installed in the received condition.

The head type, size, and strength required in a rivet are governed by such factors as the kind of forces present at the point riveted, the kind and thickness of the material to be riveted, and the location of the part on the aircraft. The type of head needed for a particular job is determined by where it is to be installed. Countersunk head rivets should be used where a smooth aerodynamic surface is required. Universal head rivets may be used in most other areas.

The size (or diameter) of the selected rivet shank should correspond in general to the thickness of the material being riveted. If an excessively large rivet is used in a thin material, the force necessary to drive the rivet properly causes an undesirable bulging around the rivet head. On the other hand, if an excessively small rivet diameter is selected for thick material, the shear strength of the rivet is not great enough to carry the load of the joint. As a general rule, the rivet diameter should be at least two and a half to three times the thickness of the thicker sheet. Rivets most commonly chosen in the assembly and repair of aircraft range from 3⁄32 inch to 3⁄8 inch in diameter. Ordinarily, rivets smaller than 3⁄32 inch in diameter are never used on any structural parts that carry stresses.

The proper sized rivets to use for any repair can also be determined by referring to the rivets (used by the manufacturer) in the next parallel row inboard on the wing or forward on the fuselage. Another method of determining the size of rivets to be used is to multiply the skin's thickness by 3 and use the next larger size rivet corresponding to that figure.

For example, if the skin is 0.040 inch thick, multiply 0.040 inch by 3 to get 0.120 inch and use the next larger size of rivet, ⅛ inch (0.125 inch).

When rivets are to pass completely through tubular members, select a rivet diameter equivalent to at least ⅛ the outside diameter of the tube. If one tube sleeves or fits over another, take the outside diameter of the outside tube and use one eighth of that distance as the minimum rivet diameter. A good practice is to calculate the minimum rivet diameter and then use the next larger size rivet.

Whenever possible, select rivets of the same alloy number as the material being riveted. For example, use 1100 and 3003 rivets on parts fabricated from 1100 and 3003 alloys, and 2117-1 and 2017-T rivets on parts fabricated from 2017 and 2024 alloys.

The size of the formed head is the visual standard of a proper rivet installation. The minimum and maximum sizes, as well as the ideal size, are shown in ***Figure 8-3***.

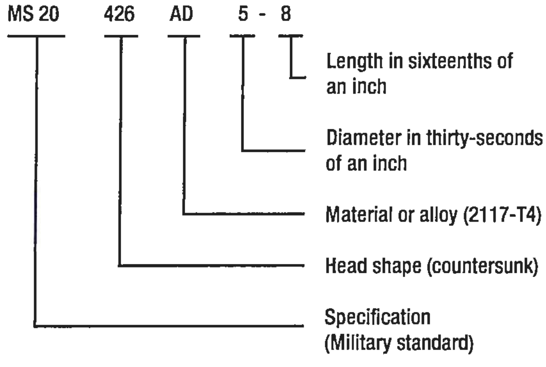


Figure 8-2. Rivet head shapes and their identifying code numbers.

INSTALLATION OF RIVETS

REPAIR LAYOUT

Repair layout involves determining the number of rivets required, the proper size and style of rivets to be used, their material, temper condition and strength, the size of the holes, the distances between the holes, and the distance between the holes and the edges of the patch. Distances are measured in terms of rivet diameter.

RIVET LENGTH

To determine the total length of a rivet to be installed, the combined thickness of the materials to be joined must first be known. This measurement is known as the grip length. The total length of the rivet equals the grip length plus the amount of rivet shank needed to form a proper shop head. The latter equals one and a half times the diameter of the rivet shank. Where A is total rivet length, B is grip length, and C is the length of the material needed to form a shop head, this formula can be represented as $A = B + C$. (***Figure 8-3***)

RIVET STRENGTH

For structural applications, the strength of the replacement rivets is of primary importance. (***Figure 8-4***) Rivets made of material that is lower in strength should not be used as replacements unless the shortfall is made up by using a larger rivet. For example, a rivet of 2024-T4 aluminum alloy should not be replaced with one of 2117-T4 or 2017-T4 aluminum alloy unless the next larger size is used.

The 2117-T rivet is used for general repair work, since it requires no heat treatment, is fairly soft and strong, and is highly corrosion resistant when used with most types of alloys. Always consult the maintenance manual for correct rivet type and material. The type of rivet head to select for a particular repair job can be determined by referring to the type used within the surrounding area by the manufacturer. A general rule to follow on a flush-riveted aircraft is to apply flush rivets on the upper surface of the wing and stabilizers, on the lower leading edge back to the spar, and on the fuselage back to the high point of the wing. Use universal head rivets in all other surface areas. Whenever possible, select rivets of the same alloy number as the material being riveted.

STRESSES APPLIED TO RIVETS

Shear is one of the two stresses applied to rivets. The shear strength is the amount of force required to cut a rivet that holds two or more sheets of material together. If the rivet holds two parts, it is under single shear; if it

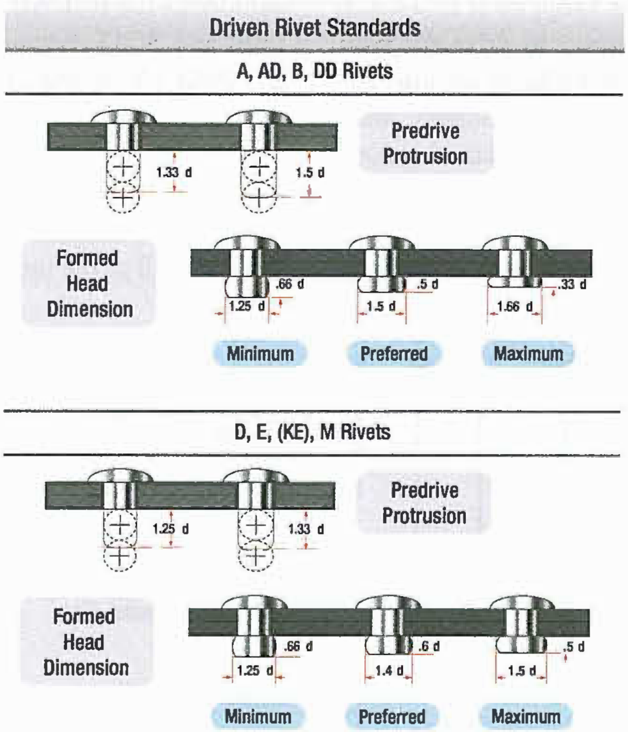


Figure 8-3. Rivet formed head dimensions.

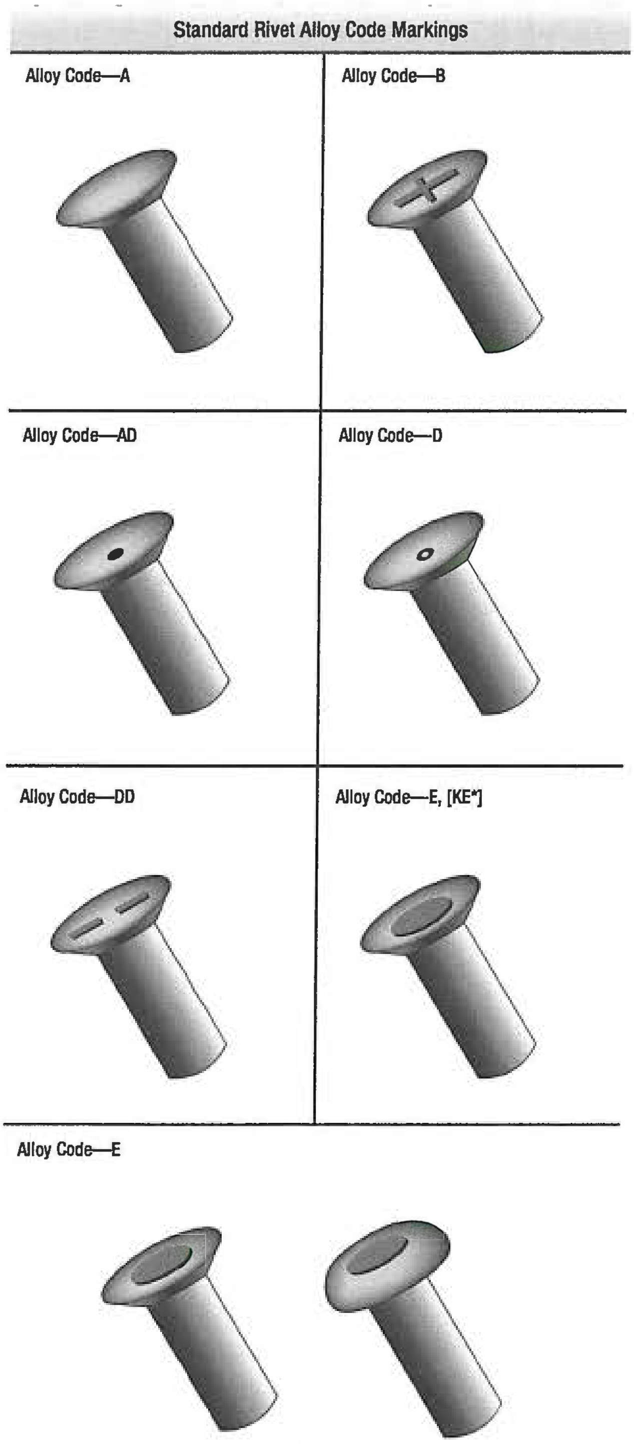


Figure 8-4. Rivet alloy strength.

holds three sheets or parts, it is under double shear. To determine the shear strength, the diameter of the rivet to be used must be found by multiplying the thickness of the skin material by 3.

For example, a material thickness of 0.040 inch multiplied by 3 equals 0.120 inch. In this case, the rivet diameter selected would be ⅛ (0.125) inch.

Tension is the other stress applied to rivets. The resistance to tension is called bearing strength and is the amount of tension required to pull a rivet through the edge of two sheets riveted together or to elongate the hole.

RIVET SPACING

Rivet spacing is measured between the centerlines of rivets in the same row. The minimum spacing between protruding head rivets shall not be less than 3½ times the rivet diameter. The minimum spacing between flush head rivets shall not be less than 4 times the diameter of the rivet. These dimensions may be used as the minimum spacing except when specified differently in a specific repair procedure or when replacing existing rivets.

On most repairs, the general practice is to use the same rivet spacing and edge distance (distance from the center of the hole to the edge of the material) that the manufacturer used.

The structural repair manual for the particular aircraft may also be consulted. Aside from this fundamental rule, there is no specific set of rules that governs spacing of rivets in all cases. However, there are certain minimum requirements that must be observed.

- When possible, rivet edge distance, rivet spacing, and distance between rows should be the same as that of the original installation.
- When new sections are to be added, the edge distance measured from the center of the rivet should never be less than 2 times the diameter of the shank; the distance between rivets or pitch should be at least 3 times the diameter; and the distance between rivet rows should never be less than 2½ times the diameter.

Figure 8-5 illustrates acceptable ways of laying out a rivet pattern for a repair.

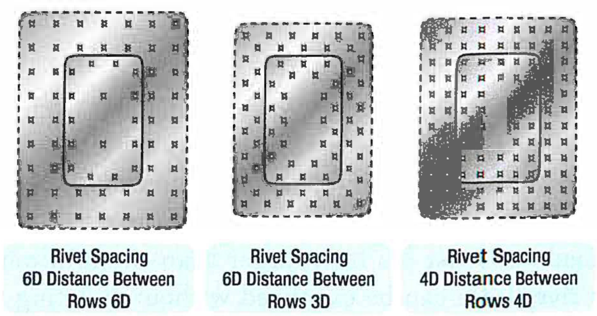


Figure 8-5. Acceptable rivet patterns.

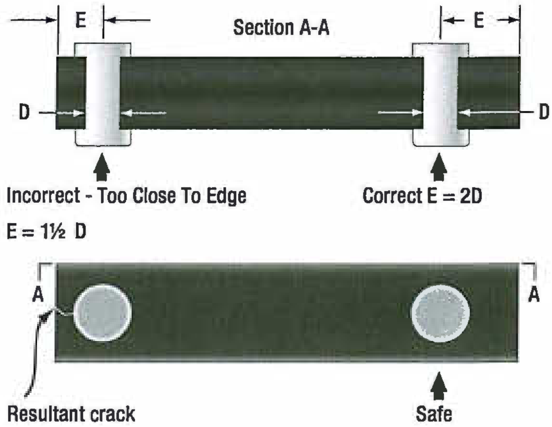
EDGE DISTANCE

Edge distance, also called edge margin by some manufacturers, is the distance from the center of the first rivet to the edge of the sheet. It should not be less than 2 or more than 4 rivet diameters and the recommended edge distance is about 2½ rivet diameters. The minimum edge distance for universal rivets is 2 times the diameter of the rivet; the minimum edge distance for countersunk rivets is 2½ times the diameter of the rivet. If rivets are placed too close to the edge of the sheet, the sheet may crack or pull away from the rivets. If they are spaced too far from the edge, the sheet is likely to turn up at the edges. (*Figure 8-6*)

It is good practice to lay out the rivets a little further from the edge so that the rivet holes can be oversized without violating the edge distance minimums. Add 1/16 inch to the minimum edge distance or determine the edge distance using the next size of rivet diameter.

Two methods for obtaining edge distance:

- The rivet diameter of a protruding head rivet is 3/32 inch. Multiply 2 times 3/32 inch to obtain the minimum edge distance, 3/16 inch, add 1/16 inch to yield the preferred edge distance of 1/4 inch.
- The rivet diameter of a protruding head rivet is 3/32 inch. Select the next size of rivet, which is 1/8 inch. Calculate the edge distance by multiplying 2 times 1/8 inch to get 1/4 inch.



Edge Distance/Edge Margin	Minimum Edge Distance	Preferred Edge Distance
Protruding Head Rivets	2 D	2 D + 1/16"
Countersunk Rivets	2½ D	2½ D + 1/16"

Figure 8-6. Minimum edge distance.

RIVET PITCH

Rivet pitch is the distance between the centers of neighboring rivets in the same row. The smallest allowable rivet pitch is 3 rivet diameters. The average rivet pitch usually ranges from 4 to 6 rivet diameters, although in some instances rivet pitch could be as large as 10 rivet diameters. Rivet spacing on parts that are subjected to bending moments is often closer to the minimum spacing to prevent buckling of the skin between the rivets. The minimum pitch also depends on the number of rows of rivets.

One-and three-row layouts have a minimum pitch of 3 rivet diameters, a two-row layout has a minimum pitch of 4 rivet diameters. The pitch for countersunk rivets is larger than for universal head rivets. If the rivet spacing is made at least 1/16 inch larger than the minimum, the rivet hole can be oversized without violating the minimum rivet spacing requirement. (*Figure 8-7*)

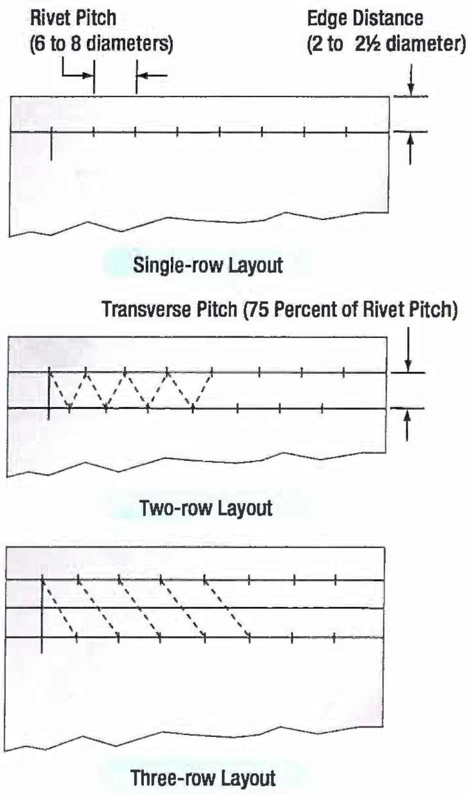


Figure 8-7. Rivet spacing.

TRANSVERSE PITCH

Transverse pitch is the perpendicular distance between rivet rows. It is usually 75 percent of the rivet pitch. The smallest allowable transverse pitch is 2½ rivet diameters. The smallest allowable transverse pitch is 2½ rivet diameters. Rivet pitch and transverse pitch often have the same dimension and are simply called rivet spacing.

RIVET LAYOUT EXAMPLE

The general rules for rivet spacing, as it is applied to a straight-row layout, are quite simple. In a one-row layout, find the edge distance at each end of the row and then lay off the rivet pitch (distance between rivets), as shown in ***Figure 8-8***. In a two-row layout, lay off the first row, place the second row a distance equal to the transverse pitch from the first row, and then lay off rivet spots in the second row so that they fall midway between those in the first row. In the three-row layout, first lay off the first and third rows, then use a straightedge to determine the second row rivet spots.

When splicing a damaged tube, and the rivets pass completely through the tube, space the rivets four to seven rivet diameters apart if adjacent rivets are at right angles to each other, and space them five to seven rivet diameters apart if the rivets are parallel to each other. The first rivet on each side of the joint should be no less than 2-½ rivet diameters from the end of the sleeve.

RIVET INSTALLATION TOOLS

The various tools needed in the normal course of driving and upsetting rivets include drills, reamers, rivet cutters or nippers, bucking bars, riveting hammers, draw sets, dimpling dies or other types of countersinking equipment, rivet guns, and squeeze riveters.

C-clamps, vises, and other fasteners used to hold sheets together when riveting were discussed earlier in the chapter. Other tools and equipment needed in the installation of rivets are discussed in the following paragraphs.

HAND TOOLS

A variety of hand tools are used in the normal course of driving and upsetting rivets. They include rivet cutters, bucking bars, hand riveters, countersinks, and dimpling tools.

RIVET CUTTER

The rivet cutter is used to trim rivets when rivets of the required length are unavailable. (***Figure 8-9***) To use the rotary rivet cutter, insert the rivet in the correct hole, place the required number of shims under the rivet head, and squeeze the cutter as if it were a pair of pliers. Rotation of the disks cuts the rivet to give the right length, which is determined by the number of shims inserted under the head. When using a large rivet cutter, place it in a vise, insert the rivet in the proper hole, and cut by pulling the handle, which shears off the rivet. If regular rivet cutters are not available, diagonal cutting pliers can be used as a substitute cutter.

BUCKING BAR

The bucking bar, sometimes called a dolly, bucking iron, or bucking block, is a heavy chunk of steel whose counter vibration during installation contributes to proper rivet installation. They come in a variety of shapes and sizes, and their weights range from a few ounces to 8 or 10 pounds, depending upon the nature of the work. Bucking bars are most often made from low-carbon steel that has been case hardened or alloy bar stock. Those made of better grades of steel last longer and require less reconditioning.

Bucking faces must be hard enough to resist indentation and remain smooth, but not hard enough to shatter. Sometimes, the more complicated bars must be forged or built up by welding. The bar usually has a concave face to conform to the shape of the shop head to be made. When selecting a bucking bar, the first consideration is shape. (***Figure 8-10***)

If the bar does not have the correct shape, it deforms the rivet head; if the bar is too light, it does not give the necessary bucking weight, and the material may become bulged toward the shop head. If the bar is too heavy, its weight and the bucking force may cause the material to bulge away from the shop head.

Rivet Spacing	Minimum Spacing	Preferred Spacing
1 and 3 rows protruding head rivet layout	3D	3D + 1/16 "
2 row protruding head rivet layout	4D	4D + 1/16 "
1 and 3 rows countersunk head rivet layout	3/1/2D	3/1/2D + 1/16 "
2 row countersunk head rivet layout	4/1/2D	4/1/2D + 1/16 "

Figure 8-8. Rivet layout.

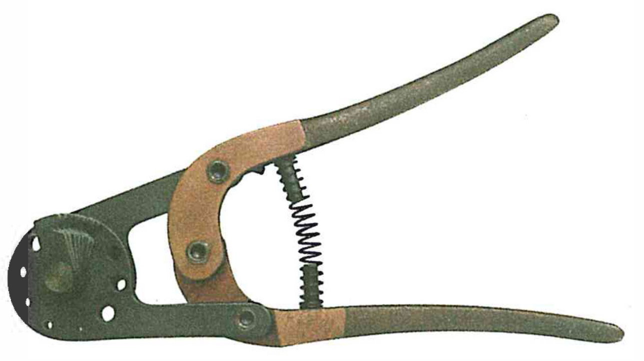


Figure 8-9. Rivet cutters.

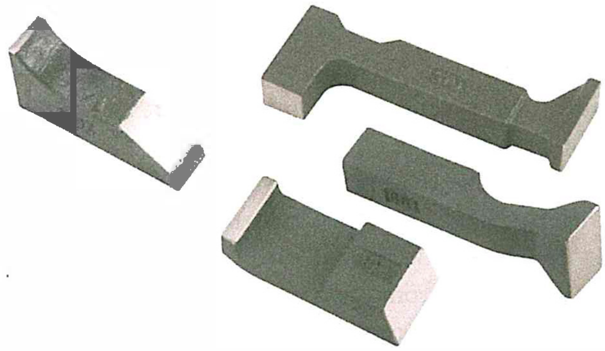


Figure 8-10. Bucking bars.

This tool is used by holding it against the shank end of a rivet while the shop head is being formed. Always hold the face of the bucking bar at right angles to the rivet shank. Failure to do so causes the rivet shank to bend with the first blows of the rivet gun and causes the material to become marred with the final blows. The bucker must hold the bucking bar in place until the rivet is completely driven. If the bucking bar is removed while the gun is in operation, the rivet set may be driven through the material. Allow the weight of the bucking bar to do most of the work and do not bear down too heavily on the shank of the rivet. The operator's hands merely guide the bar and supply the necessary tension and rebound action.

Coordinated bucking allows the bucking bar to vibrate in unison with the gun set. With experience, a high degree of skill can be developed.

Defective rivet heads can be caused by lack of proper vibrating action, the use of a bucking bar that is too light or too heavy, and failure to hold the bucking bar at right angles to the rivet. The bars must be kept clean, smooth, and well polished. Their edges should be slightly rounded to prevent marring the material surrounding the riveting operation.

HAND RIVET SET

A hand rivet set is a tool equipped with a die for driving a particular type rivet. Rivet sets are available to fit every size and shape of rivet head. The ordinary set is made of ½ inch carbon tool steel about 6 inches in length and is knurled to prevent slipping in the hand. Only the face of the set is hardened and polished.

Sets for universal rivets are recessed (or cupped) to fit the rivet head. In selecting the correct set, be sure it provides the proper clearance between the set and the sides of the rivet head and between the surfaces of the metal and the set. Flush or flat sets are used for countersunk and flathead rivets. To seat flush rivets properly, be sure that the flush sets are at least 1 inch in diameter.

Special draw sets are used to draw up the sheets to eliminate any opening between them before the rivet is bucked. Each draw set has a hole $^{1}/_{32}$-inch larger than the diameter of the rivet shank for which it is made. Occasionally, the draw set and rivet header are incorporated into one tool. The header part consists of a hole shallow enough for the set to expand the rivet and head when struck with a hammer.

COUNTERSINKING TOOL

The countersink is a tool that cuts a cone-shaped depression around the rivet hole to allow the rivet to set flush with the surface of the skin. Countersinks are made with angles to correspond with the various angles of countersunk rivet heads. The standard countersink has a 100° angle, as shown in ***Figure 8-11.***

Special microstop countersinks (commonly called stop countersinks) are available that can be adjusted to any desired depth and have cutters to allow interchangeable holes with various countersunk angles to be made. (***Figure 8-12***)

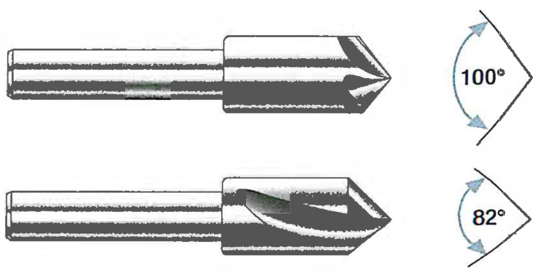


Figure 8-11. Countersinks.

Some stop countersinks also have a micrometer set mechanism, in 0.001-inch increments, for adjusting their cutting depths.

DIMPLING DIES

Dimpling is done with a male and female die (punch and die set). The male die has a guide the size of the rivet hole and with the same degree of countersink as the rivet. The female die has a hole with a corresponding degree of countersink into which the male guide fits.

RIVETING POWER TOOLS

The most common power tools used in riveting are the pneumatic rivet gun, rivet squeezers, and the microshaver.

PNEUMATIC RIVET GUN

The pneumatic rivet gun is the most common rivet upsetting tool used in airframe repair work. It is available in many sizes and types. (***Figure 8-13***) The manufacturer's recommended capacity for each gun is usually stamped on the barrel. Pneumatic guns operate on air pressure of 90 to 100 pounds per square inch and are used in conjunction with interchangeable rivet sets. Each set is designed to fit the specific type of rivet and the location of the work. The shank of the set is designed to fit into the rivet gun. An air-driven hammer inside the barrel of the gun supplies force to buck the rivet. Slow hitting rivet guns that strike from 900 to 2 500 blows per minute are the most common type. (***Figure 8-14***)

These blows are slow enough to be easily controlled and heavy enough to do the job. These g uns are sized by the largest rivet size continuously driven with size often based on the Chicago Pneumatic Company's old "X" series. A 4X gun (dash 8 or ¼ rivet) is used for normal work. The less powerful 3X gun is used for smaller rivets in thinner structure. 7X guns are used for large rivets in thicker structures. A rivet gun should upset a rivet in 1 to 3 seconds. With practice, an aircraft technician learns the length of time needed to hold down the trigger.

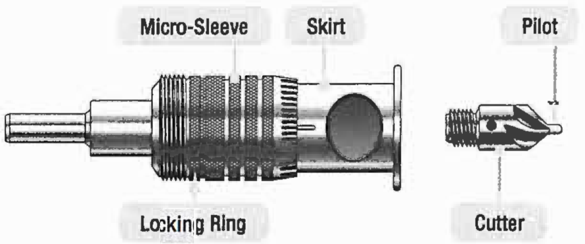


Figure 8-12. Microstop countersink.

Figure 8-14. Pneumatic rivet gun.

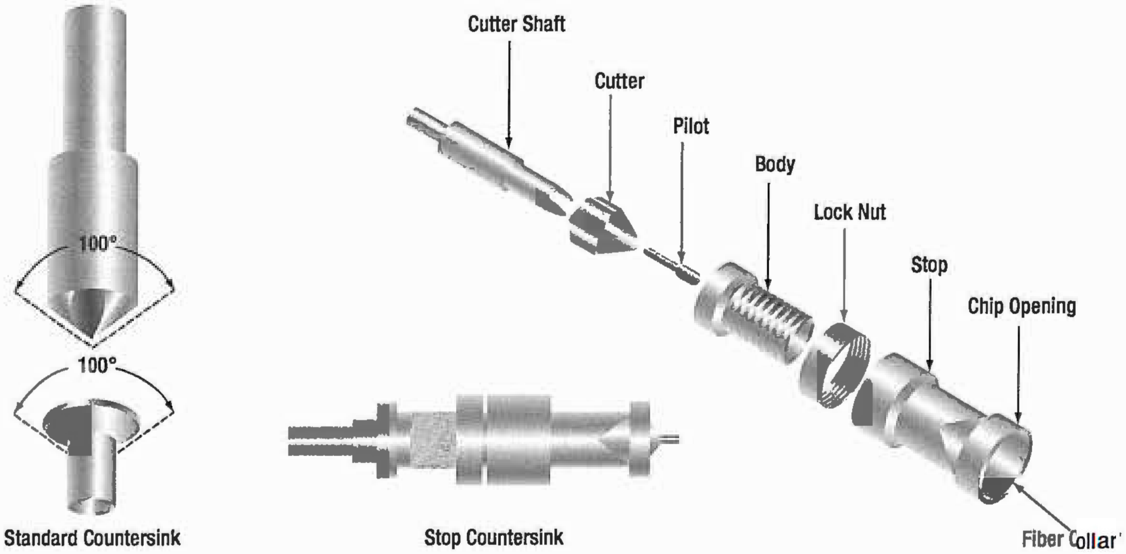


Figure 8-13. Countersinks.

A rivet gun with the correct header (rivet set) must be held snugly against the rivet head and perpendicular to the surface while a bucking bar of the proper weight is held against the opposite end. The force of the gun must be absorbed by the bucking bar and not the structure being riveted. When the gun is triggered, the rivet is driven.

Always make sure the correct rivet header and the retaining spring are installed. Test the rivet gun on a piece of wood and adjust the air valve to a setting that is comfortable for the operator. The driving force of the rivet gun is adjusted by a needle valve on the handle. Adjustments should never be tested against anything harder than a wooden block to avoid header damage. If the adjustment fails to provide the best driving force, a different size gun is needed. A gun that is too powerful is hard to control and may damage the work. On the other hand, if the gun is too light, it may work harden the rivet before the head can be fully formed.

The riveting action should start slowly and be one continuous burst. If the riveting starts too fast, the rivet header might slip off the rivet and damage the rivet (smiley) or damage the skin (eyebrow). Try to drive the rivets within 3 seconds, because the rivet will work harden if the driving process takes too long. The dynamic of the driving process has the gun hitting, or vibrating, the rivet and material, which causes the bar to bounce, or counter vibrate. These opposing blows (low frequency vibrations) squeeze the rivet, causing it to swell and then form the upset head. Some precautions to be observed when using a rivet gun are:

1. Never point a rivet gun at anyone at any time. A rivet gun should be used for one purpose only: to drive or install rivets.
2. Never depress the trigger mechanism unless the set is held tightly against a block of wood or a rivet.
3. Always disconnect the air hose from the rivet gun when it is not in use for any appreciable length of time.

While traditional tooling has changed little in the past 60 years, significant changes have been made in rivet gun ergonomics. Reduced vibration rivet guns and bucking bars have been developed to reduce the incidence of carpal tunnel syndrome and enhance operator comfort.

RIVET SETS/HEADERS

Pneumatic guns are used in conjunction with interchangeable rivet sets or headers. Each is designed to fit the type of rivet and location of the work. The shank of the rivet header is designed to fit into the rivet gun. An appropriate header must be a correct match for the rivet being driven. The working face of a header should be properly designed and smoothly polished. They are made of forged steel, heat treated to be tough but not too brittle.

Flush headers come in various sizes. Smaller ones concentrate the driving force in a small area for maximum efficiency. Larger ones spread the driving force over a larger area and are used for the riveting of thin skins.

Non-flush headers should fit to contact about the center two thirds of the rivet head. They must be shallow enough to allow slight upsetting of the head in driving and some misalignment without eyebrowing the riveted surface. Care must be taken to match the size of the rivet. A header that is too small marks the rivet; while one too large marks the material.

Rivet headers are made in a variety of styles. (***Figure 8-15***) The short, straight header is best so the gun can be brought close to the work. Offset headers may be used to reach rivets in obstructed places. Long headers can be necessary when the gun cannot be brought close to the work due to structural interference. Rivet headers should be kept clean.

COMPRESSION RIVETING

Compression riveting (squeezing) is of limited value because this method of riveting can be used only over the edges of sheets or assemblies where conditions permit, and where the reach of the rivet squeezer is deep enough. The three types of rivet squeezers - hand, pneumatic, and pneudraulic - operate on the same principles. In the hand rivet squeezer, compression is supplied by hand pressure; in the pneumatic rivet squeezer, by air pressure; and in the pneudraulic, by a combination of air and hydraulic pressure. One jaw is stationary and serves as a bucking bar, the other jaw is movable and does the upsetting. Riveting with a squeezer is a quick method and requires only one operator.

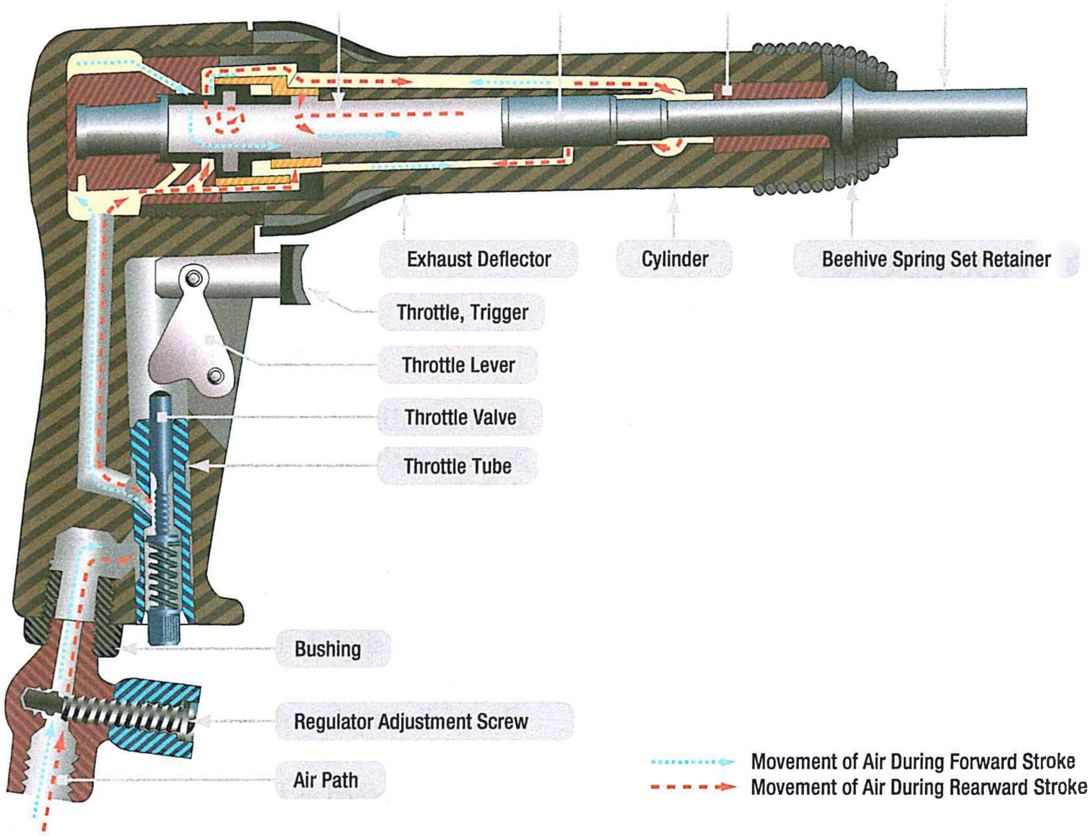


Figure 8-15. Components of a rivet gun.

These riveters are equipped with either a C-yoke or an alligator yoke in various sizes to accommodate any size of rivet. The working capacity of a yoke is measured by its gap and its reach. The gap is the distance between the movable jaw and the stationary jaw; the reach is the inside length of the throat measured from the center of the end sets. End sets for rivet squeezers serve the same purpose as rivet sets for pneumatic rivet guns and are available with the same type heads, which are interchangeable to suit any type of rivet head. One part of each set is inserted in the stationary jaw, while the other part is placed in the movable jaws.

Figure 8-16. Rivet headers.

The manufactured head end set is placed on the stationary jaw whenever possible. During some operations, it may be necessary to reverse the end sets, placing the manufactured head end set on the movable jaw.

MICROSHAVERS

A microshaver is used if the smoothness of the material (such as skin) requires that all countersunk rivets be driven within a specific tolerance. (***Figure 8-16***)

This tool has a cutter, a stop, and two legs or stabilizers. The cutting portion of the microshaver is inside the stop. The depth of the cut can be adjusted by pulling outward on the stop and turning it in either direction (clockwise for deeper cuts).

The marks on the stop permit adjustments of 0.001 inch. If the microshaver is adjusted and held correctly, it can cut the head of a countersunk rivet to within 0.002 inch without damaging the surrounding material.

Adjustments should always be made first on scrap material. When correctly adjusted, the microshaver leaves a small round dot about the size of a pinhead on the microshaved rivet. It may occasionally be necessary to shave rivets, normally restricted to MS20426 head rivets, after driving to obtain the required flushness. Shear head rivets should never be shaved.

RIVETING PROCEDURE

The riveting procedure consists of transferring and preparing the hole, drilling, and driving the rivets.

HOLE TRANSFER

Accomplish transfer of holes from a drilled part to another part by placing the second part over first and using established holes as a guide. Using an alternate method, scribe hole location through from drilled part onto part to be drilled, spot with a center punch, and drill.

HOLE PREPARATION

It is very important that the rivet hole be of the correct size and shape and free from burrs. If the hole is too small, the protective coating is scratched from the rivet when the rivet is driven through the hole. If the hole is too large, the rivet does not fill the hole completely. When it is bucked, the joint does not develop its full strength, and structural failure may occur at that spot.

If countersinking is required, consider the thickness of the metal and adopt the countersinking method recommended for that thickness. If dimpling is required, keep hammer blows or dimpling pressures to a minimum so that no undue work hardening occurs in the surrounding area.

DRILLING

When drilling holes in new pieces of metal being used for a repair, they may be drilled with either a light power drill or a hand drill. The standard shank twist drill is most commonly used. Drill bit sizes for rivet holes should be the smallest size that permits easy insertion of the rivet, approximately 0.003-inch greater than the largest tolerance of the shank diameter. The recommended clearance drill bits for the common rivet diameters are shown in ***Figure 8-17.*** Hole sizes for other fasteners are normally found on work documents, prints, or in manuals.

Figure 8-17. Microshaver.

Before drilling, center punch all rivet locations. The center punch mark should be large enough to prevent the drill from slipping out of position, yet it must not dent the surface surrounding the center punch mark. Place a bucking bar behind the metal during punching to help prevent denting. To make a rivet hole the correct size, first drill a slightly undersized hole (pilot hole). Ream the pilot hole with a twist drill of the appropriate size to obtain the required dimension.

To drill, proceed as follows:

1. Ensure the bit is the correct size and shape.
2. Place the drill in the center-punched mark. When using a power drill, rotate the bit a few turns before starting the motor.
3. While drilling, always hold the drill at a 90° angle to the work or the curvature of the material.
4. Avoid excessive pressure, let the bit do the cutting, and never push the bit through stock.
5. Remove all burrs with a countersink or a file.
6. Clean away all drill chips.

When holes are drilled through sheet metal, small burrs are formed around the edge of the hole. This is especially true when using a hand drill because the drill speed is slow and there is a tendency to apply more pressure per drill revolution. Remove all burrs with a burr remover or larger size drill bit before riveting.

DRIVING THE RIVET

Although riveting equipment can be either stationary or portable riveting equipment is the most common type of riveting equipment used to drive solid shank rivets in airframe repair work.

Before driving any rivets into the sheet metal parts, be sure all holes line up perfectly, all shavings and burrs have been removed, and the parts to be riveted are securely fastened with temporary fasteners. Depending on the job, the riveting process may require one or two people. In solo riveting, the riveter holds a bucking bar with one hand and operates a riveting gun with the other.

If the job requires two aircraft technicians, a shooter, or gunner, and a bucker work together as a team to install rivets. An important component of team riveting is an efficient signaling system that communicates the status of the riveting process. This signaling system usually consists of tapping the bucking bar against the work and is often called the tap code. One tap may mean not fully seated, hit it again, while two taps may mean good rivet, and three taps may mean bad rivet, remove and drive another. Radio sets are also available for communication between the technicians.

Once the rivet is installed, there should be no evidence of rotation of rivets or looseness of riveted parts. After the trimming operation, examine for tightness. Apply a force of 10 pounds to the trimmed stem. A tight stem is one indication of an acceptable rivet installation. Any degree of looseness indicates an oversize hole and requires replacement of the rivet with an oversize shank diameter rivet. A rivet installation is assumed satisfactory when the rivet head is seated snugly against the item to be retained (0.005-inch feeler gauge should not go under rivet head for more than half the circumference) and the stem is proved tight.

COUNTERSUNK RIVETS

An improperly made countersink reduces the strength of a flush-riveted joint and may even cause failure of the sheet or the rivet head. The two methods of countersinking commonly used for flush riveting in aircraft construction and repair are:

- Machine or drill countersinking.
- Dimpling or press countersinking.

The proper method for any particular application depends on the thickness of the parts to be riveted, the height and angle of the countersunk head, the tools available, and accessibility.

COUNTERSINKING

When using countersunk rivets, it is necessary to make a conical recess in the skin for the head. The type of countersink required depends upon the relation of the thickness of the sheets to the depth of the rivet head. Use the proper degree and diameter countersink and cut only deep enough for the rivet head and metal to form a flush surface.

Countersinking is an important factor in the design of fastener patterns, as the removal of material in the countersinking process necessitates an increase in the number of fasteners to assure the required load-transfer strength. If countersinking is done on metal below a certain thickness, a knife edge with less than the minimum bearing surface or actual enlarging of the hole may result. The edge distance required when using countersunk fasteners is greater than when universal head fasteners are used.

The general rule for countersinking and flush fastener installation procedures has been reevaluated in recent years because countersunk holes have been responsible for fatigue cracks in aircraft pressurized skin. In the past, the general rule for countersinking held that the fastener head must be contained within the outer sheet. A combination of countersinks too deep (creating a knife edge), number of pressurization cycles, fatigue, deterioration of bonding materials, and working fasteners caused a high stress concentration that resulted in skin cracks and fastener failures. In primary structure and pressurized skin repairs, some manufacturers are currently recommending the countersink depth be no more than ⅔ the outer sheet thickness or down to 0.020 inch minimum fastener shank depth, whichever is greater. Dimple the skin if it is too thin for machine countersinking. (***Figure 8-18***)

Keep the rivet high before driving to ensure the force of riveting is applied to the rivet and not to the skin. If the rivet is driven while it is flush or too deep, the surrounding skin is work hardened.

Rivet Diameter (in)	Drill Size	
	Pilot	Final
3/32	3/32 (0.0937)	#40 (0.098)
1/8	1/8 (0.125)	#30 (0.1285)
5/32	5/32 (0.1562)	#21 (0.159)
3/16	3/16 (0.1875)	#11 (0.191)
1/4	1/4 (0.250)	F (0.257)

Figure 8-18. Drill sizes for standard rivets.

RIVETING

COUNTERSINKING TOOLS

While there are many types of countersink tools, the most commonly used has an included angle of 100°. Sometimes types of 82° or 120° are used to form countersunk wells. (*Figure 8-11*) A six-fluted countersink works best in aluminum. There are also four- and three-fluted countersinks, but those are harder to control from a chatter standpoint. A single-flute type, such as those manufactured by the Weldon Tool Company®, works best for corrosion-resistant steel. (*Figure 8-19*)

Figure 8-19. Chip chaser.

The microstop countersink is the preferred tool for countersinking. (*Figure 8-12*)

It has an adjustable-sleeve cage that functions as a limit stop and holds the revolving countersink in a vertical position. Its threaded and replaceable cutters may have either a removable or an integral pilot that keeps the cutter centered in the hole. The pilot should be approximately 0.002-inch smaller than the hole size. It is recommended to test adjustments on a piece of scrap material before countersinking repair or replacement parts. Freehand countersinking is needed where a micro-stop countersink cannot fit. This method should be practiced on scrap material to develop the required skill. Holding the drill motor steady and perpendicular is as critical during this operation as when drilling.

Chattering is the most common problem encountered when countersinking. Some precautions that may eliminate or minimize chatter include:

- Use sharp tooling.
- Use a slow speed and steady firm pressure.
- Use a piloted countersink with a pilot approximately 0.002 inch smaller than the hole.
- Use back-up material to hold the pilot steady when countersinking thin sheet material.
- Use a cutter with a different number of flutes.
- Pilot drill an undersized hole, countersink, and then enlarge the hole to final size.

DIMPLING

Dimpling is the process of making an indentation or a dimple around a rivet hole to make the top of the head of a countersunk rivet flush with the surface of the metal. Dimpling is done with a male and female die, or forms, often called punch and die set. The male die has a guide the size of the rivet hole and is beveled to correspond to the degree of countersink of the rivet head. The female die has a hole into which the male guide fits and is beveled to a corresponding degree of countersink.

When dimpling, rest the female die on a solid surface. Then, place the material to be dimpled on the female die. Insert the male die in the hole to be dimpled and, with a hammer, strike the male die until the dimple is formed. Two or three solid hammer blows should be sufficient. A separate set of dies is necessary for each size of rivet and shape of rivet head. An alternate method is to use a countersunk head rivet instead of the regular male punch die, and a draw set instead of the female die, and hammer the rivet until the dimple is formed.

Dimpling dies for light work can be used in portable pneumatic or hand squeezers. (*Figure 8-20*) If the dies are used with a squeezer, they must be adjusted accurately to the thickness of the sheet being dimpled. A table riveter is also used for dimpling thin skin material and installing rivets. (*Figure 8-21*)

COIN DIMPLING

The coin dimpling, or coin pressing, method uses a countersink rivet as the male dimpling die. Place the female die in the usual position and back it with a bucking bar. Place the rivet of the required type into the hole and strike the rivet with a pneumatic riveting hammer. Coin dimpling should be used only when the regular male die is broken or not available. Coin pressing has the distinct disadvantage of the rivet hole needing to be drilled to correct rivet size before the dimpling operation is accomplished. Since the metal stretches during the dimpling operation, the hole becomes enlarged and the rivet must be swelled slightly before driving to produce a close fit. Because the rivet head causes slight distortions in the recess, and these

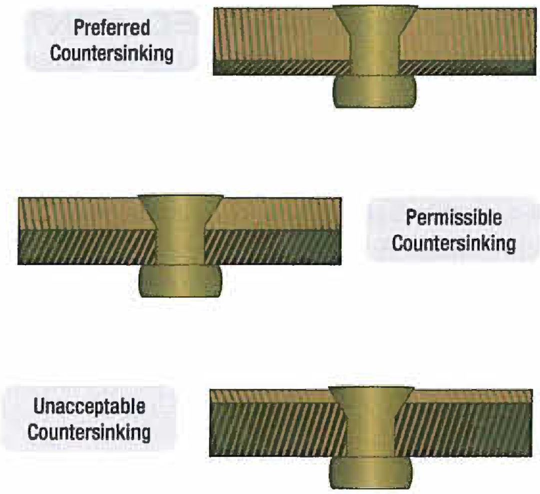


Figure 8-20. Countersinking dimensions.

Figure 8-21. Single-flute countersink.

are characteristic only to that particular rivet head, it is wise to drive the same rivet that was used as the male die during the dimpling process. Do not substitute another rivet, either of the same size or a size larger.

RADIUS DIMPLING

Radius dimpling uses special die sets that have a radius and are often used with stationary or portable squeezers. Dimpling removes no metal and, due to the nestling effect, gives a stronger joint than the non-flush type. A dimpled joint reduces the shear loading on the rivet and places more load on the riveted sheets.

NOTE: Dimpling is also done for flush bolts and other flush fasteners.

Dimpling is required for sheets that are thinner than the minimum specified thickness for countersinking. However, dimpling is not limited to thin materials. Heavier parts may be dimpled without cracking by specialized hot dimpling equipment. The temper of the material, rivet size, and available equipment are all factors to be considered in dimpling. (***Figure 8-22***)

HOT DIMPLING

Hot dimpling is the process that uses heated dimpling dies to ensure the metal flows better during the dimpling process. Hot dimpling is often performed with large stationary equipment available in a sheet metal shop. The metal being used is an important factor because each metal presents different dimpling problems. For example, 2024-T3 aluminum alloy can be satisfactorily

Figure 8-22. Hand and pneumatic type rivet squeezers.

dimpled either hot or cold, but may crack in the vicinity of the dimple after cold dimpling because of hard spots in the metal. Hot dimpling prevents such cracking.

7075-T6 aluminum alloys are always hot dimpled. Magnesium alloys also must be hot dimpled because, like 7075-T6, they have low formability qualities. Titanium is another metal that must be hot dimpled because it is tough and resists forming. The same temperature and dwell time used to hot dimple 7075-T6 is used for titanium. 100° Combination Pre-dimple and Countersink Method Metals of different thicknesses are sometimes joined by a combination of dimpling and countersinking. (***Figure 8-23***)

A countersink well made to receive a dimple is called a subcountersink. These are most often seen where a thin web is attached to heavy structure. It is also used on thin gap seals, wear strips, and repairs for worn countersinks.

DIMPLING INSPECTION

To determine the quality of a dimple, it is necessary to make a close visual inspection. Several features must be checked. The rivet head should fit flush and there should be a sharp break from the surface into the dimple. The sharpness of the break is affected by dimpling pressure and metal thickness. Selected dimples should be checked by inserting a fastener to make sure that the flushness requirements are met. Cracked dimples are caused by poor dies, rough holes, or improper heating.

Two types of cracks may form during dimpling:

- Radial cracks—start at the edge and spread outward as the metal within the dimple stretches. They are most common in 2024-T3. A rough hole or a dimple that is too deep causes such cracks. A small tolerance is usually allowed for radial cracks.
- Circumferential cracks—downward bending into the draw die causes tension stresses in the upper portion of the metal. Under some conditions, a crack may be created that runs around the edge of the dimple. Such cracks do not always show since they may be underneath the cladding. When found, they are cause for rejection. These cracks are most common in hot dimpled 7075 T6 aluminum alloy material. The usual cause is insufficient dimpling heat.

INSPECTION OF RIVETED JOINTS

To obtain high structural efficiency in the manufacture and repair of aircraft, an inspection must be made of all rivets before the part is put in service. This inspection consists of examining both the shop and manufactured heads and the surrounding skin and structural parts for deformities. A scale or rivet gauge can be used to check the condition of the upset rivet head to see that it conforms to the proper requirements. Deformities in the manufactured head can be detected by the trained eye alone. (***Figure 8-24***)

Figure 8-23. Table riveter.

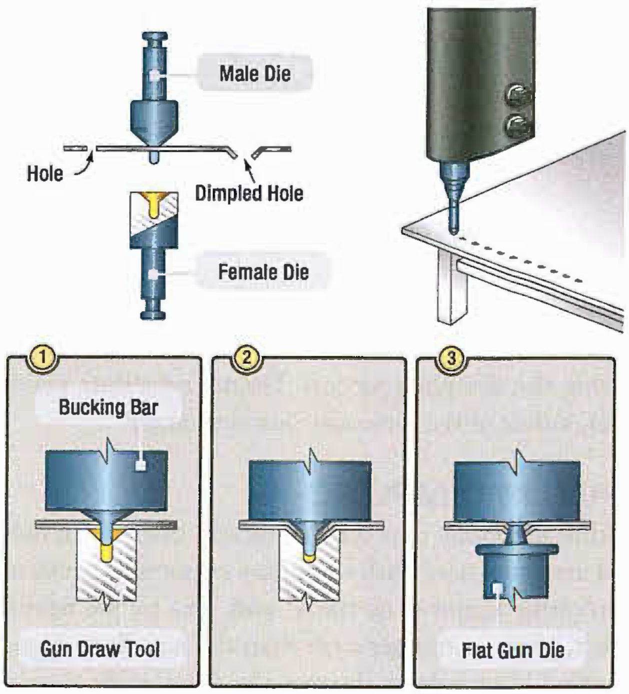


Figure 8-24. Dimpling techniques.

Some common causes of unsatisfactory riveting are improper bucking, rivet set slipping off or being held at the wrong angle, and rivet holes or rivets of the wrong size. Additional causes for unsatisfactory riveting are countersunk rivets not flush with the well, work not properly fastened together during riveting, the presence of burrs, rivets too hard, too much or too little driving, and rivets out of line.

Occasionally, during an aircraft structural repair, it is wise to examine adjacent parts to determine the true condition of neighboring rivets. In doing so, it may be necessary to remove the paint. The presence of chipped or cracked paint around the heads may indicate shifted or loose rivets. Look for tipped or loose rivet heads. If the heads are tipped or if rivets are loose, they show up in groups of several consecutive rivets and probably tipped in the same direction. If heads that appear to be tipped are not in groups and are not tipped in the same direction, tipping may have occurred during some previous installation.

Inspect rivets known to have been critically loaded, but that show no visible distortion, by drilling off the head and carefully punching out the shank. If, upon examination, the shank appears joggled and the holes in the sheet misaligned, the rivet has failed in shear. In that case, try to determine what is causing the shearing stress and take the necessary corrective action. Flush rivets that show head slippage within the countersink or dimple, indicating either sheet bearing failure or rivet shear failure, must be removed for inspection and replacement.

Joggles in removed rivet shanks indicate partial shear failure. Replace these rivets with the next larger size. Also, if the rivet holes show elongation, replace the rivets with the next larger size. Sheet failures such as tear-outs, cracks between rivets, and the like usually indicate damaged rivets. The complete repair of the joint may require replacement of the rivets with the next larger size.

The general practice of replacing a rivet with the next larger size (1/32 inch greater diameter) is necessary to obtain the proper joint strength of rivet and sheet when the original rivet hole is enlarged. If the rivet in an elongated hole is replaced by a rivet of the same size, its ability to carry its share of the shear load is impaired and joint weakness results.

REMOVAL OF RIVETS

When a rivet has to be replaced, remove it carefully to retain the rivet hole's original size and shape. If removed correctly, the rivet does not need to be replaced with one of the next larger size. Also, if the rivet is not removed properly, the strength of the joint may be weakened and the replacement of rivets made more difficult.

When removing a rivet, work on the manufactured head. It is more symmetrical about the shank than the shop head, and there is less chance of damaging the rivet hole or the material around it. To remove rivets, use hand tools, a power drill, or a combination of both.

The procedure for universal or protruding head rivet removal is as follows:

1. File a flat area on the head of the rivet and center punch the flat surface for drilling.
   NOTE: On thin metal, back up the rivet on the upset head when center punching to avoid depressing the metal.
2. Use a drill bit one size smaller than the rivet shank to drill out the rivet head.
   NOTE: When using a power drill, set the drill on the rivet and rotate the chuck several revolutions by hand before turning on the power. This procedure helps the drill cut a good starting spot and eliminates the chance of the drill slipping off and tracking across the metal.
3. Drill the rivet to the depth of its head, while holding the drill at a 90° angle. Do not drill too deeply, as the rivet shank will then turn with the drill and tear the surrounding metal.
   NOTE: The rivet head often breaks away and climbs the drill, which is a signal to withdraw the drill.
4. If the rivet head does not come loose of its own accord, insert a drift punch into the hole and twist slightly to either side until the head comes off.
5. Drive the remaining rivet shank out with a drift punch slightly smaller than the shank diameter.

On thin metal or unsupported structures, support the sheet with a bucking bar while driving out the shank. If the shank is unusually tight after the rivet head is removed, drill the rivet about two-thirds through the thickness of the material and then drive the rest of it out with a drift punch. ***Figure 8-25*** shows the preferred procedure for removing universal rivets.

The procedure for the removal of countersunk rivets is the same as described above except no filing is necessary. Be careful to avoid elongation of the dimpled or the countersunk holes. The rivet head should be drilled to approximately one half the thickness of the top sheet. The dimple in 2117–T rivets usually eliminates the necessity of filing and center punching the rivet head.

To remove a countersunk or flush head rivet, you must:

1. Select a drill about 0.003-inch smaller than the rivet shank diameter.
2. Drill into the exact center of the rivet head to the approximate depth of the head.
3. Remove the head by breaking it off. Use a punch as a lever.
4. Punch out the shank. Use a suitable backup, preferably wood (or equivalent), or a dedicated backup block. If the shank does not come out easily, use a small drill and drill through the shank. Be careful not to elongate the hole.

REPLACING RIVETS

Replace rivets with those of the same size and strength whenever possible. If the rivet hole becomes enlarged, deformed, or otherwise damaged, drill or ream the hole for the next larger size rivet. Do not replace a rivet with a type having lower strength properties, unless the lower strength is adequately compensated by an increase in size or a greater number of rivets. It's acceptable to replace 2017 rivets of 3⁄16 inch diameter or less, and 2024 rivets of 5⁄32 inch diameter or less with 2117 rivets for general repairs, provided the replacement rivets are 1⁄32 inch greater in diameter than the rivets they replace.

METHOD OF DOUBLE FLUSH RIVETING

A rivet installation technique known as the National Advisory Committee for Aeronautics (NACA) method has primary applications in fuel tank areas. (***Figure 8-26***)

To make a NACA rivet installation, the shank is upset into a 82° countersink. In driving, the gun may be used on either the head or shank side. The upsetting is started with light blows, then the force increased and the gun or bar moved on the shank end so as to form a head inside the countersink well. If desired, the upset head may be shaved flush after driving. The optimal strength is achieved by cutting the countersink well to the dimensions given in ***Figure 8-27.*** Material thickness minimums must be carefully adhered to.

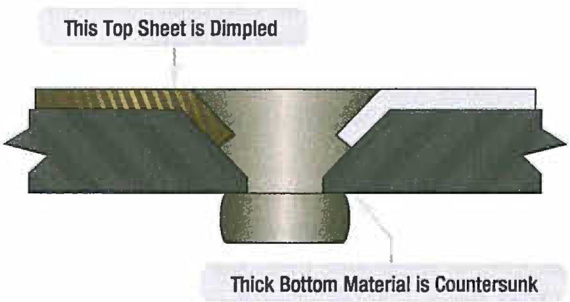


Figure 8-25. Predimple and countersink method.


Figure 8-26. A part temporarily held together with Cleco fastenerss.


Figure 8-27. A wing nut temporary fastener.

Question: 8-1
The ________________ rivet is the most common type of rivet used in aircraft construction.

Question: 8-2
What two stresses are applied to rivets?

Question: 8-3
A ________________ is used to trim rivets when rivets of the required length are unavailable.

Question: 8-4
Each ________________ is designed to fit the type of rivet and location of the work.

Question: 8-5
The two methods of countersinking commonly used for flush riveting in aircraft construction and repair are ________________ and ________________.

Question: 8-6
A dimpled joint reduces the ____________ loading on the rivet and places more load on the riveted sheets.

Question: 8-7
Replace rivets with those of the same ________________ and ________________ whenever possible.

ANSWERS

Answer: 8-1
solid shank.

Answer: 8-2
tension and stress.

Answer: 8-3
rivet cutter.

Answer: 8-4
rivet set (header).

Answer: 8-5
machine or drill countersinking.
dimpling or press countersinking.

Answer: 8-6
shear.

Answer: 8-7
strength and size.

MAINTENANCE PRACTICES

PIPES AND HOSES

SUB-MODULE 09

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 09 PIPES AND HOSES Knowledge Requirements		
7.9 - Pipes and Hoses Bending and belling/flaring aircraft pipes; Inspection and testing of aircraft pipes and hoses; Installation and clamping of pipes. Note: The words "pipe and line" mean the same thing: a rigid tube for the transportation of liquids.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

PIPES AND HOSES

Occasionally, it may be necessary to repair or replace damaged aircraft fluid lines. Very often the repair can be made simply by replacing the tubing. However, if replacements are not available, the needed parts may have to be fabricated. Replacement tubing should be of the same size and material as the original tubing.

All tubing is pressure tested prior to initial installation, and is designed to withstand several times the normal operating pressure to which it will be subjected. If a tube bursts or cracks, it is generally the result of excessive vibration, improper installation, or damage caused by collision with an object. All tubing failures should be carefully studied and the cause of the failure determined.

TUBING SIZES

Metal tubing is sized by outside diameter (o.d.), which is measured fractionally in sixteenths of an inch. Thus, number 6 tubing is 6⁄16" (or 3⁄8") and number 8 tubing is 8⁄16" (or ½"), and so forth. The tube diameter is typically printed on all rigid tubing. In addition to other classifications or means of identification, tubing is manufactured in various wall thicknesses. Thus, it is important when installing tubing to know not only the material and outside diameter, but also the thickness of the wall. The wall thickness is typically printed on the tubing in thousands of an inch. To determine the inside diameter (i.d.) of the tube, subtract twice the wall thickness from the outside diameter.

For example, a number 10 piece of tubing with a wall thickness of 0.063" has an inside diameter of 0.625" – 2(0.063") = 0.499".

FABRICATION OF METAL TUBE LINES

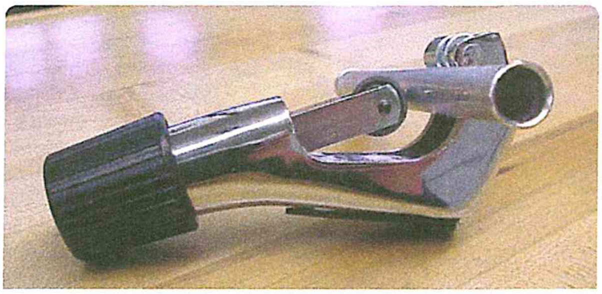
Damaged tubing and fluid lines should be repaired with new parts whenever possible. Unfortunately, sometimes replacement is impractical and repair is necessary. Scratches, abrasions, or minor corrosion on the outside of fluid lines may be considered negligible and can be smoothed out with a burnishing tool or aluminum wool. Limitations on the amount of damage that can be repaired in this manner are discussed in this chapter under "*Rigid Tubing Inspection and Repair.*"

If a fluid line assembly is to be replaced, the fittings can often be salvaged; then the repair will involve only tube forming and replacement.

Tube forming consists of four processes: Cutting, bending, flaring, and beading. If the tubing is small and made of soft material, the assembly can be formed by hand bending during installation. If the tube is ¼" diameter or larger, hand bending without the aid of tools is impractical.

TUBE CUTTING

When cutting tubing, it is important to produce a square end, free of burrs. Tubing may be cut with a tube cutter or a hacksaw. The cutter can be used with any soft metal tubing, such as copper, aluminum, or aluminum alloy. Correct use of the tube cutter is shown in ***Figure 9-1.*** Special chipless cutters are available for cutting aluminum 6061-T6, corrosion resistant steel and titanium tubing.



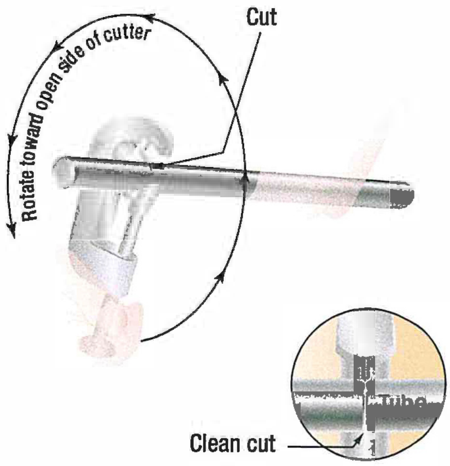


Figure 9-1. Tube cutting.

A new piece of tubing should be cut approximately 10 percent longer than the tube to be replaced to provide for minor variations in bending. Place the tubing in the cutting tool, with the cutting wheel at the point where the cut is to be made. Rotate the cutter around the tubing, applying a light pressure to the cutting wheel by intermittently twisting the thumbscrew. Too much pressure on the cutting wheel at one time could deform the tubing or cause excessive burring. After cutting the tubing, carefully remove any burrs from inside and outside the tube. Use a knife or the burring edge attached to the tube cutter. The deburring operation can be accomplished by the use of a deburring tool, shown in ***Figure 9-2***. This tool is capable of removing both the inside and outside burrs by just turning the tool end for end.

When performing the deburring operation, use extreme care that the wall thickness of the end of the tubing is not reduced or fractured. Very slight damage of this type can lead to fractured flares or defective flares which will not seal properly. Use a fine-tooth file to file the end square and smooth.

If a tube cutter is not available, or if tubing of hard material is to be cut, use a fine-tooth hacksaw, preferably one having 32 teeth per inch. The use of a saw will decrease the amount of work hardening of the tubing during the cutting operation. After sawing, file the end of the tube square and smooth, removing all burrs.

An easy way to hold small diameter tubing, when cutting it, is to place the tube in a combination flaring tool and clamp the tool in a vise Make the cut about one half inch from the flaring tool. This procedure keeps sawing vibrations to a minimum and prevents damage to the tubing if it is accidentally hit with the hacksaw frame or file handle while cutting Be sure all filings and cuttings are removed from the tube.

TUBE BENDING

The objective in tube bending is to obtain a smooth bend without flattening the tube. Tubing under ¼" in diameter usually can be bent without the use of a bending tool. For larger sizes, either portable hand benders or production benders are usually used. ***Figure 9-3*** shows preferred methods and standard bend radii for bending tubing by tube size.

Using a hand bender, insert the tubing into the groove of the bender, so that the measured end is left of the form block. Align the two zeros and align the mark on the tubing with the L on the form handle. If the measured end is on the right side, then align the mark on the tubing with the R on the form handle. With a steady motion, pull the form handle until the zero mark on the form handle lines up with the desired angle of bend, as indicated on the radius block. (***Figure 9-4***)

Figure 9-2. Deburring tool types.

Type Bender	AB	AB	B	B	B	BC	B	BC	B	BC	C	BC	C
Tube od	⅛"	3/16"	¼"	5/16"	⅜"	⅜"	7/16"	½"	½"	⅝"	⅝"	¾"	¾"
Standard Bend	⅜"	7/16"	9/16"	11/16"	11/16"	15/16"	1⅜"	1½"	1¼"	2"	1½"	2½"	1¾"
Type Bender	C	B	C	C	C	C	C	C	C	C	C	C	C
Tube od	⅞"	1"	1"	1⅛"	1¼"	1⅜"	1⅜"	1½"	1½"	1¾"	2"	2½"	3"
Standard Bend	2"	3½"	3"	3½"	3¾"	5"	6"	5"	6"	7"	8"	10"	12"

A–Hand B–Portable hand benders C–Production bender

Figure 9-3. Standard bend radii to which standard bending tools will form the various sizes of tubes.

Figure 9-4. Tube bending.

Bend the tubing carefully to avoid excessive flattening, kinking, or wrinkling. A small amount of flattening in bends is acceptable, but the small diameter of the flattened portion must not be less than 75 percent of the original outside diameter. Tubing with flattened, wrinkled, or irregular bends should not be installed. Wrinkled bends usually result from trying to bend thin wall tubing without using a tube bender. Excessive flattening will cause fatigue failure of the tube. Examples of correct and incorrect tubing bends are shown in ***Figure 9-5***.

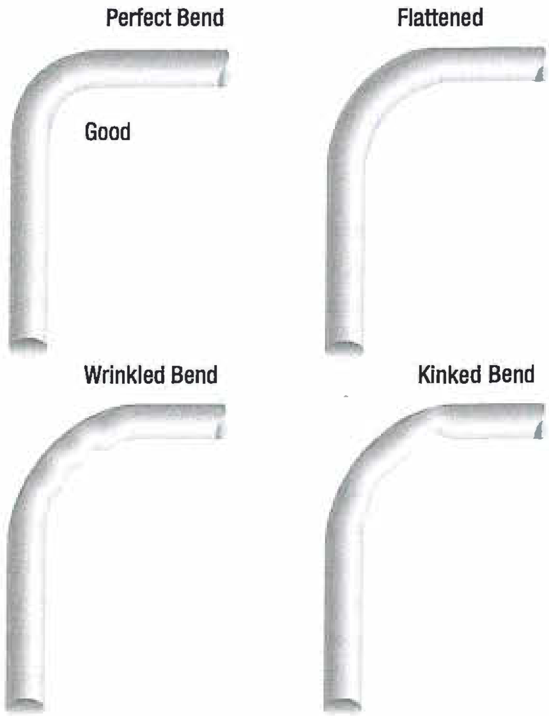


Figure 9-5. Correct and incorrect tubing bends.

Tube bending machines for all types of tubing are generally used in repair stations and large maintenance shops. With such equipment, proper bends can be made on large diameter tubing and on tubing made from hard material. The production CNC™ tube bender is an example of this type of machine. (***Figure 9-6***)

The ordinary production tube bender will accommodate tubing ranging from ¼" to 1½" outside diameter. Benders for larger sizes are available, and the principle of their operation is similar to that of the hand tube bender. The radius blocks are so constructed that the radius of bend will vary with the tube diameter. The radius of bend is usually stamped on the block.

Figure 9-6. CNC tube bending machine.

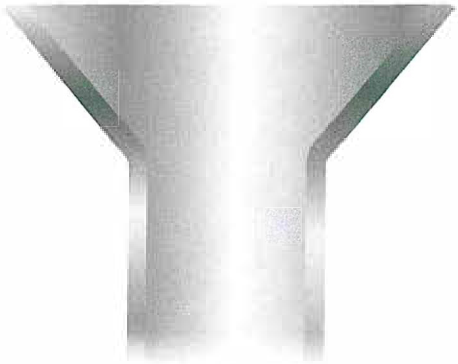
ALTERNATIVE BENDING METHODS

When hand or production tube benders are not available or are not suitable for a particular bending operation, a filler of metallic composition or of dry sand may be used to facilitate bending. When using this method, cut the tube slightly longer than is required. The extra length is for inserting a plug (which may be wooden) in each end. The tube can also be closed by flattening the ends or by soldering metal disks in them.

After plugging one end, fill and pack the tube with fine, dry sand and plug tightly. Both plugs must be tight so they will not be forced out when the bend is made. After the ends are closed, bend the tubing over a forming block shaped to the specified radius. In a modified version of the filler method, a fusible alloy is used instead of sand. In this method, the tube is filled under hot water with a fusible alloy that melts at 160 °F. The alloy-filled tubing is then removed from the water, allowed to cool, and bent slowly by hand around a forming block or with a tube bender. After the bend is made, the alloy is again melted under hot water and removed from the tubing. When using either filler methods, make certain that all particles of the filler are removed. Visually inspect with a borescope to make certain that no particles will be carried into the system in which the tubing is installed. Store the fusible alloy filler where it will be free from dust or dirt. It can be remelted and reused as often as desired. Never heat this filler in any other way than the prescribed method, as the alloy will stick to the inside of the tubing, making them both unusable.

TUBE FLARING

Two kinds of flares are generally used in aircraft tubing: the single flare and the double flare. (***Figure 9-7 A and B***) Flares are frequently subjected to extremely high pressures; therefore, the flare on the tubing must be properly shaped or the connection will leak or fail. A flare made too small produces a weak joint, which may leak or pull apart; if made too large, it interferes with the proper engagement of the screw thread on the fitting and will cause leakage. A crooked flare is the result of the tubing not being cut squarely. If a flare is not made properly, flaws cannot be corrected by applying additional torque when tightening the fitting.


A. Single-flared End

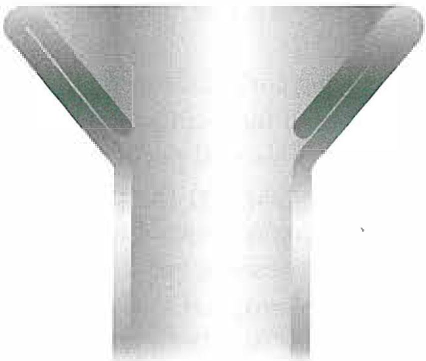

B. Double-flared End

Figure 9-7. Cutaway view of single and double-flared tube ends.

The flare and tubing must be free from cracks, dents, nicks, scratches, or any other defects. The flaring tool used for aircraft tubing has male and female dies ground to produce a flare of 35° to 37°. Under no circumstance is it permissible to use an automotive-type flaring tool which produces a flare of 45°. (***Figure 9-8***)

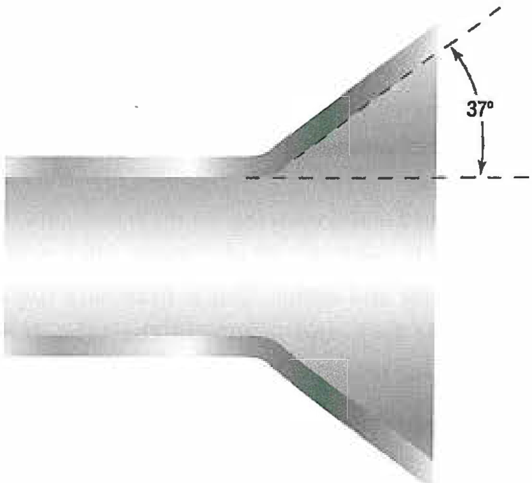


Figure 9-8. Flaring tool.

The single-flare hand flaring tool, similar to that shown in ***Figure 9-9***, is used for flaring tubing. The tool consists of a flaring block or grip die, a yoke, and a flaring pin. The flaring block is a hinged double bar with holes corresponding to various sizes of tubing. These holes are countersunk on one end to form the outside support against which the flare is formed. The yoke is used to center the flaring pin over the end of the tube to be flared. Two types of flaring tools are used to make flares on tubing: the impact type and the rolling type.

Instructions for Rolling-Type Flaring Tools

Use these tools only to flare soft copper, aluminum, and brass tubing. Do not use with corrosion resistant steel or titanium. Cut the tube squarely and remove all

Figure 9-9. Hand flaring tool.

burrs. Slip the fitting nut and sleeve on the tube. Loosen clamping screw used for locking the sliding segment in the die holder. This will permit their separation. The tools are self-gauging; the proper size flare is produced when tubing is clamped flush with the top of the die block. Insert tubing between the segments of the die block that correspond to the size of the tubing to be flared. Advance the clamp screw against the end segment and tighten firmly. Move the yoke down over the top of the die holder and twist it clockwise to lock it into position. Turn the feed screw down firmly, and continue until a slight resistance is felt. This indicates an accurate flare has been completed. Always read the tool manufacturer's instructions, because there are several different types of rolling-type flaring tools that use slightly different procedures.

Instructions for Double Flaring

A double flare is used on soft aluminum alloy tubing ⅜" outside diameter and under. This is necessary to prevent cutting off the flare and failure of the tube assembly under operating pressures. A double flare is smoother and more concentric than a single flare and therefore seals better. It is also more resistant to the shearing effect of torque.

Deburr both the inside and outside of the tubing to be flared. Cut off the end of the tubing, if it appears damaged. Anneal brass, copper, and aluminum by heating to a dull red and cool rapidly in cold water. Open the flaring tool by unscrewing both clamping screws. Select the hole in the flaring bar that matches the tubing diameter and place the tubing with the end you have just prepared, extending above the top of the bar by a distance equal to the thickness of the shoulder of the adapter insert. Tighten clamping screws to hold tubing securely. Insert pilot of correctly sized adapter into tubing. Slip yoke over the flaring bars and center over adapter. Advance the cone downward until the shoulder of the adapter rests on the flaring bar. This bells out the end of the tubing. Next, back off the cone just enough to remove the adapter. After removing the adapter, advance the cone directly into the belled end of the tubing. This folds the tubing on itself and forms an accurate double flare without cracking or splitting the tubing. To prevent thinning out of the flare wall, do not over tighten. (***Figure 9-10***)

BEADING

Rigid tubing may be joined to either an end item (such as a brake cylinder), another section of either rigid tubing, or to a flexible hose (such as a drain line). In the case of connection to an end item or another tube, fittings are required, which may or may not necessitate flaring of the tube. In the case of attachment to a hose, it may be necessary to bead the rigid tube so that a clamp can be used to hold the hose onto the tube.

Figure 9-10. Double flare tool.

Tubing may be beaded with a hand beading tool, with machine beading rolls, or with grip dies. The method to be used depends on the diameter and wall thickness of the tube and the material from which it was made.

The hand beading tool is used with tubing having ¼" to 1" outside diameter. The bead is formed by using the beader frame with the proper rollers attached. The inside and outside of the tube is lubricated with light oil to reduce the friction between the rollers during beading. The sizes, marked in sixteenths of an inch on the rollers, are for the outside diameter of the tubing that can be beaded with the rollers. (***Figure 9-11***)

Separate rollers are required for the inside of each tubing size, and care must be taken to use the correct parts when beading. The hand beading tool works somewhat like the tube cutter in that the roller is screwed down intermittently while rotating the beading tool around the tubing. In addition, a small vise (tube holder) is furnished with the kit.

Other methods and types of beading tools and machines are available, but the hand beading tool is used most often. As a rule, beading machines are limited to use with large diameter tubing, over $1^{15}/_{16}$", unless special rollers are supplied. The grip die method of beading is confined to small tubing.

Figure 9-11. Hand beading tool.

RIGID TUBING INSTALLATION AND INSPECTION

Before installing a line assembly in an aircraft, inspect the line carefully. Remove dents and scratches, and be sure all nuts and sleeves are snugly mated and securely fitted by proper flaring of the tubing. The line assembly should be clean and free of all foreign matter.

CONNECTION AND TORQUE

Never apply compound to the faces of the fitting or the flare, for it will destroy the metal-to-metal contact between the fitting and flare, a contact which is necessary to produce the seal. Be sure that the line assembly is properly aligned before tightening the fittings. Do not pull the installation into place with torque on the nut. Correct and incorrect methods of installing flared tube assemblies are illustrated in ***Figure 9-12***. Always tighten fittings to the correct torque value when installing a tube assembly. Over tightening a fitting may badly damage or completely cut off the tube flare, or it may ruin the sleeve or fitting nut. Failure to tighten sufficiently also may be serious, as this condition may allow the line to blow out of the assembly or to leak under system pressure. The use of torque wrenches and the prescribed torque values prevents over tightening or under tightening. If a tube fitting assembly is tightened properly, it may be removed and re-tightened many times before reflaring is necessary.

FLARELESS TUBE INSTALLATION

Tighten the nut by hand until an increase in resistance to turning is encountered. Should it be impossible to run the nut down with the fingers, use a wrench, but be alert for the first signs of bottoming. It is important that the final tightening commence at the point where the nut just begins to bottom. Use a wrench and turn the nut one-sixth turn (one flat on a hex nut). Use a wrench on the connector to prevent it from turning while tightening the nut. After the tube assembly is installed, the system should be pressure tested. It is permissible to tighten the nut an additional one-sixth turn (making a total of one-third turn), should a connection leak. If leakage still occurs after tightening the nut a total of one-third turn, remove the assembly and inspect the components for scores, cracks, presence of foreign material, or damage from over tightening. Several aircraft manufacturers include torque values in their maintenance manuals to tighten the flareless fittings. The following notes, cautions, and faults apply to the installation of rigid tubing.

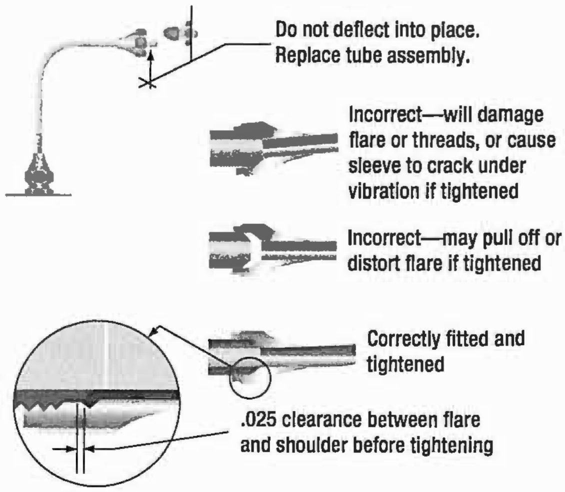


Figure 9-12. Correct and incorrect methods of tightening flared fittings.

Note: Overtightening a flareless tube nut drives the cutting edge of the sleeve deeply into the tube, causing the tube to be weakened to the point where normal in-flight vibration could cause the tube to shear. After inspection (if no discrepancies are found), reassemble the connections and repeat the pressure test procedures.

Never tighten the nut beyond one-third turn (two flats on the hex nut); this is the maximum the fitting may be tightened without the possibility of permanently damaging the sleeve and nut.

Flares distorted into nut threads; sleeve cracked; flare cracked or split; flare out of round; inside of flare rough or scratched; and threads of nut or union dirty, damaged, or broken are common errors found when flaring.

RIGID TUBING INSPECTION AND REPAIR

Minor dents and scratches in tubing may be repaired. Scratches or nicks not deeper than 10 percent of the wall thickness in aluminum alloy tubing, which are not in the heel of a bend, may be repaired by burnishing with hand tools. The damage limits for hard, thin-walled corrosion-resistant steel and titanium tubing are considerably less than for aluminum tubing, and might depend on the aircraft manufacturer. Consult the aircraft maintenance manual for damage limits. Replace lines with severe die marks, seams, or splits in the tube. Any crack or deformity in a flare is unacceptable and is cause for rejection. A dent of less than 20 percent of the tube diameter is not objectionable, unless it is in the heel of a bend. To remove dents, draw a bullet of proper size through the tube by means of a length of cable, or push the bullet through a short straight tube by means of a dowel rod. In this case, a bullet is a ball bearing or slug normally made of steel or some other hard metal. In the case of soft aluminum tubing, a hard wood slug or dowel may even be used as a bullet. (***Figure 9-13***)

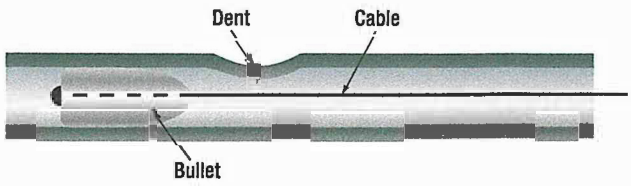


Figure 9-13. Dent removal using a bullet.

A severely damaged line should be replaced. However, the line may be repaired by cutting out the damaged section and inserting a tube section of the same size and material. Flare both ends of the undamaged and replacement tube sections and make the connection by using standard unions, sleeves, and tube nuts.

Aluminum 6061-T6, corrosion resistant steel 304-1/8h and Titanium 3AL-2.5V tubing can be repaired by swaged fittings. If the damaged portion is short enough, omit the insert tube and repair by using one repair union. (***Figure 9-14***) When repairing a damaged line, be very careful to remove all chips and burrs. Any open line that is to be left unattended for some time should be sealed, using metal, wood, rubber, or plastic plugs or caps.

When repairing a low-pressure line using a flexible fluid connection assembly, position the hose clamps carefully to prevent overhang of the clamp bands or chafing of the tightening screws on adjacent parts. If chafing can occur, the hose clamps should be repositioned on the hose. ***Figure 9-15*** illustrates the design of a flexible fluid connection assembly and gives the maximum allowable angular and dimensional offset.

When replacing rigid tubing, ensure that the layout of the new line is the same as that of the line being replaced. Remove the damaged or worn assembly, taking care not to further damage or distort it, and use it as a forming template for the new part. If the old length of tubing cannot be used as a pattern, make a wire template, bending the pattern by hand as required for the new assembly. Then bend the tubing to match the wire pattern. Never select a path that does not require bends in the tubing. A tube cannot be cut or flared accurately enough so that it can be installed without bending and still be free from mechanical strain. Bends are also necessary to permit the tubing to expand or contract under temperature changes and to absorb vibration. If the tube is small (under ¼") and can be hand formed, casual bends may be made to allow for this. It the tube must be machine formed, definite bends must be made to avoid a straight assembly. Start all bends a reasonable distance from the fittings because the sleeves and nuts must be slipped back during the fabrication of flares and during inspections. In all cases, the new tube assembly should be so formed prior to installation that it will not be necessary to pull or deflect the assembly into alignment by means of the coupling nuts.

FLEXIBLE HOSE

FLEXIBLE HOSE INSPECTION

Check the flexible hose and hose assemblies for deterioration at each inspection period. Leakage, separation of the cover or braid from the inner tube, cracks, hardening, lack of flexibility, or excessive "cold flow" are apparent signs of deterioration and reason for replacement. The term "cold flow" describes the deep, permanent impressions in the hose produced by the pressure of hose clamps or supports.

When failure occurs in a flexible hose equipped with swaged end fittings, the entire assembly must be replaced. Install a new hose of correct size and length, complete with factory installed end fittings.

When failure occurs in hose equipped with reusable end fittings, a replacement line can be fabricated with the use of such tooling as may be necessary to comply with the assembly instructions of the manufacturer.

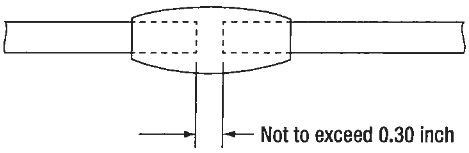
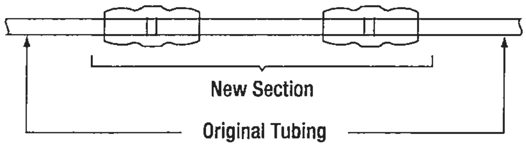
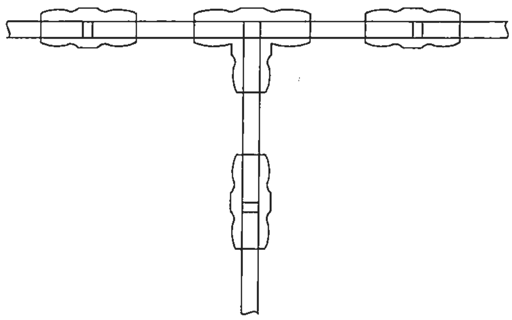
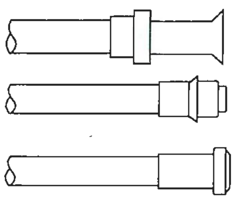
Type of Failure	Repair Method
1. Pin hole leak or circumferential crack in tubing.t 	1. a. Make 1 or 2 cuts as necessary, to remove damaged section. If 2 cuts are required, the distance between them shall not exceed 0. 30". If distance is more than 0.30 inch, go to repair method 2. b. Swage 1 tube-to-tube union in tube section under repair.
2. Longitudinal crack in tubing (crack length in excess of 0.30"). 	2. a. Make 2 cuts to enable removal of damaged section. b. Remove damaged section and duplicate. c. Swage replacement section into tubing under repair using 2 tube-to-tube unions.
3. Leaking tee or elbow (permanent tube connection type). 	3. a. Cut out defective tee or elbow. b. Duplicate tubing sections for each branch. c. Swage splice sections to tee or elbow. d. Connect each splice section to tubing under repair using a tube to tube union.
4. Leaking flared, flareless, or lipseal end fittings. 	4. a. Cut tubing to remove defective fitting. b. Swage appropriate end fitting to tube end. c. Connect new end fitting to mating connection, torquing nut as required.

Figure 9-14. Permaswage™ repair.

FABRICATION AND REPLACEMENT OF FLEXIBLE HOSE

To make a hose assembly, select the proper size hose and end fitting. MS-type end fittings for flexible hose are detachable and may be reused if determined to be serviceable. The inside diameter of the fitting is the same as the inside diameter of the hose to which it is attached. (***Figure 9-16 and 9-17***)

FLEXIBLE HOSE TESTING

All flexible hose must be proof-tested after assembly and applying pressure to the inside of the hose assembly. The proof-test medium may be a liquid or gas. For example, hydraulic, fuel, and oil lines are generally tested using hydraulic oil or water, whereas air or instrument lines are tested with dry, oil-free air or nitrogen. When testing with a liquid, all trapped air is bled from the assembly prior to tightening the cap or plug. Hose tests, using

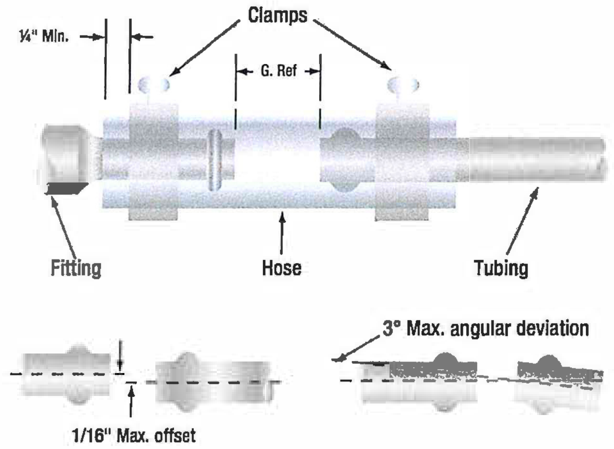


Figure 9-15. Flexible fluid connection assembly.

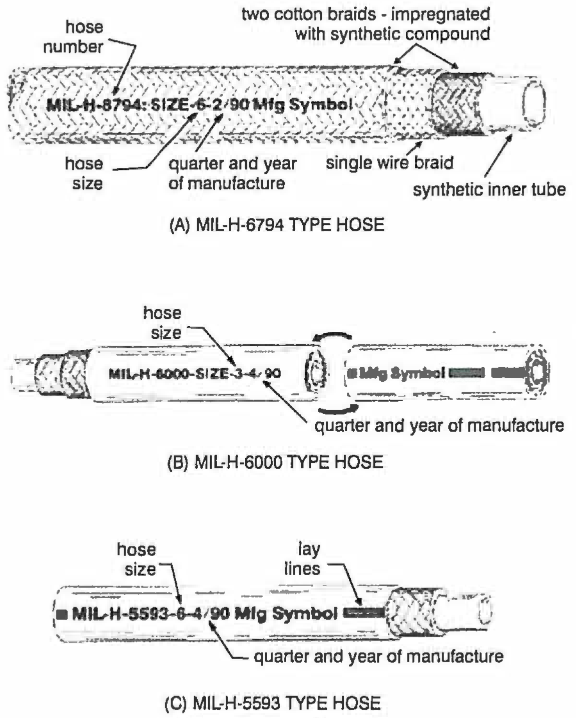


Figure 9-16. Hose identification markings.

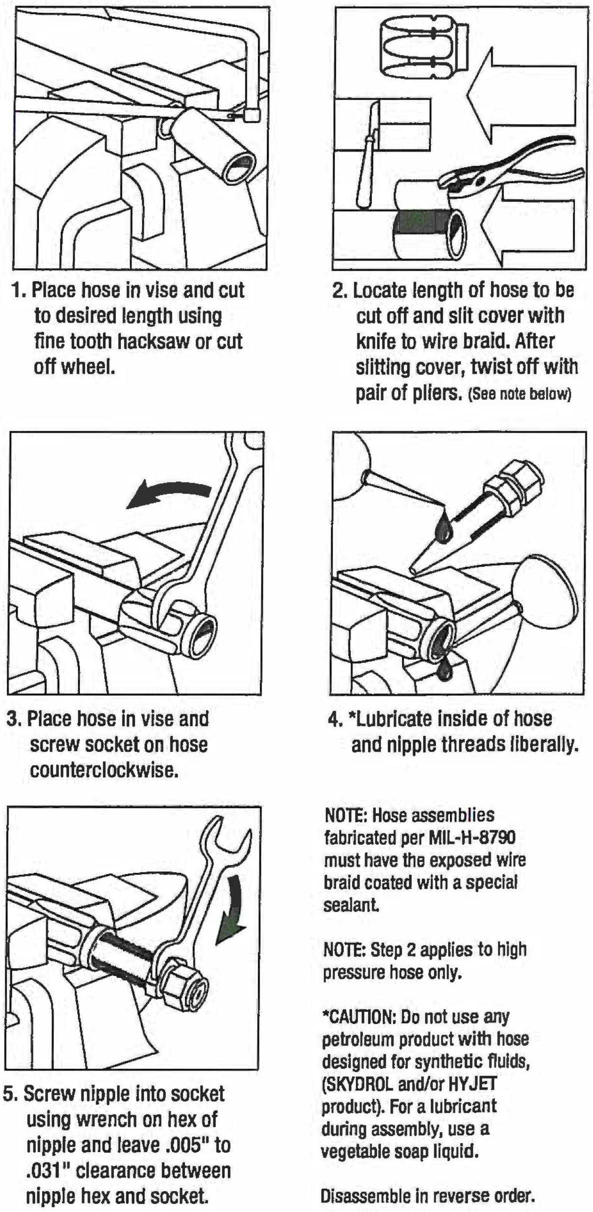


Figure 9-17. Assembly of MS fitting to flexible hose.

a gas, are conducted underwater. In all cases, follow the hose manufacturer's instructions for proof-test pressure and fluid to be used when testing a specific hose assembly. (***Figure 9-18***)

When a flexible hose has been repaired or overhauled using existing hardware and new hose material, and before the hose is installed on the aircraft, it is recommended that the hose be tested to at least 1.5 system pressure. A hydraulic hose burst test stand is used for testing flexible hose. (***Figure 9-19***) A new hose can be operationally checked after it is installed in the aircraft using system pressure.

FLEXIBLE HOSE SIZE DESIGNATIONS

Hose is designated by a dash number, according to its size. The dash number is stenciled on the side of the hose and indicates the size tubing with which the hose is compatible. It does not denote inside or outside diameter. When the dash number of the hose corresponds with the dash number of the tubing, the proper size hose is being used. Dash numbers are shown in ***Figure 9-17.***

INSTALLATION OF FLEXIBLE HOSE ASSEMBLIES

Slack—Hose assemblies must not be installed in a manner that will cause a mechanical load on the hose.

Single Wire Braid Fabric Covered

MIL. Part No.	Tube Size o.d. (inches)	Hose Size i.d. (inches)	Hose Size o.d. (inches)	Recomm. Operating Pressure (PSI)	Min. Burst Pressure (PSI)	Max. Proof Pressure (PSI)	Min. Bend Radius (inches)
MIL-H-8794-3-L	3/16	1/8	.45	3,000	12,000	6,000	3.00
MIL-H-8794-4-L	1/4	3/16	.52	3,000	12,000	6,000	3.00
MIL-H-8794-5-L	5/16	1/4	.58	3,000	10,000	5,000	3.38
MIL-H-8794-6-L	3/8	5/16	.67	2,000	9,000	4,500	4.00
MIL-H-8794-8-L	1/2	13/32	.77	2,000	8,000	4,000	4.63
MIL-H-8794-10-L	5/8	1/2	.92	1,750	7,000	3,500	5.50
MIL-H-8794-12-L	3/4	5/8	1.08	1,750	6,000	3,000	6.50
MIL-H-8794-16-L	1	7/8	1.23	800	3,200	1,600	7.38
MIL-H-8794-20-L	1 1/4	1 1/8	1.50	600	2,500	1,250	9.00
MIL-H-8794-24-L	1 1/2	1 3/8	1.75	500	2,000	1,000	11.00
MIL-H-8794-32-L	2	1 13/16	2.22	350	1,400	700	13.25
MIL-H-8794-40-L	2 1/2	2 3/8	2.88	200	1,000	300	24.00
MIL-H-8794-48-L	3	3	3.56	200	800	300	33.00

Construction: Seamless synthetic rubber inner tube reinforced with one fiber braid, one braid of high tensile steel wire and covered with an oil resistant rubber impregnated fiber braid.

Identification: Hose is identified by specification number, size number, quarter year and year, hose manufacturer's identification.

Uses: Hose is approved for use in aircraft hydraulic, pneumatic, coolant, fuel, and oil systems.

Operating Temperattures:
Sizes 3 through 12: Minus 65 °F to plus 250 °F
Sizes 16 through 48: Minus 40 °F to plus 275 °F

Note: Maximum temperatures and pressures should not be used simultaneously.

Multiple Wire Braid Rubber Covered

MIL. Part No.	Tube Size o.d. (inches)	Hose Size i.d. (inches)	Hose Size o.d. (inches)	Recomm. Operating Pressure (PSI)	Min. Burst Pressure (PSI)	Max. Proof Pressure (PSI)	Min. Bend Radius (inches)
MIL-H-8788- 4-L	1/4	7/32	.63	3,000	16,000	8,000	3.00
MIL-H-8788- 5-L	5/16	9/32	.70	3,000	14,000	7,000	3.38
MIL-H-8788- 6-L	3/8	11/32	.77	3,000	14,000	7,000	5.00
MIL-H-8788- 8-L	1/2	7/16	.86	3,000	14,000	7,500	5.75
MIL-H-8788-10-L	5/8	9/16	1.03	3,000	12,000	6,000	6.50
MIL-H-8788-12-L	3/4	11/16	1.22	3,000	12,000	6,000	7.75
MIL-H-8788-16-L	1	7/8	1.50	3,000	10,000	5,000	9.63

Construction: Seamless synthetic rubber inner tube reinforced with one fiber braid, two or more steel wire braids, and covered with synthetic rubber cover (for gas applications request perforated cover).

Identification: Hose is identified by specification number, size number, quarter year and year, hose manufacturer's identification.

Uses: High pressure hydraulic, pneumatic, coolant, fuel and oil.

Operating Temperatures:
Minus 65 °F to plus 200 °F

Figure 9-18. Aircraft hose specifications.

When installing flexible hose, provide slack or bend in the hose line from 5 to 8 percent of its total length to provide for changes in length that will occur when pressure is applied. Flexible hose contracts in length and expands in diameter when pressurized. Protect all flexible hoses from excessive temperatures, either by locating the lines so they will not be affected or by installing shrouds around them.

When hose assemblies are subject to considerable vibration or flexing, sufficient slack must be left between rigid fittings. Install the hose so that flexure does not occur at the end fittings. The hose must remain straight for at least two hose diameters from the end fittings. Avoid clamp locations that will restrict or prevent hose flexure.

Hoses must be installed without twisting to avoid possible rupture of the hose or loosening of the attaching nuts. Use of swivel connections at one or both ends will relieve twist stresses. Twisting of the hose can be determined from the identification stripe running along its length. This stripe should not spiral around the hose.

To avoid sharp bends in the hose assembly, use elbow fittings, hose with elbow-type end fittings, or the appropriate bend radii. Bends that are too sharp will reduce the bursting pressure of flexible hose considerably below its rated value. (***Figure 9-20***)

Figure 9-19. Hydraulic hose burst test stand.

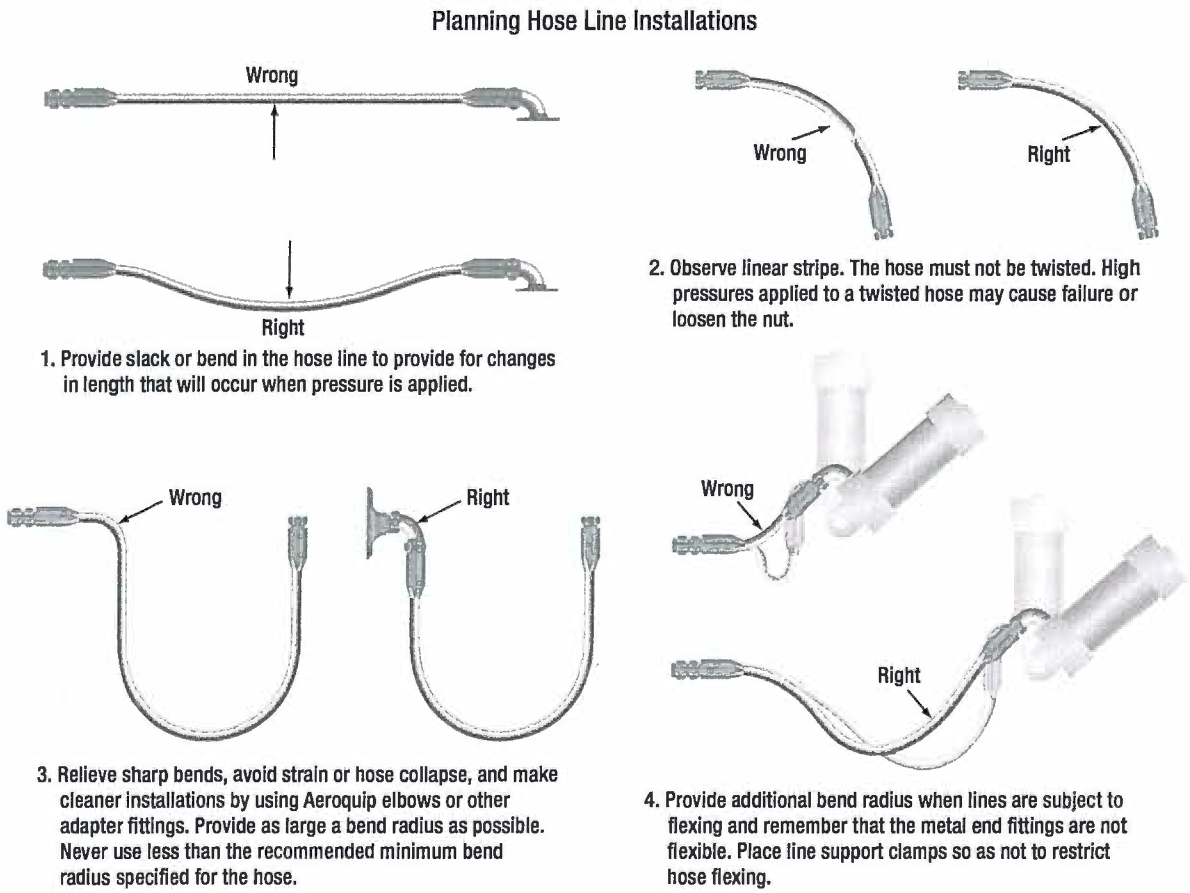


Figure 9-20. Flexible hose installation.

The hose assembly must clear all other lines, equipment, and adjacent structure under every operating condition.

Flexible hose should be installed so that it will be subject to a minimum of flexing during operation. Although hose must be supported at least every 24 inches, closer supports are desirable. Flexible hose must never be stretched tightly between two fittings. If clamps do not seal at specified tightening, examine hose connections and replace parts as necessary. The above is for initial installation and should not be used for loose clamps.

For retightening loose hose clamps in service, proceed as follows: Non-self-sealing hose—if the clamp screw cannot be tightened with the fingers, do not disturb unless leakage is evident. If leakage is present, tighten one-fourth turn. Self-sealing hose—if looser than finger-tight, tighten to finger-tight and add one-fourth turn. (***Figure 9-21***)

Initial Installation Only	Worm screw type clamp (10 threads per inch)	Clamps — radial and other type (28 threads per inch)
Self sealing hose approximately 15 in-lb	Finger-tight plus 2 complete turns	Finger-tight plus 2½ complete turns
All other aircraft hose approximately 25 in-lb	Finger-tight plus 1¼ complete turns	Finger-tight plus 2 complete turns

Figure 9-21. Hose clamp tightening.

HOSE CLAMPS

To ensure proper sealing of hose connections and to prevent breaking hose clamps or damaging the hose, follow the hose clamp tightening instructions carefully. When available, use the hose clamp torque-limiting wrench. These wrenches are available in calibrations of 15 and 25 in-lb limits. In the absence of torque limiting wrenches, follow the finger-tight-plus-turns method. Because of the variations in hose clamp design and hose structure, the values given in ***Figure 9-21*** are approximate. Therefore, use good judgment when tightening hose clamps by this method. Since hose connections are subject to "cold flow" or a setting process, a follow-up tightening check should be made for several days after installation. Support clamps are used to secure the various lines to the airframe or powerplant assemblies. Several types of support clamps are used for this purpose.

The most commonly used clamps are the rubber-cushioned and plain. The rubber-cushioned clamp is used to secure lines subject to vibration; the cushioning prevents chafing of the tubing. (***Figure 9-22***)

The plain clamp is used to secure lines in areas not subject to vibration.

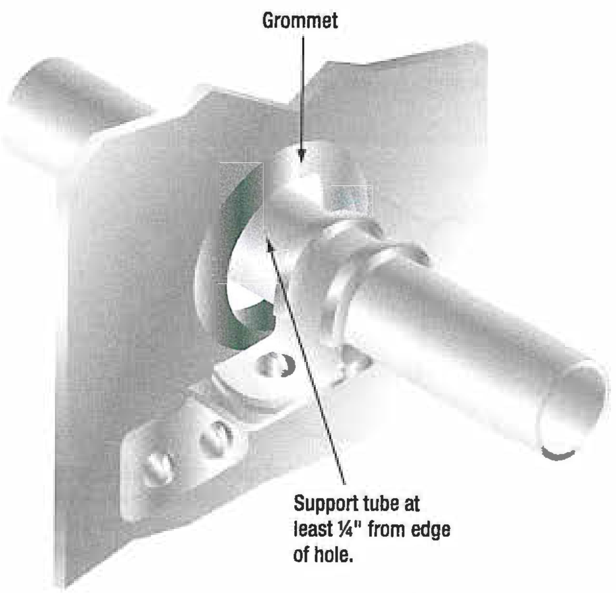


Figure 9-22. Rubber-cushioned clamp.

A Teflon™ cushioned clamp is used in areas where the deteriorating effect of Skydrol, hydraulic fluid, or fuel is expected. However, because it is less resilient, it does not provide as good a vibration-damping effect as other cushion materials. Use bonded clamps to secure metal hydraulic, fuel, or oil lines in place.

Unbonded clamps should be used only for securing wiring. Remove any paint or anodizing from the portion of the tube at the bonding clamp location. Make certain that clamps are of the correct size. Clamps or supporting clips smaller than the outside diameter of the hose may restrict the flow of fluid through the hose. All fluid lines must be secured at specified intervals. The maximum distance between supports for rigid tubing is shown in ***Figure 9-23.***

Tube O. D. (in.)	Distance Between Supports (in.)	
	Aluminium Alloy	Steel
1/8	9 1/2	11 1/2
3/16	12	14
1/4	13 1/2	16
5/16	15	18
3/8	16 1/2	20
1/2	19	23
5/8	22	25 1/2
3/4	24	27 1/2
1	26 1/2	30

Figure 9-23. Maximum distance between supports for fluid tubing.

Question: 9-1
All tubing is ________________ prior to initial installation.

Question: 9-2
The flaring tool used for aircraft tubing has male and female dies ground to produce a flare of ________ degrees.

Question: 9-3
Never apply ________________ to the faces of the fitting or the flare, for it will destroy the metal-to-metal contact between the fitting and flare, a contact which is necessary to produce the seal.

Question: 9-4
When installing flexible hose, provide ________________ in the hose line from 5 to 8 percent of its total length to provide for changes in length that will occur when pressure is applied.

Question: 9-5
A Teflon™ - cushioned clamp is used in areas where the deteriorating effect of ________________ or fuel is expected.

ANSWERS

Answer: 9-1
pressure tested.

Answer: 9-2
35° to 37°.

Answer: 9-3
compound.

Answer: 9-4
slack or bend.

Answer: 9-5
Skydrol™ hydraulic fluid.

SUB-MODULE 10

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 10 SPRINGS Knowledge Requirements		
7.10 - Springs Inspection and testing of springs.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:

(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

SPRINGS

INSPECTION AND TESTING OF SPRINGS

Springs will generally require little in the way of maintenance. Those that are in exposed areas can become corroded over time and those in areas of high temperature can, if they become overheated, lose their temper and cease to have the necessary mechanical compliance to satisfy the task for which they were designed.

It is important that any exposed springs are carefully inspected for signs of corrosion and overheating. Corrosion occurs on static springs and reduces the capacity of the loads that the spring can carry. When a spring carrying a cyclic load becomes corroded, the combination of fatigue and corrosion results in a serious loss of fatigue strength.

Overheating is evidenced as blistering of the surface protection and, in extreme cases, a change of color of the metal due to the loss of temper. When overheating is detected, it must be assumed that the spring is not suitable for the designed task.

In some instances, springs have to be checked against figures or graphs to prove whether they are in a suitable condition to continue in service. Some checks have to be done at prescribed intervals whilst others are done on an 'opportunity basis', such as when a brake caliper is dismantled for overhaul.

The most common check done on a coil spring is static (length) measurement. The manufacturer publishes the exact dimension of the unloaded spring with a small range of tolerance. The servicing technician accurately measures the length of the spring and compares it to the published dimension. If within tolerance limits, the spring is returned to service.

Another common check, usually completed in a workshop environment, is the load/deflection check. This check is done on the springs which are used in more critical services, such as piston engine valve springs. A special test rig is used, to load the spring with either a compressive, tensile or a torsional loading and a meter on the rig will display the load versus deflection figures. (***Figure 10-1***)

A series of loads are subsequently applied to the spring and the relevant deflections noted. Upon completion, the figures are compared to a graph, published by the spring manufacturer, to establish the serviceability of the spring. If a spring fails any of these checks it is simply replaced with a serviceable item.

Figure 10-1. A spring compression tester.

Question: 10-1
It is important that any exposed springs are carefully inspected for signs of __________________ and __________________.

Question: 10-2
The most common check done on a coil spring is __________________ measurement.

ANSWERS

Answer: 10-1
corrosion.
overheating.

Answer: 10-2
static (length).

MAINTENANCE PRACTICES

BEARINGS

SUB-MODULE 11

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 11 BEARINGS Knowledge Requirements		
7.11 - Bearings Testing, cleaning and inspection of bearings; Lubrication requirements of bearings; Defects in bearings and their causes.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
- (a) The applicant should be able to understand the theoretical fundamentals of the subject.
- (b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- (c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
- (d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- (e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

BEARINGS

Maintenance practices on bearings includes disassembly for access, cleaning, inspection and lubrication of bearings.

CLEANING THE WHEEL BEARINGS

The bearings should be removed from the wheel to be cleaned with the recommended solvent, such as Varsol, Naptha, or Stoddard® solvent. Soaking the bearings in solvent is acceptable to loosen any dried-on grease. Bearings are brushed clean with a soft bristle brush and dried with compressed air. Never rotate the bearing while drying with compressed air. The high speed metal-to-metal contact of the bearing rollers with the race causes heat that damages the metal surfaces. The bearing parts could also cause injury should the bearing come apart. Always avoid steam cleaning of bearings. The surface finish of the metals will be compromised leading to early failure.

WHEEL BEARING INSPECTION

Once cleaned, the wheel bearing is inspected. There are many unacceptable conditions of the bearing and bearing cup, which are grounds for rejection. In fact, nearly any flaw detected in a bearing assembly is likely to be grounds for replacement.

Common conditions of a bearing that are cause for rejection are as follows:

- Galling—caused by rubbing of mating surfaces. The metal gets so hot it welds, and the surface metal is destroyed as the motion continues and pulls the metal apart in the direction of motion. (*Figure 11-1*)
- Spalling—a chipped away portion of the hardened surface of a bearing roller or race. (*Figure 11-2*)
- Overheating—caused by lack of sufficient lubrication results in a bluish tint to the metal surface. The ends of the rollers shown were overheated causing the metal to flow and deform, as well as discolor. The bearing cup raceway is usually discolored.(*Figure 11-3*)
- Brinelling—caused by excessive impact. It appears as indentations in the bearing cup raceways. Any static overload or severe impact can cause true brinelling that leads to vibration and premature bearing failure. (*Figure 11-4*)

Figure 11-1. Galling is caused by rubbing of mating surfaces.

Figure 11-2. Spalling is a chipped away portion of the hardened surface.

Figure 11-3. Overheating results in a bluish tint to the metal surface.

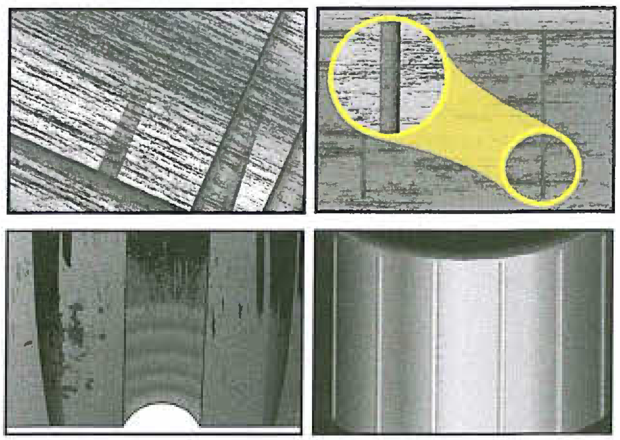


Figure 11-4. Brinelling appears as indentations in the bearing cup raceways.

- False Brinelling—caused by vibration of the bearing while in a static state. Even with a static overload, lubricant can be forced from between the rollers and the raceway. Submicroscopic particles removed at the points of metal-to-metal contact oxidize. They work to remove more particles spreading the damage. This is also known as frictional corrosion. It can be identified by a rusty coloring of the lubricant. (***Figure 11-5***)
- Staining and surface marks—located on the bearing cup as grayish black streaks with the same spacing as the rollers and caused by water that has gotten into the bearing. It is the first stage of deeper corrosion that follows. (***Figure 11-6***)
- Etching and corrosion—caused when water and the damage caused by water penetrates the surface treatment of the bearing element. It appears as a reddish/brown discoloration. (***Figure 11-7***)
- Bruising—caused by fine particle contamination possibly from a bad seal or improper maintenance of bearing cleanliness. It leaves a less than smooth surface on the bearing cup. (***Figure 11-8***)

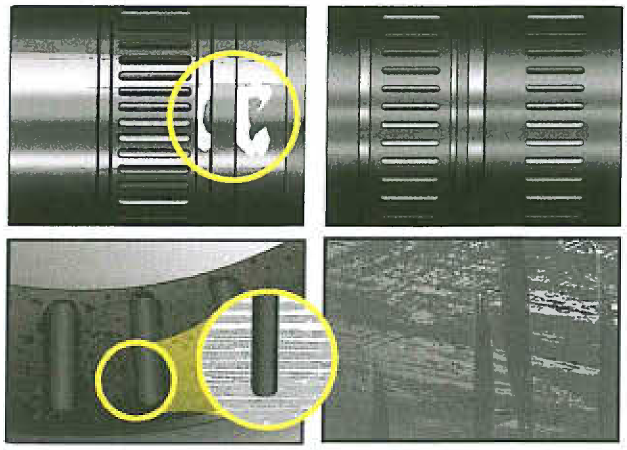


Figure 11-5. False brinelling is caused by vibration of the bearing while in a static state.

Figure 11-6. Staining and surface marks on the bearing.

Figure 11-7. Etching and corrosion appears as a reddish/brown discoloration.

Figure 11-8. Bruising leaves a less than smooth surface on the bearing cup.

The bearing cup does not require removal for inspection; however, it must be firmly seated in the wheel half boss. There should be no evidence that a cup is loose or able to spin. (***Figure 11-9***) The cup is usually removed by heating the wheel in a controlled oven and pressing it out or tapping it out with a non-metallic drift. The installation procedure is similar. The wheel is heated and the cup is cooled with dry ice before it is tapped into place with a non-metallic hammer or drift. The outside of the race is often sprayed with primer before insertion. Consult the wheel manufacturer's maintenance manual for specific instructions.

When inspecting a bearing, feel is important. When rotated, the action of the bearing should feel smooth when rotated. Roughness indicates that there may be concealed damage. The bearing should also be relatively tight with no excessive play.

CONTAMINATION AND CORROSION

Contamination is a leading cause of bearing failure. Abrasive substances like sand, grit, or dust that get in a bearing can cause dents or scratches in the bearing race or rolling elements. This results in vibration and wear. Common sources of contamination are poor handling procedures, dirty hands or tools, and foreign matter in the lubricant or cleaning fluid used on the bearing. A clean ,properly lubricated, and installed bearing delivers extensively reliable service.

Bearing corrosion is caused by some sort of chemical attack on the bearing materials. Moisture is a leading cause. Evidence of corrosion is black pitting marks or reddish brown rust areas on the rolling elements, raceways or cages. Vibration and wear result. Follow the manufacturer's guidelines for bearing treatment, installation procedures and servicing intervals to prevent corrosion.

ELECTRIC CURRENT DAMAGE

When an electric current passes through a bearing, proceeding from one ring to the other via the rolling elements, damage will occur. At the contact surfaces the process is similar to electric arc welding. Such electric currents can be of a low level but last for considerable lengths of time (such as voltage leakage from a motor or generator) or be very high level for a short duration (such as that caused by a lightning strike of the aircraft). Equal amounts of damage can occur from both situations.

The appearance of the damage is dark brown or grayish black fluting (corrugation) or craters in raceways and rollers. Balls have dark discoloration only. Sometimes zigzag burns in ball bearings raceways. Also, localized burns in raceways and on rolling elements.

The material is heated to temperatures ranging from tempering to melting levels. This leads to the appearance of discolored areas, varying in size, where the material has been tempered, re-hardened or melted. Small craters also form where the metal has melted.

The passage of electric current frequently leads to the formation of fluting (corrugation) in bearing raceways. Rollers are also subject to fluting, while there is only dark discoloration of balls. It can be difficult to distinguish between electric current damage and vibration damage. A feature of the fluting caused by electric current is the dark bottom of the corrugations, as opposed to the bright or rusty appearance at the bottom of the vibration induced fluting. Another distinguishing feature is the lack of damage to the rolling elements of bearings with raceway fluting caused by vibrations.
(***Figure 11-10 A and B***)

Both alternating and direct currents cause damage to bearings. Even low amperage currents are dangerous. Non-rotating bearings are much more resistant to electric current damage than bearings in rotation. The extent of the damage depends on a number of factors: current intensity, duration, bearing load, speed and lubricant. The only way of avoiding damage of this nature is to prevent any electric current from passing through the bearing.

Figure 11-9. Bearing cups spinning in the wheel is shown.

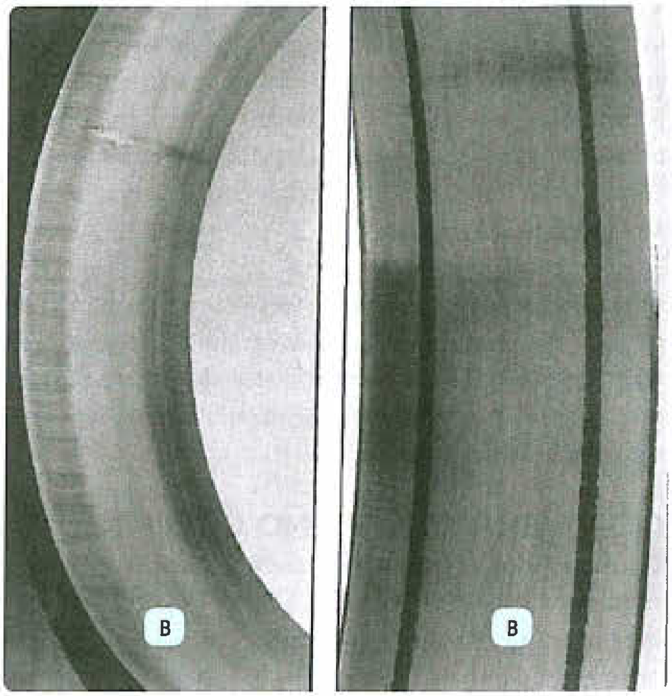


Figure 11-10. (A) Fluting caused by the passage of electric current (B) outer ring damaged by electric current.

BEARING HANDLING AND LUBRICATION

Handling of bearings is of the utmost importance. Contamination, moisture, and vibration, even while the bearing is in a static state, can ruin a bearing. Avoid conditions where these may affect bearings and be sure to install and torque bearings into place according to manufacturer's instructions. Proper lubrication is a partial deterrent to negative environmental impacts on a bearing.

Use the lubricant recommended by the manufacturer. Use of a pressure bearing packing tool or adapter is also recommended as the best method to remove any contaminants from inside the bearing that may have remained after cleaning. (***Figure 11-11***)

STORAGE

If a cleaned bearing is not going to be installed immediately, it should be coated in rust-preventing inhibiting oil or other treatment specified by the manufacturer, wrapped in greaseproof paper, boxed and labeled. The bearing should always be stored horizontally, in a clean dry atmosphere.

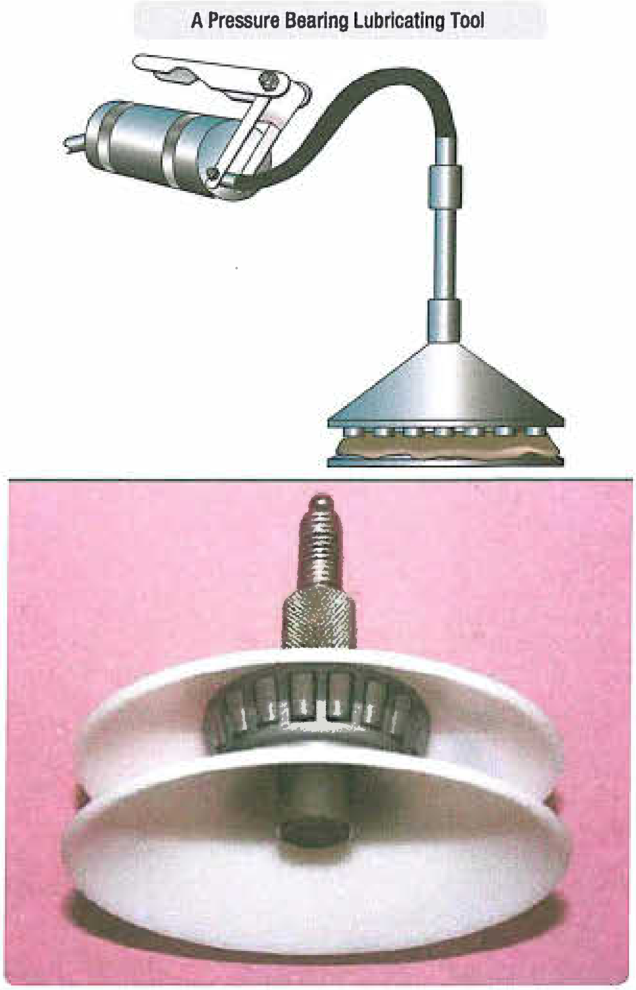


Figure 11-11. A pressure bearing lubricating tool.

Question: 11-1
Maintenance practices on bearings includes disassembly for access, cleaning, inspection and _________________ of bearings.

Question: 11-2
A clean properly lubricated and installed bearing delivers extensively _________________ service.

Question: 11-3
Stored bearings should alway be stored _________________ in a clean dry atmosphere.

Question: 11-4
_________________ is a type of metal deformation caused by the rubbing together of mating surfaces.

Question: 11-5
Rather than by impact as with brinelling, _________________ is damage often caused by vibration of the bearing in a static state.

Question: 11-6
Burn marks on the balls or raceways of a bearing are signs of damage caused by _________________.

ANSWERS

Answer: 11-1
lubrication.

Answer: 11-2
reliable.

Answer: 11-3
lubricated.
horizontally

Answer: 11-4
Galling

Answer: 11-5
False Brinelling

Answer: 11-6
electric current

MAINTENANCE PRACTICES

TRANSMISSIONS

SUB-MODULE 12

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 12 TRANSMISSIONS Knowledge Requirements		
7.12 - Transmissions Inspection of gears, backlash; Inspection of belts and pulleys, chains and sprockets; Inspection of screw jacks, lever devices, push-pull rod systems.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

TRANSMISSIONS

A transmission is a mechanism for transferring power. Transmission is achieved through the use of gears, belts and pulleys, chains and sprockets, jackscrews, levers, and push-pull rods. Aircraft have numerous transmission devices the most notable of which is the reduction gearbox between an engine and a propeller.

GEARS

The purpose of a gear is the transmission of power through motion. The contact and movement within a gear system result in stress and wear. Therefore, it is important to visually examine all gears for cracked or chipped teeth and the presence of pitting or excessive wear.

Deep pit marks or excessive wear on gear teeth are reasons for rejecting and replacing a gear. Minor scratches and abrasions on a gear's bearing surfaces can normally be dressed out with a fine abrasive cloth, however, deep scratches or scoring is unacceptable. Correct gear backlash must be checked and maintained to ensure proper gear mesh.

LASH AND PATTERN

The lash and pattern of a gear is determined by how the teeth of one gear mate with the teeth of another gear. If the teeth of one gear are set too tightly into the teeth of another, there will be no lash and the gears will not be properly lubricated because a film of oil must be present between the teeth of the gears as they mesh. If the gears are meshed too high in relation to the teeth, the load will be transmitted to the smallest portion of the tooth, breaking the teeth because of the load area. (***Figure 12-1***)

The ideal placement of the teeth is in the middle area. At this position the teeth will receive proper lubrication and loading. At this point a measurable amount of lash may sometimes be felt by holding one gear and trying to move the other gear. In most instances this is a minute amount of lash and will be measured with a backlash flag and a dial indicator. A typical gear may have 0.003 to 0.004 lash. In all instances the amount of lash will be given in the maintenance manual and must be followed.

The gear pattern is the contact area of one gear with another. Application of a dye to the gears before operating them under specified load conditions allows the die to color the gear in the area where two gears contact each other. Ideally, this contact pattern will be located in the middle of the gear teeth as shown in ***Figure 12-2***.

Testing and adjusting gear backlash and pattern must always be done in accordance with manufacturer's instruction. Shims or spacers are often used to obtain the correct relationship between the gears. (***Figure 12-3***)

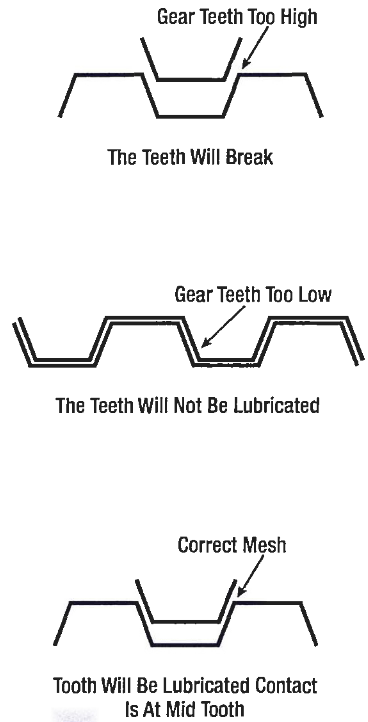


Figure 12-1. Various gear tooth positions with mating gears.

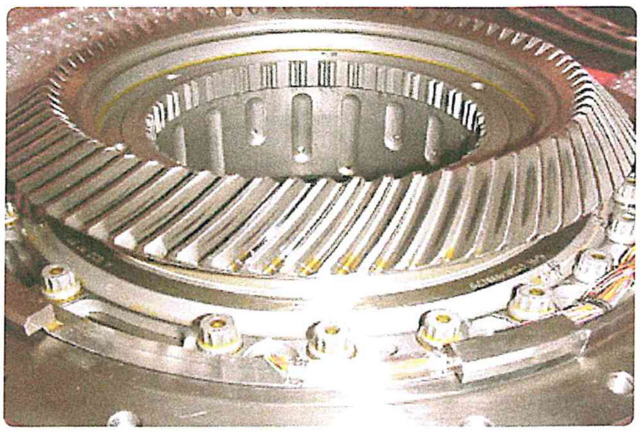


Figure 12-2. Dye transfer shows correct gear pattern.

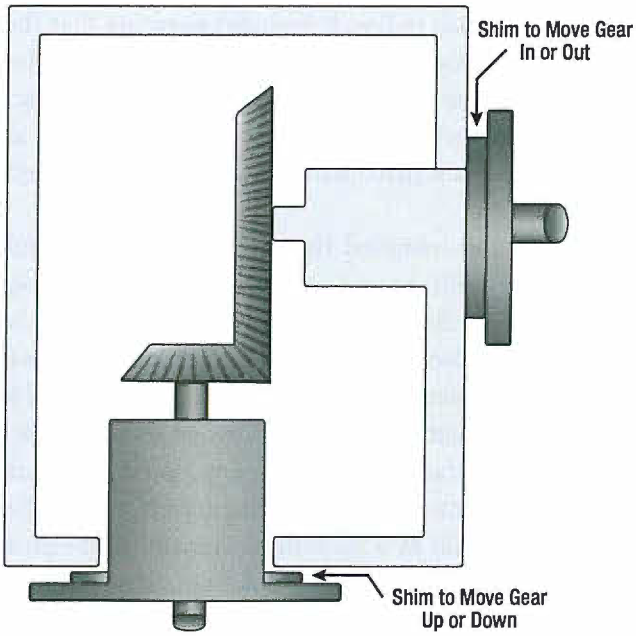


Figure 12-3. Typical shim method of moving gear positions.

BELTS AND PULLEYS

Many piston engine aircraft powerplants use a belt and pulley arrangement to drive the alternator or vacuum pump. (*Figure 12-4*) They might also be used in some other accessory on larger aircraft. Belts must be inspected for wear and degradation. Cracking, chipping, fraying or splitting are cause for replacement. Pulleys must be aligned correctly so that the belt cycles without any vibration or excessive wear.

A drive belt must operate at a designed tension. The tension can often be tested by pushing on the belt in an unsupported location and observing its deflection. An adjustment is typically made by moving the alternator and its pulley location via an adjusting bolt on the mounting bracket. In addition to a condition inspection before each flight, belts are inspected during regular maintenance inspections. Belts may be life-limited parts that are changed periodically despite appearance. Follow the manufacturer's instruction when maintaining a belt and pulley transmission. Always replace a belt with a belt of the exact same part number.

Figure 12-4. An alternator drive belt on a piston aircraft engine.

CHAINS AND SPROCKETS

A chain and sprocket transmission may be encounter in an aircraft. The main issues with this type of transmission are cleanliness and lubrication for proper operation and excessive wear through elongation. Follow manufacturer's instruction for cleaning and lubricating the chain and sprocket. Measure the chain as specified and replace if elongated or worn beyond limits.

JACK SCREWS

A jack screw transmission of power is common on aircraft. It is often used as the drive for lowering and raising flaps and on stabilizer and rudder trim mechanisms. A gear arrangement or gearbox is used to transfer the power to the jack screw.

A ball nut attached to the moving component is rotated which follows the helically ground jack screw until the component is in the selected position. Lubrication and backlash are the two primary maintenance concerns with a jack screw arrangement.

The jackscrew must be cleaned before lubricating or making clearance adjustments. Regular lubrication intervals are specified in maintenance data due to the environmental exposure of many jackscrew installations. Ball nut wear is possible and is also checked. Use of jigs or special measuring tools is common.

LEVERS

Levers can be found in numerous places within an aircraft and maintenance of these items can vary, depending on their location and purpose. As a rule, levers will be used to transmit thrust from one medium to another. For example, a push/pull system may drive a lever that operates a service, with an increase or decrease of mechanical advantage or a change of direction. Apart from the bearings of the lever requiring lubrication, (unless they are sealed-for-life bearings), there is little maintenance required, other than physical checks for damage, distortion and cracks.

Some commonly visible lever are shown in ***Figure 12-5.*** The action produced by moving the levers is hidden below the console.

PUSH-PULL ROD SYSTEMS

Push-pull tubes are used as linkage in various types of mechanically operated systems. This type of linkage eliminates the problem of varying tension and permits the transfer of either compression or tension stress through a single tube. A push-pull tube assembly consists of a hollow aluminum alloy or steel tube with an adjustable end fitting and a check nut at either end. (***Figure 12-6***)

The check nuts secure the end fittings after the tube assembly has been adjusted to its correct length. Push-pull tubes are generally made in short lengths to prevent vibration and bending under compression loads.

Inspection of push pull rods includes ensuring that they are perfectly straight (unless designed otherwise). When installed, the assembly should be correctly aligned and should move freely. The spherical rod end bushing are either sealed or are fitted with a fitting to be lubricated.

The bolt or pin installed through the rod end should be in good condition and safetied properly. The bores through which the rod end bolt connect the rod to an assembly must also be inspected. The bolt may have to be removed for inspection. Rod ends do fail and should be inspected frequently and replaced when recommended. This is particularly important since push-pull tube assemblies are often used in flight controls and landing gear. There should be a smooth movement in the push-pull rod assembly free from binding. Anything else should prompt further inspection.

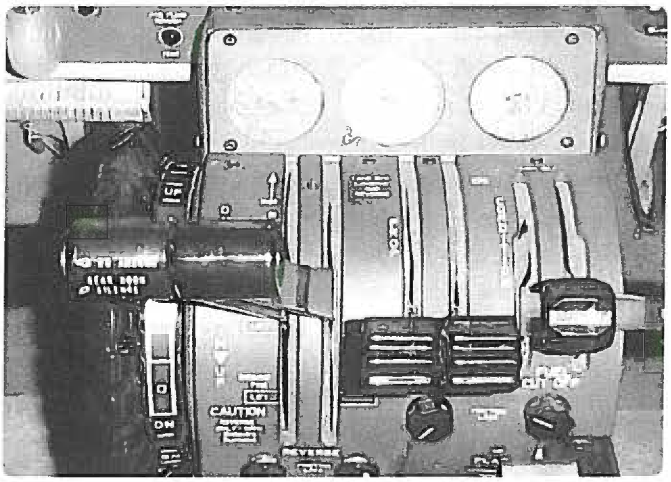


Figure 12-5. Aircraft engine control levers.

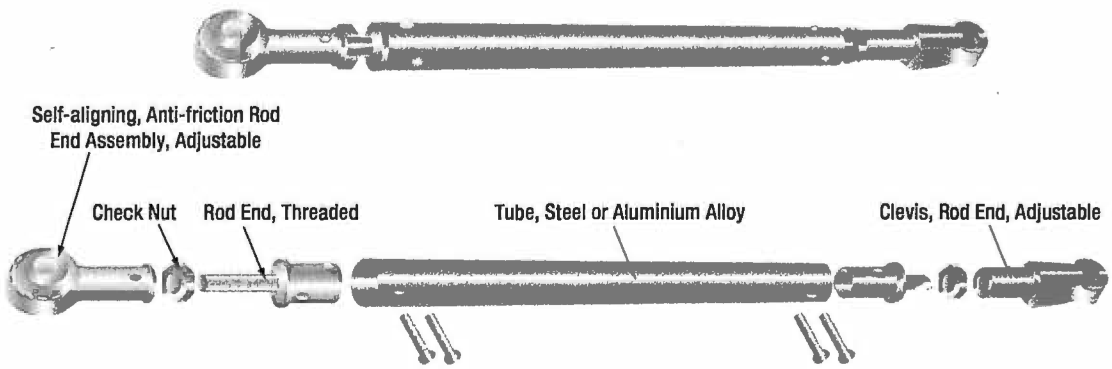


Figure 12-6. Push-pull tube assembly.

Question: 12-1
A transmission is a mechanism for transferring ________________.

Question: 12-4
If the lash and pattern of gears is too close, they may fail due to lack of ________________.

Question: 12-2
Many piston engine aircraft powerplants use a ________________ arrangement to drive the alternator or vacuum pump.

Question: 12-5
The main issues affecting the longevity of chain and sprocket transmissions are ________________ and ________________.

Question: 12-3
A ________________ type linkage eliminates the problem of varying tension and permits the transfer of either compression or tension stress through a single tube.

Question: 12-6
The key factor which determines the proper operation of push-pull systems is ________________.

ANSWERS

Answer: 12-1
power.

Answer: 12-2
belt and pulley.

Answer: 12-3
push-pull rod system.

Answer: 12-4
lubrication

Answer: 12-5
cleanliness, lubrication

Answer: 12-6
proper alignment

MAINTENANCE PRACTICES

CONTROL CABLES

SUB-MODULE 13

PART-66 SYLLABUS	LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 13 CONTROL CABLES Knowledge Requirements		
7.13 - Control Cables Swaging of end fittings; Inspection and testing of control cables; Bowden cables; aircraft flexible control systems.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

CONTROL CABLES

SWAGING OF END FITTINGS

Control cables are terminated at the end via swaging. Hand-woven 5-tuck splices were used on some older aircraft but are obsolete now unless an effort is being made to restore or maintain an antique aircraft to its original configuration. The hand-woven splice only maintains about 75% of the cable strength.

Swage-type terminals, manufactured in accordance to AN standard, are suitable for use in civil aircraft up to, and including, maximum cable loads. When swaging tools are used, it is important that all the manufacturers' instructions, including "go and no-go" dimensions, be followed in detail to avoid defective and inferior swaging. Observance of all instructions should result in a terminal developing the full-rated strength of the cable. Critical dimensions, both before and after swaging, are shown in ***Figure 13-1***.

TERMINALS

When swaging terminals onto cable ends, observe the following procedures. Cut the cable to the proper length allowing for growth during swaging. Apply a preservative compound to the cable ends before insertion into the terminal barrel.

NOTE: Never solder cable ends to prevent fraying, since the presence of the solder will greatly increase the tendency of the cable to pull out of the terminal.

Insert the cable into the terminal approximately 1 inch, and bend toward the terminal, then push the cable end entirely into the terminal barrel. The bending action puts a kink or bend in the cable end, and provides enough friction to hold the terminal in place until the swaging operation can be performed. Bending also tends to separate the strands inside the barrel, thereby reducing the strain on them.

NOTE: If the terminal is drilled completely through, push the cable into the terminal until it reaches the approximate position shown in ***Figure 13-2***. If the hole is not drilled through, insert the cable until the end rests against the bottom of the hole.

Accomplish the swaging operation in accordance with the instructions furnished by the manufacturer of the swaging equipment.

Inspect the terminal after swaging to determine that it is free from the die marks and splits, and is not out-of-round. Check for cable slippage in the terminal and for cut or broken wire strands. Using a "go no-go" gauge or a micrometer, check the terminal shank diameter as shown in ***Figure 13-1*** and ***Figure 13-3***.

Test the cable by proof-loading it to 60 percent of its rated breaking strength.

		Before Swaging				After Swaging	
Cable Size (inches)	Wire Strands	Outside Diameter	Bore Diameter	Bore Length	Swaging Length	Minimum Breaking Strength (pounds)	Shank Diameter *
1/16	7 x 7	0.160	0.078	1.042	0.969	480	0.138
3/32	7 x 7	.218	.109	1.261	1.188	920	.190
1/8	7 x 19	.250	.141	1.511	1.438	2,000	.219
5/32	7 x 19	.297	.172	1.761	1.688	2,800	.250
3/16	7 x 19	.359	.203	2.011	1.938	4,200	.313
7/32	7 x 19	.427	.234	2.261	2.188	5,600	.375
1/4	7 x 19	.494	.265	2.511	2.438	7,000	.438
9/32	7 x 19	.563	.297	2.761	2.688	8,000	.500
5/16	7 x 19	.635	.328	3.011	2.938	9,800	.563
3/8	7 x 19	.703	.390	3.510	3.438	14,400	.625

*Use gauges in kit for checking diameters.

Figure 13-1. Straight-shank terminal dimensions.

SPLICING

Completely severed cables or those badly damaged in a localized area, may be repaired by the use of an eye terminal bolted to a clevis terminal. (***Figure 13-4A***) However, this type of splice can only be used in free lengths of cable which do not pass over pulleys or through fair-leads.

SWAGED BALL TERMINALS

On some aircraft cables, swaged ball terminals are used for attaching cables to quadrants and special connections where space is limited. Single shank terminals are generally used at the cable ends, and double shank fittings may be used at either the end or in the center of the cable. Dies are supplied with the swaging machines for attaching these terminals to cables by the method in the following paragraph.

The steel balls and shanks have a hole through the center, and are slipped over the cable and positioned in the desired location. Perform the swaging operation in accordance with the instructions furnished by the manufacturer of the swaging equipment. Check the swaged fitting with a "go no-go" gauge to see that the fitting is properly compressed, and inspect the physical condition of the finished terminal. (***Figure 13-5***)

CABLE SLIPPAGE IN TERMINAL

Ensure that the cable is properly inserted in the terminal after the swaging operation is completed. Instances have been noted wherein only ¼ inch of the cable was swaged in the terminal.

Observance of the following precautions should minimize this possibility:

- Measure the length of the terminal end of the fitting to determine the proper length of cable to be inserted into the barrel of the fitting.
- Lay off this length at the end of the cable and mark with masking tape. Since the tape will not slip, it will provide a positive marking during the swaging process.
- After swaging, check the tape marker to make certain that the cable did not slip during the swaging operation.

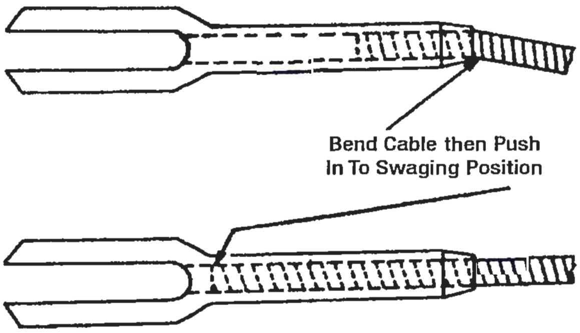


Figure 13-2. Insertion of cable into terminal.

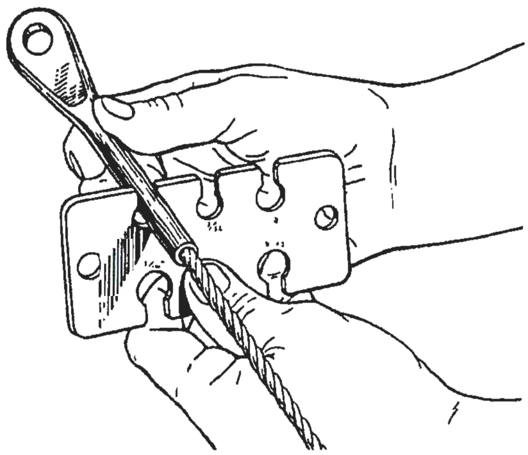


Figure 13-3. Gauging terminal shank after swaging.

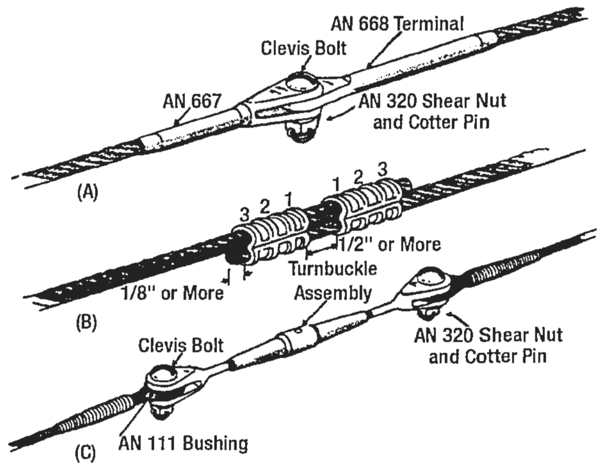


Figure 13-4. Typical cable splices.

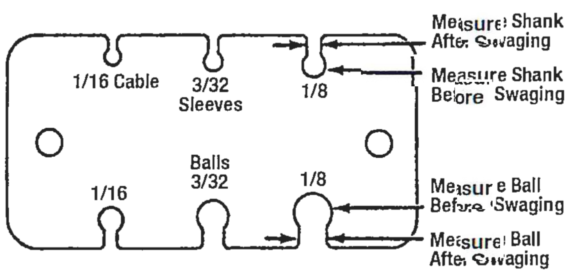


Figure 13-5. Typical terminal gauge.

- Remove the tape and paint the junction of the swaged fitting and cable with red paint.
- At all subsequent service inspections of the swaged fitting, check for a gap in the painted section to see if cable slippage has occurred.

NICOPRESS® SWAGED END FITTINGS

The Nicopress® process, a patented process using copper sleeves, is commonly used to create end fittings on control cables. It may be used up to the full rated strength of the cable when the cable is looped around a thimble. (***Figure 13-6***)

This process may also be used in place of the 5-tuck splice on cables up to and including ⅜ inch diameter. Whenever this process is used for cable splicing, it is imperative that the tools, instructions, and data supplied by Nicopress® be followed exactly to ensure the desired cable function and strength is attained. The use of sleeves that are fabricated of material other than copper requires engineering approval for the specific application. Before undertaking a Nicopress® splice, determine the proper tool and sleeve for the cable to be used. Refer to ***Figure 13-7 and Figure 13-8*** for details on sleeves, tools, and the number of presses required for the various sizes of aircraft cable. The tool must be in good working condition and properly adjusted to ensure a satisfactory splice.

To compress a sleeve, have it well centered in the tool groove with the major axis of the sleeve at right angles to the tool. If the sleeve appears to be out of line after the press is started, open the tool, re-center the sleeve, and complete the press.

Before undertaking a thimble-eye splice, initially position the cable so the end will extend slightly beyond the sleeve, as the sleeve will elongate somewhat when it is compressed. If the cable end is inside the sleeve, the splice may not hold the full strength of the cable. It is desirable that the oval sleeve be placed in close proximity to the thimble points, so that when compressed, the sleeve will contact the thimble as shown in ***Figure 13-6***.

The sharp ends of the thimble may be cut off before being used; however, make certain the thimble is firmly secured in the cable loop after the splice has been completed. When using a sleeve requiring three

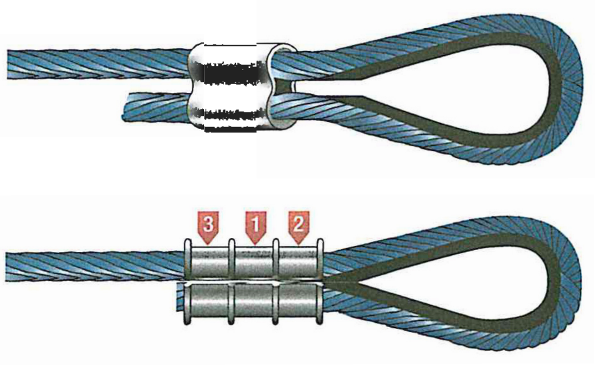


Figure 13-6. Typical Nicopress® thimble-eye splice.

compressions, make the center compression first, the compression next to the thimble second, and the one farthest from the thimble last.

Lap or running splices may also be made with copper oval sleeves. When making such splices, it is usually necessary to use two sleeves to develop the full strength of the cable. The sleeves should be positioned as shown in ***Figure 13-4B***, and the compressions made in the order shown. As in the case of eye splices, it is desirable to have the cable ends extend beyond the sleeves sufficiently to allow for the increased length of the compressed sleeves. Stop sleeves may be used for special cable end and intermediate fittings. They are installed in the same manner as Nicopress oval sleeves.

NOTE: All stop sleeves are plain copper. Certain sizes are colored for identification.

Terminal Gauge. To make a satisfactory copper sleeve installation, it is important that the amount of sleeve pressure be kept uniform. The completed sleeves should be checked periodically with the proper gauge.

Hold the gauge so that it contacts the major axis of the sleeve. The compressed portion at the center of the sleeve should enter the gauge opening with very little clearance, as shown in ***Figure 13-9***. If it does not, the tool must be adjusted accordingly.

The preceding information regarding copper oval sleeves and stop sleeves is based on tests made with flexible aircraft cable. The sleeves may also be used on wire ropes of other construction, if each specific type of cable is proof-tested initially. Because of variation in rope strengths, grades, construction, and actual diameters, the test is necessary to insure proper selection

	Copper Oval Sleeve Stock No.						
Cable Size	Plain	Plated*	Manual Tool No.	Sleeve Length Before Compression (approx.) (inches)	Sleeve Length After Compression (approx.) (inches)	Number of Presses	Tested Strength (pounds)
3/64	18-11-B4	28-11-B4	51-B4-887	3/8	7/16	1	340
1/16	18-1-C	28-1-C	51-C-887	3/8	7/16	1	550
3/32	18-2-G	28-2-G	51-G-887	7/16	1/2	1	1,180
1/8	18-3-M	28-3-M	51-M-850	9/16	3/4	3	2,300
5/32	18-4-P	28-4-P	51-P-850	5/8	7/8	3	3,050
3/16	18-6-X	28-6-X	51-X-850	1	1 1/4	4	4,350
7/32	18-8-F2	28-8-F2	51-F2-850	7/8	1 1/16	4	5,790
1/4	18-10-F6	28-10-F6	3-F6-950	1 1/8	1 1/2	3	7,180
5/16	18-13-G9	28-13-G9	3-G9-950	1 1/4	1 5/8	3	11,130
			No. 635 Hydraulic Tool Dies				
3/64	18-23-H5	28-23-H5	Oval H5	1 1/2	1 7/8	1	16,800
1/16	18-24-J8	28-24-J8	Oval J8	1 3/4	2 1/8	2	19,700
3/32	18-25-K8	28-25-K8	Oval K8	1 7/8	2 1/2	2	25,200
1/8	18-27-M1	28-27-M1	Oval M1	2	2 5/8	3	31,025
5/32	18-28-N5	28-28-N5	Oval N5	2 3/8	3 1/8	3	39,200

*Required on stainless cables due to electrolysis caused by different types of metals.

Figure 13-7. Copper oval sleeve data.

	Copper Stop Sleeve Data				
Cable Size (inch)	Sleeve No.	Tool No.	Sleeve	Sleeve	Tested Strength (pounds)
3/64	871-12-B4	51-B4-887	7/32	11/64	280
1/16	871-1-C	51-C-887	7/32	13/64	525
3/32	871-17-J (Yellow)	51-MJ	5/16	21/64	600
1/8	S71-18-J (Red)	51-MJ	5/16	21/64	800
5/32	871-19-M	51-MJ	5/16	27/64	1,200
3/16	871-20-M (Black)	51-MJ	5/16	27/64	1,600
7/32	871-22-M	51-MJ	5/8	7/16	2,300
1/4	871-23-F6	3-F6-950	11/16	21/32	3,500
5/16	871-26-F6	3-F6-950	11/16	21/32	3,800

NOTE: All stop sleeves are plain copper. Certain sizes are colored for identification.

Figure 13-8. Copper stop sleeve data.

of materials, the correct pressing procedure, and an adequate margin of safety for the intended use.

CABLE SYSTEM INSPECTION

Aircraft cable systems are subject to a variety of environmental conditions and deterioration. Wire or strand breakage is easy to visually recognize. Other kinds of deterioration such as wear, corrosion, and/or distortion are not easily seen; therefore, control cables should be removed periodically for a more detailed inspection. At each annual or 100 hour inspection,

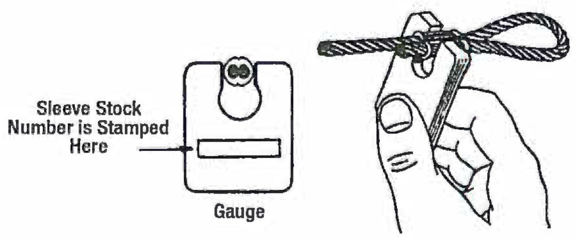


Figure 13-9. Typical terminal gauge.

all control cables must be inspected for broken wires strands. Any cable assembly that has one broken wire strand located in a critical fatigue area must be replaced. A critical fatigue area is defined as the working length of a cable where the cable runs over, under, or around a pulley, sleeve, or through a fair-lead; or any section where the cable is flexed, rubbed, or worked in any manner; or any point within 1 foot of a swaged-on fitting.

A swaged-on fitting can be an eye, fork, ball, ball and shank, ball and double shank, threaded stud, threaded stud and turnbuckle, compression sleeve, or any hardware used as a termination or end fitting on the cable. These fittings may be attached by various swaging methods such as rotary swaging, roll swaging, hydraulic pressing, and hand swaging tools. (See MIL-T-781.) The pressures exerted on the fittings during the swaging process sometimes pinch the small wires in the cable. This can cause premature failure of the pinched wires, resulting in broken wires.

Close inspection in these critical fatigue areas, must be made by passing a cloth over the area to snag on broken wires. This will clean the cable for a visual inspection, and detect broken wires if the cloth snags on the cable. Also, a very careful visual inspection must be made since a broken wire will not always protrude or stick out, but may lie in the strand and remain in the position of the helix as it was manufactured. Broken wires of this type may show up as a hairline crack in the wire. If a broken wire of this type is suspected, further inspection with a magnifying glass of 7 power or greater, is recommended. ***Figure 13-10*** shows a cable with broken wires that was not detected by wiping, but was found during a visual inspection. The damage became readily apparent when the cable was removed and bent as shown.

Kinking of wire cable can be avoided if properly handled and installed. Kinking is caused by the cable taking a spiral shape as the result of unnatural twist. One of the most common causes for this twist is improper unreeling and uncoiling. In a kinked cable, strands and wires are out of position, which creates unequal tension and brings excessive wear at this part of the cable. Even though the kink may be straightened so that the damage appears to be slight, the relative adjustment between the strands has been disturbed so that the cable cannot give maximum service and should be replaced.

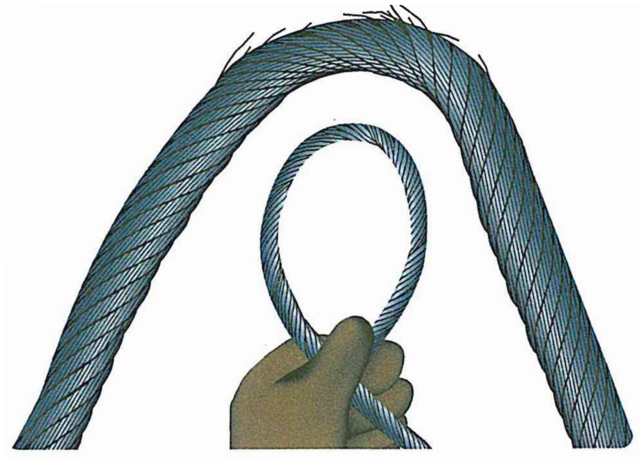


Figure 13-10. Cable inspection technique.

Inspect cables for a popped core or loose strands. Replace any cable that has a popped core or loose strands regardless of wear or broken wires.

Nylon jacketed cable with any cracks or necking down in the diameter of the jacket shall be replaced. Usable cable life is over when these conditions begin to appear in the nylon jacket.

External wear patterns will extend along the cable equal to the distance the cable moves at that location and may occur on one side of the cable or on its entire circumference. Replace flexible and non-flexible cables when the individual wires in each strand appear to blend together (outer wires worn 40 to 50 percent) as depicted in ***Figure 13-11***. Actual instances of cable wear beyond the recommended replacement point are shown in ***Figure 13-12***.

As wear is taking place on the exterior surface of a cable, the same condition is taking place internally, particularly in the sections of the cable which pass over pulleys and quadrants. This condition (shown in ***Figure 13-13***) is not easily detected unless the strands of the cable are separated. This type of wear is a result of the relative motion between inner wire surfaces. Under certain conditions, the rate of this type of wear can be greater than that occurring on the surface.

Areas especially conducive to cable corrosion are battery compartments, lavatories, wheel wells, etc.; where a concentration of corrosive fumes, vapors, and liquids can accumulate. Carefully examine any cable for corrosion, when it has a broken wire in a section that is not in

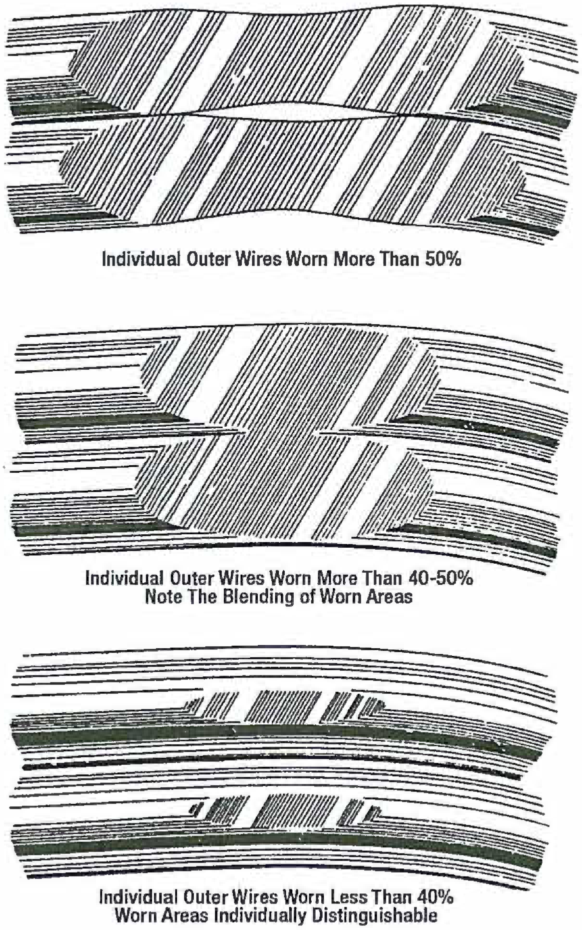


Figure 13-11. Cable wear patterns.

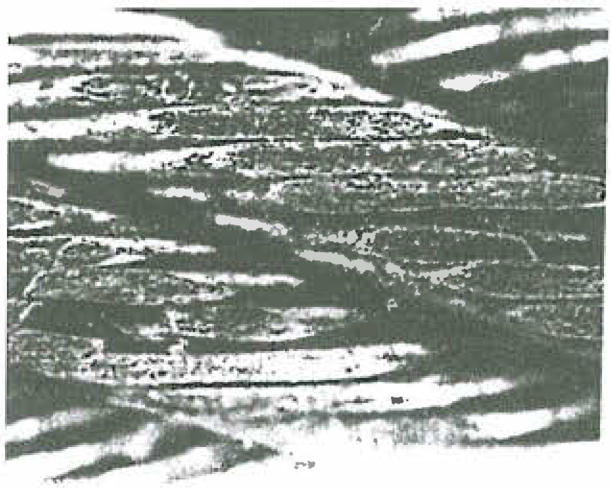


Figure 13-12. Worn cable (replacement necessary).

contact with a wear producing airframe component, such as a pulley, fair-lead, etc. If the surface of the cable is corroded, relieve cable tension and carefully force the cable open by reverse twisting and visually inspect the interior. Corrosion on the interior strands of the cable constitutes failure, and the cable must be replaced. If no internal corrosion is detected, remove loose external

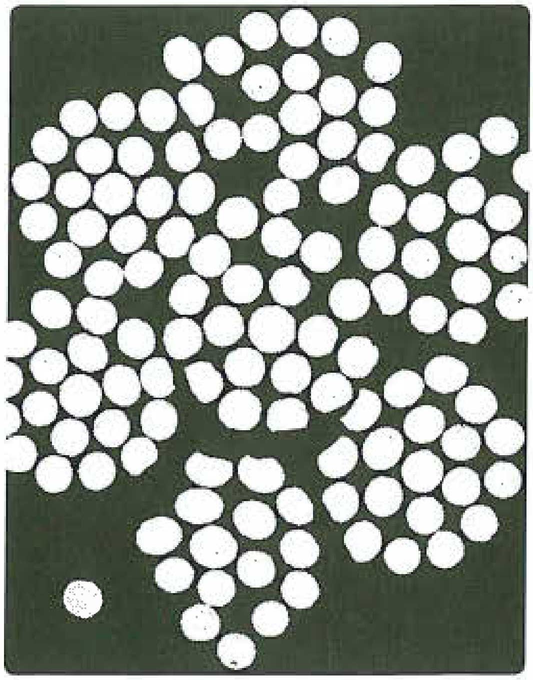


Figure 13-13. Internal end view of cable wear.

rust and corrosion with a clean, dry, coarse weave rag, or fiber brush. Do not use metallic wool or solvents to clean installed cables. Use of metallic wool will embed dissimilar metal particles in the cables and create further corrosion problems.

Solvents will remove internal cable lubricant allowing cable strands to abrade and further corrode. After thorough cleaning, sparingly apply specification MIL-C-16173, grade 4, corrosion-preventive compound to cable. Do not apply the material so thick that it will interfere with the operation of cables at fair-leads, pulleys, or grooved bellcrank areas. Examine cable runs for incorrect routing, fraying, twisting, or wear at fair-leads, pulleys, anti abrasion strips, and guards. Look for interference with adjacent structure, equipment, wiring, plumbing, and other controls. Inspect cable systems for binding, full travel, and security of attaching hardware. Check for slack in the cable system by attempting to move the control column and/or pedals while the gust locks are installed on the control surfaces. With the gust locks removed, actuate the controls and check for friction or hard movement. These are indications that excessive cable tension exists.

Note: If the control movement is stiff after maintenance is performed on control surfaces, check for parallel cables twisted around each other, or cables connected in reverse.

Check swaged terminal reference marks for an indication of cable slippage within the fitting. Inspect the fitting assembly for distortion and/or broken strands at the terminal. Ensure that all bearings and swivel fittings (bolted or pinned) pivot freely to prevent binding and subsequent failure. Check turnbuckles for proper thread exposure and broken or missing safety wires/clips.

Inspect pulleys for roughness, sharp edges, and presence of foreign material embedded in the grooves. Examine pulley bearings to ensure proper lubrication, smooth rotation; and freedom from flat spots, dirt, and paint spray. During the inspection, rotate the pulleys, which only turn through a small arc, to provide a new bearing surface for the cable. Maintain pulley alignment to prevent the cable from riding on the flanges and chafing against guards, covers, or adjacent structure. Check all pulley brackets and guards for damage, alignment, and security. Various cable system malfunctions may be detected by analyzing pulley conditions. These include such discrepancies as too much tension, misalignment, pulley bearing problems, and size mismatches between cables and pulleys. Examples of these conditions are shown in ***Figure 13-14.***

Inspect fair-leads for wear, breakage, alignment, cleanliness, and security. Examine cable routing at fair-leads to ensure that deflection angles are no greater than 3° maximum. Determine that all guides and anti-abrasion strips are secure and in good condition. Examine pressure seals for wear and/or material deterioration. Seal guards should be positioned to prevent jamming of a pulley in case pressure seal fails and pieces slide along the cable.

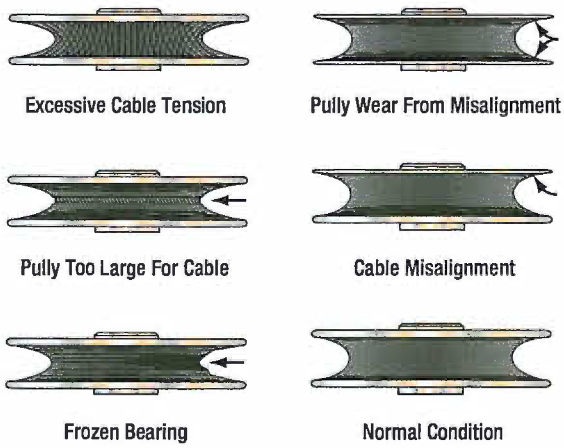


Figure 13-14. Pulley wear patterns.

MANUFACTURER WIRE SPLICES

Manufacturers splice cable wires during the mass production of spools of wire. These splices have been mistaken for defects in the cable because individual wire end splices were visible after assembly of a finished cable length. In some instances, the process of twisting outer strands around the core strand may also slightly flatten individual outer wires, particularly in the area of a wire splice. This flattening is the result of die-sizing the cable, and does not affect the strength of the cable. These conditions (as shown in ***Figure 13-15***) are normal, and are not a cause for cable rejection.

TESTING CABLE TENSION

For the aircraft to operate as it was designed, the cable tension for the flight controls must be correct. To determine the amount of tension on a cable, a tensiometer is used. When properly maintained, a tensiometer is 98 percent accurate. Cable tension is determined by measuring the amount of force needed to make an offset in the cable between two hardened steel blocks called anvils. A riser or plunger is pressed against the cable to form the offset. Several manufacturers make a variety of tensiometers, each type designed for different kinds of cable, cable sizes, and cable tensions. (***Figure 13-16***)

Carefully adjust control cable tension in accordance with the airframe manufacturer's recommendations. On large aircraft, take the temperature of the immediate area into consideration when using a tension meter. For long cable sections, use the average of two or three temperature readings to obtain accurate tension values. If necessary, compensate for extreme surface temperature variations that may be encountered if the aircraft is operated primarily in unusual geographic or climatic conditions such as arctic, arid, or tropic locations.

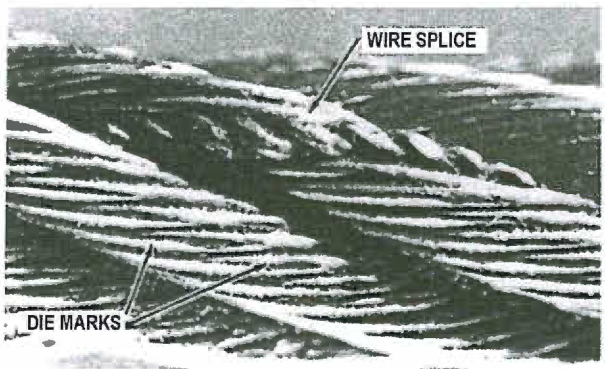


Figure 13-15. Manufacturer's wire splice.

Figure 13-16. Tensiometer.

Use rigging pins and gust locks, as necessary, to ensure satisfactory results. At the completion of rigging operations, check turnbuckle adjustment and safetying in accordance with section 10 of this chapter.

AIRCRAFT FLEXIBLE CONTROL SYSTEMS

BOWDEN CABLE SYSTEMS

A typical Bowden cable control might be a brake lever on the control column operating a remote brake control valve. Maintenance of Bowden cable systems is usually restricted to cleaning and lubrication of the inner cable at regular intervals and adjustment of the outer conduit (e.g. if the brakes needed adjustment). Lubrication keeps moisture out of the cable to prevent it freezing at low temperatures.

Servicing of Bowden cables is minimal. Inspect the cable ends for fraying and corrosion. Also, inspect the conduit for kinks and signs of wear. Adjust the cable for slackness by using the adjustment nut (i.e. screw out to increase the length of conduit to take up the slackness in cable). Ensure the adjustment nut is locked when finished. And, as stated, lubricate the inner cable at regular intervals prescribed by the manufacturer.

TELEFLEX CABLE SYSTEMS

The Teleflex cable system is more complex than the Bowden cable system in that the operating cable, within the conduit, is actually a number of spirally wound cables which surround a core tension cable, giving it support.

This allows the cable to transmit a push force as easily as a pull force, doing away with the need for any form of return spring. A typical use of a Teleflex system might be a throttle lever to an engine fuel control system connection.

The Teleflex cable system is a snug fit within the conduit and, because there might be the chance of it becoming seized due to foreign objects, dirt or freezing, it is vital that the inner cables are regularly removed, cleaned and lubricated with low temperature grease. It is also important that the conduits are thoroughly cleaned using a form of 'pull-through' prior to the inner cable being installed. At longer intervals, it is necessary to inspect the outer conduit for signs of damage or kinking; which can cause the control to become tight or 'notchy'.

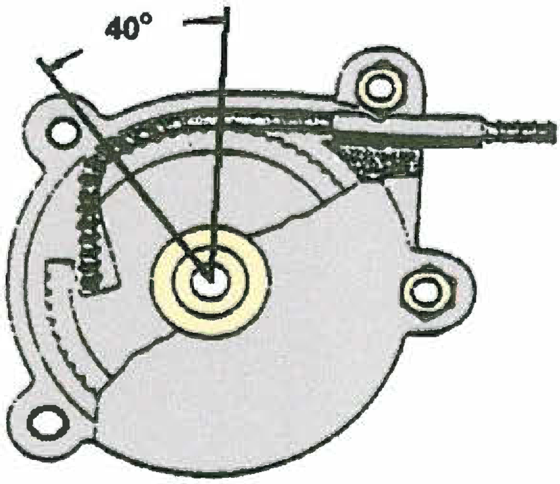


Figure 13-17. Method of attaching to box type unit.

ATTACHMENT OF TELEFLEX END FITTINGS

For the box-type end unit, tuck the cable into the slot in the pinion and ensure that the cable helix engages with the pinion teeth to give a wrap of at least 40 degrees ("single entry" units). On double entry units the cable should engage with the pinion to give a wrap of 180 degrees, the cable projecting through the lead-out hole throughout the travel of the control. Ensure that the cable end does not foul the blanked end of the conduit when fully extended. All box units should be packed with recommended grease. (***Figure 13-17***)

On the sliding end fittings (fork end type), unscrew the threaded hexagon plug from the body, screw the lock nut right back, and pass the cable through the plug. Screw the lock spring on to the end of the cable so that 3⁄16 inch of cable projects. Insert the cable end, with its lock spring, into the bore of the body of the end fitting, and screw the hexagon plug down tightly to prevent the body from rotating. Check that the free end of the cable is beyond the inspection hole, but not beyond the fork gap (for a fork end fitting). Tighten the lock nut and turn up the tab washer.

Check that the distance from the face of the body to the end of the sliding tube does not exceed 0.45 inch (0.35 inch old type, without tab washer). This ensures that the lock spring is tightly compressed. (***Figure 13-18***)

In assembling, the body of the end fitting must not be screwed on to the hexagon plug. The plug should be screwed into the fork, not fork into plug. Failure to apply this rule will result in the lock spring unscrewing. The same method should be used when removing the fork, and care should be taken not to jam the spring and foul up the wire wrap.

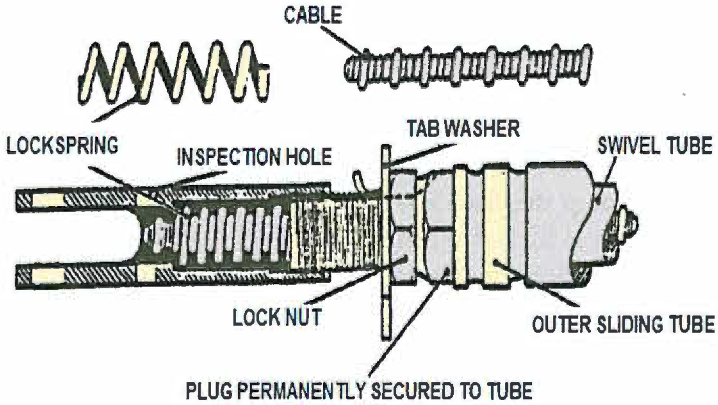


Figure 13-18. Teleflex end fitting assembly.

Question: 13-1
Control cables are terminated at the end via ________________.

Question: 13-2
A ______________ is defined as the working length of a cable where the cable runs over, under, or around a pulley, sleeve, or through a fair-lead; or any section where a control cable is flexed, rubbed, or worked in any manner; or any point within 1 foot of a swaged-on fitting.

Question: 13-3
To determine the amount of tension on a cable, a ________________ is used.

Question: 13-5
A cable system that allows the cable to transmit a push force as easily as a pull force, doing away with the need for any form of return spring is a ________________ cable system.

Question: 13-6
The principle advantage to a Teleflex cable over a Bowden cable system is its ability to ______________.

Question: 13-6
A pulley showing a cross hatch appearance pattern inside its groove is an indication of ________________.

ANSWERS

Answer: 13-1
swaging.

Answer: 13-2
critical fatigue area.

Answer: 13-3
tensiometer.

Answer: 13-4
Teleflex.

Answer: 13-5
provide a push as well as a pull force.

Answer: 13-6
excessive cable tension.

SUB-MODULE 14

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 14 MATERIAL HANDLING Knowledge Requirements		
7.14 - Material Handling		
7.14.1 - Sheet Metal Marking out and calculation of bend allowance; Sheet metal working, including bending and forming; Inspection of sheet metal work.	2	-
7.14.2 - Composite and Non-metallic Bonding practices; Environmental conditions; Inspection methods.	2	-

MATERIAL HANDLING

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

SHEET METAL FORMING PROCESS

Before a part is attached to the aircraft during either manufacture or repair, it has to be shaped to fit into place. This shaping process is called forming. It may be a simple process, such as making one or two holes for attaching. Or, it may be a complex process, such as making shapes with complex curvatures. Forming, which tends to change the shape or contour of a flat sheet or extruded shape, is accomplished by either stretching or shrinking the material in a certain area to produce curves, flanges, and various irregular shapes. Since the operation involves altering the shape of the stock material, the amount of shrinking and stretching almost entirely depends on the type of material used. Fully annealed (heated and cooled) material can withstand considerably more stretching and shrinking and can be formed at a much smaller bend radius than when it is in any of the tempered conditions.

When aircraft parts are formed at the factory, they are made on large presses or by drop hammers equipped with dies of the correct shape. Factory engineers, who designate specifications for the materials to be used to ensure the finished part has the correct temper when it leaves the machines, plan every part. Factory draftsmen prepare a layout for each part. (***Figure 14-1***)

Forming processes used on the flight line and those practiced in the maintenance or repair shop cannot duplicate a manufacturer's resources, but similar techniques of factory metal working can be applied in the handcrafting of repair parts.

Figure 14-1. Aircraft formed at a factory.

Forming usually involves the use of extremely light-gauge alloys of a delicate nature that can be readily made useless by coarse and careless workmanship. A formed part may seem outwardly perfect, yet a wrong step in the forming procedure may leave the part in a strained condition. Such a defect may hasten fatigue or may cause sudden structural failure.

Of all the aircraft metals, pure aluminum is the most easily formed. In aluminum alloys, ease of forming varies with the temper condition. Since modern aircraft are constructed chiefly of aluminum and aluminum alloys, this section deals with the procedures for forming aluminum or aluminum alloy parts with a brief discussion of working with stainless steel, magnesium, and titanium.

Most parts can be formed without annealing the metal, but if extensive forming operations, such as deep draws (large folds) or complex curves, are planned, the metal should be in the dead soft or annealed condition. During the forming of some complex parts, operations may need to be stopped and the metal annealed before the process can be continued or completed. For example, alloy 2024 in the "0" condition can be formed into almost any shape by the common forming operations, but it must be heat treated afterward.

FORMING OPERATIONS AND TERMS

Forming requires either stretching or shrinking the metal, or sometimes doing both. Other processes used to form metal include bumping, crimping, and folding.

STRETCHING

Stretching metal is achieved by hammering or rolling metal under pressure. For example, hammering a flat piece of metal causes the material in the hammered area to become thinner in that area. Since the amount of metal has not been decreased, the metal has been stretched. The stretching process thins, elongates, and curves sheet metal. It is critical to ensure the metal is not stretched too much, making it too thin, because sheet metal does not rebound easily. (***Figure 14-2***)

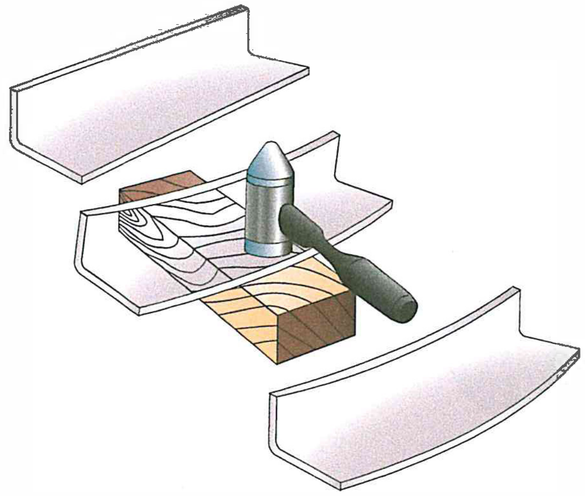


Figure 14-2. Stretch forming metal.

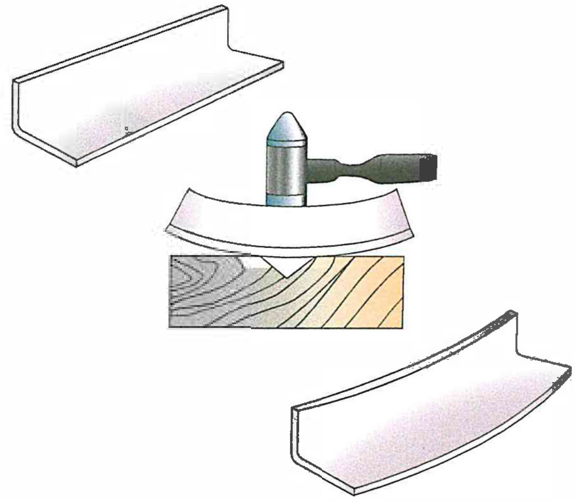


Figure 14-3. Shrink forming metal.

Stretching one portion of a piece of metal affects the surrounding material, especially in the case of formed and extruded angles. For example, hammering the metal in the horizontal flange of the angle strip over a metal block causes its length to increase (stretched), making that section longer than the section near the bend. To allow for this difference in length, the vertical flange, which tends to keep the material near the bend from stretching, would be forced to curve away from the greater length.

SHRINKING

Shrinking metal is much more difficult than stretching it. During the shrinking process, metal is forced or compressed into a smaller area.

This process is used when the length of a piece of metal, especially on the inside of a bend, is to be reduced. Sheet metal can be shrunk in by hammering on a V-block or by crimping and then using a shrinking block. To curve the formed angle by the V-block method, place the angle on the V-block and gently hammer downward against the upper edge directly over the "V." While hammering, move the angle back and forth across the V-block to compress the material along the upper edge. Compression of the material along the upper edge of the vertical flange will cause the formed angle to take on a curved shape. The material in the horizontal flange will merely bend down at the center, and the length of that flange will remain the same. (*Figure 14-3*)

To make a sharp curve or a sharply bent flanged angle, crimping and a shrinking block can be used. In this process, crimps are placed in the one flange, and then by hammering the metal on a shrinking block, the crimps are driven, or shrunk, one at a time.

Cold shrinking requires the combination of a hard surface, such as wood or steel, and a soft mallet or hammer because a steel hammer over a hard surface stretches the metal, as opposed to shrinking it. The larger the mallet face is, the better.

BUMPING

Bumping involves shaping or forming malleable metal by hammering or tapping—usually with a rubber, plastic, or rawhide mallet. During this process, the metal is supported by a dolly, a sandbag, or a die. Each contains a depression into which hammered portions of the metal can sink. Bumping can be done by hand or by machine.

CRIMPING

Crimping is folding, pleating, or corrugating a piece of sheet metal in a way that shortens it by turning down a flange on a seam. It is often used to make one end of a piece of stove pipe slightly smaller so that one section may be slipped into another. Crimping one side of a straight piece of angle iron with crimping pliers causes it to curve. (*Figure 14-4*)

FOLDING SHEET METAL

Folding sheet metal is to make a bend or crease in sheets, plates, or leaves. Folds are usually thought of as sharp, angular bends and are generally made on folding machines such as the box and pan brake discussed earlier in this chapter.

Figure 14-4. Crimping metal.

LAYOUT AND FORMING

TERMINOLOGY

The following terms are commonly used in sheet metal forming and flat pattern layout. Familiarity with these terms aids in understanding how bend calculations are used in a bending operation. ***Figure 14-5*** illustrates most of these terms.

- Base measurement—the outside dimensions of a formed part. Base measurement is given on the drawing or blueprint or may be obtained from the original part.
- Leg—the longer part of a formed angle.
- Flange—the shorter part of a formed angle—the opposite of leg. If each side of the angle is the same length, then each is known as a leg.
- Grain of the metal—natural grain of the material is formed as the sheet is rolled from molten ingot.
- Bend lines—should be made to lie at a 90° angle to the grain of the metal if possible.
- Bend allowance (BA)—refers to the curved section of metal within the bend (the portion of metal that is curved in bending). The bend allowance may be considered as being the length of the curved portion of the neutral line.
- Bend radius—the arc is formed when sheet metal is bent. This arc is called the bend radius. The bend radius is measured from a radius center to the inside surface of the metal. The minimum bend radius depends on the temper, thickness, and type of material. Always use a Minimum Bend Radius Table to determine the minimum bend radius for the alloy to be used. Minimum bend radius charts can be found in manufacturer's maintenance manuals.
- Bend tangent line (BL)—the location at which the metal starts to bend and the line at which the metal stops curving. All the space between the band tangent lines is the bend allowance.
- Neutral axis—an imaginary line that has the same length after bending as it had before bending. (***Figure 14-6***)
  After bending, the bend area is 10 to 15 percent thinner than before bending. This thinning of the bend area moves the neutral line of the metal in towards the radius center. For calculation purposes, it is often assumed that the neutral axis is located at the center of the material, although the neutral axis is not exactly in the center of the material. However, the amount of error incurred is so slight that, for most work, assuming it is at the center is satisfactory.
- Mold line (ML)—an extension of the flat side of a part beyond the radius.
- Mold line dimension (MLD)—the dimension of a part made by the intersection of mold lines. It is the dimension the part would have if its corners had no radius.
- Mold point—the point of intersection of the mold lines. The mold point would be the outside corner of the part if there were no radius.
- K-Factor—the percentage of the material thickness where there is no stretching or compressing of the material, such as the neutral axis. This percentage has been calculated and is one of 179 numbers on the K chart corresponding to one of the angles between 0° and 180° to which metal can be bent.

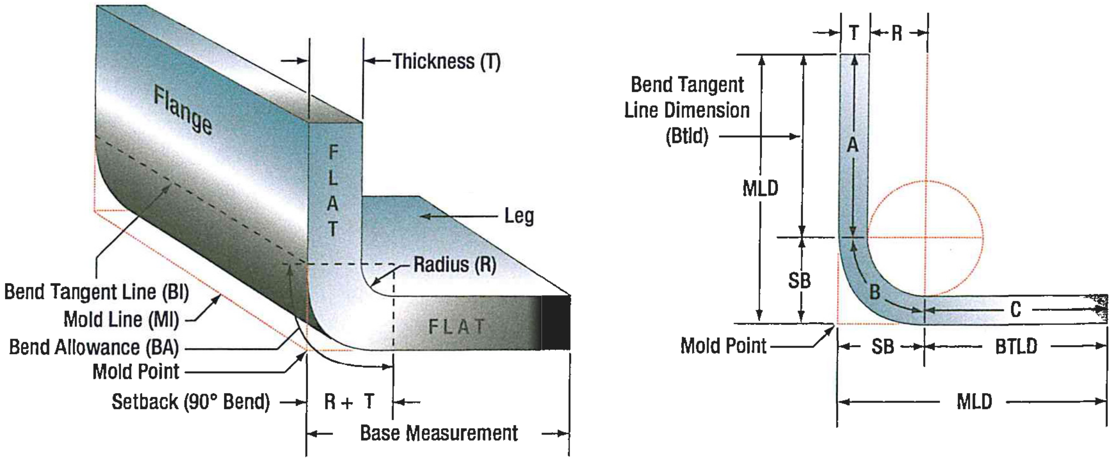


Figure 14-5. Bend allowance terminology.

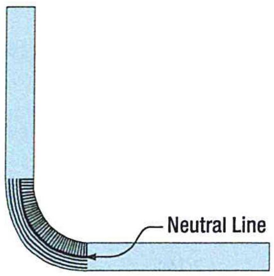


Figure 14-6. Neutral line.

Whenever metal is to be bent to any angle other than 90° (K-factor of 90° equal to 1), the corresponding K-factor number is selected from the chart and is multiplied by the sum of the radius (R) and the thickness (T) of the metal. The product is the amount of setback (see next paragraph) for the bend. If no K chart is available, the K-factor can be calculated with a calculator by using the following formula: the K value is the tangent of one-half the bend angle. (***Figure 14-7***)

- Setback (SB)—the distance the jaws of a brake must be setback from the mold line to form a bend. In a 90° bend, SB = R + T (radius of the bend plus thickness of the metal). The setback dimension must be determined prior to making the bend because setback is used in determining the location of the beginning bend tangent line. When a part has more than one bend, setback must be subtracted for each bend. The majority of bends in sheet metal are 90° bends.

The K-factor must be used for all bends that are smaller or larger than 90°.

SB = K (R + T)

- Sight line—also called the bend or brake line, it is the layout line on the metal being formed that is set even with the nose of the brake and serves as a guide in bending the work.
- Flat—that portion of a part that is not included in the bend. It is equal to the base measurement (MLD) minus the setback.

Flat = MLD - SB

- Closed angle—an angle that is less than 90° when measured between legs, or more than 90° when the amount of bend is measured.
- Open angle—an angle that is more than 90° when measured between legs, or less than 90° when the amount of bend is measured.
- Total developed width (TDW)—the width of material measured around the bends from edge to edge. Finding the TDW is necessary to determine the size of material to be cut. The TDW is less than the sum of mold line dimensions since the metal is bent on a radius and not to a square corner as mold line dimensions indicate.

LAYOUT OR FLAT PATTERN DEVELOPMENT

To prevent any waste of material and to get a greater degree of accuracy in the finished part, it is wise to make a layout or flat pattern of a part before forming it. Construction of interchangeable structural and nonstructural parts is achieved by forming flat sheet stock to make channel, angle, zee, or hat section members. Before a sheet metal part is formed, make a flat pattern to show how much material is required in the bend areas, at what point the sheet must be inserted

Degree	K	Degree	K	Degree	K	Degree	K	Degree	K
1	0.0087	37	0.3346	73	0.7399	109	1.401	145	3.171
2	0.0174	38	0.3443	74	0.7535	110	1.428	146	3.270
3	0.0261	39	0.3541	75	0.7673	111	1.455	147	3.375
4	0.0349	40	0.3639	76	0.7812	112	1.482	148	3.487
5	0.0436	41	0.3738	77	0.7954	113	1.510	149	3.605
6	0.0524	42	0.3838	78	0.8097	114	1.539	150	3.732
7	0.0611	43	0.3939	79	0.8243	115	1.569	151	3.866
8	0.0699	44	0.4040	80	0.8391	116	1.600	152	4.010
9	0.0787	45	0.4142	81	0.8540	117	1.631	153	4.165
10	0.0874	46	0.4244	82	0.8692	118	1.664	154	4.331
11	0.0963	47	0.4348	83	0.8847	119	1.697	155	4.510
12	0.1051	48	0.4452	84	0.9004	120	1.732	156	4.704
13	0.1139	49	0.4557	85	0.9163	121	1.767	157	4.915
14	0.1228	50	0.4663	86	0.9324	122	1.804	158	5.144
15	0.1316	51	0.4769	87	0.9489	123	1.841	159	5.399
16	0.1405	52	0.4877	88	0.9656	124	1.880	160	5.671
17	0.1494	53	0.4985	89	0.9827	125	1.921	161	5.975
18	0.1583	54	0.5095	90	1.000	126	1.962	162	6.313
19	0.1673	55	0.5205	91	1.017	127	2.005	163	6.691
20	0.1763	56	0.5317	92	1.035	128	2.050	164	7.115
21	0.1853	57	0.5429	93	1.053	129	2.096	165	7.595
22	0.1943	58	0.5543	94	1.072	130	2.144	166	8.144
23	0.2034	59	0.5657	95	1.091	131	2.194	167	8.776
24	0.2125	60	0.5773	96	1.110	132	2.246	168	9.514
25	0.2216	61	0.5890	97	1.130	133	2.299	169	10.38
26	0.2308	62	0.6008	98	1.150	134	2.355	170	11.43
27	0.2400	63	0.6128	99	1.170	135	2.414	171	12.70
28	0.2493	64	0.6248	100	1.191	136	2.475	172	14.30
29	0.2586	65	0.6370	101	1.213	137	2.538	173	16.35
30	0.2679	66	0.6494	102	1.234	138	2.605	174	19.08
31	0.2773	67	0.6618	103	1.257	139	2.674	175	22.90
32	0.2867	68	0.6745	104	1.279	140	2.747	176	26.63
33	0.2962	69	0.6872	105	1.303	141	2.823	177	38.18
34	0.3057	70	0.7002	106	1.327	142	2.904	178	57.29
35	0.3153	71	0.7132	107	1.351	143	2.988	179	114.59
36	0.3249	72	0.7265	108	1.376	144	3.077	180	Inf.

Figure 14-7. K-factor.

into the forming tool, or where bend lines are located. Bend lines must be determined to develop a flat pattern for sheet metal forming.

When forming straight angle bends, correct allowances must be made for setback and bend allowance. If shrinking or stretching processes are to be used, allowances must be made so that the part can be turned out with a minimum amount of forming.

MAKING STRAIGHT LINE BENDS

When forming straight bends, the thickness of the material, its alloy composition, and its temper condition must be considered. Generally speaking, the thinner the material is, the more sharply it can be bent (the smaller the radius of bend), and the softer the material is, the sharper the bend is.

Other factors that must be considered when making straight line bends are bend allowance, setback, and brake or sight line.

The radius of bend of a sheet of material is the radius of the bend as measured on the inside of the curved material. The minimum radius of bend of a sheet of material is the sharpest curve, or bend, to which the sheet can be bent without critically weakening the metal at the bend. If the radius of bend is too small, stresses and strains weaken the metal and may result in cracking.

A minimum radius of bend is specified for each type of aircraft sheet metal. The minimum bend radius is affected by the kind of material, thickness of the material, and temper condition of the material. Annealed sheet can be bent to a radius approximately equal to its thickness. Stainless steel and 2024-T3 aluminum alloy require a fairly large bend radius.

BENDING A U-CHANNEL

To understand the process of making a sheet metal layout, the steps for determining the layout of a sample U-channel will be discussed. When using bend allowance calculations, the following steps for finding the total developed length can be computed with formulas, charts, or computer-aided design (CAD) and computer-aided manufacturing (CAM) software packages. This channel is made of 0.040-inch 2024-T3 aluminum alloy. (***Figure 14-8***)

Step 1: Determine the Correct Bend Radius

Minimum bend radius charts are found in manufacturers' maintenance manuals. A radius that is too sharp cracks the material during the bending process. Typically, the drawing indicates the radius to use, but it is a good practice to double check. For this layout example, use the minimum radius chart in ***Figure 14-9*** to choose the correct bend radius for the alloy, temper, and the metal thickness. For 0.040, 2024-T3 the minimum allowable radius is 0.16 inch or 5⁄32 inch.

Step 2: Find the Setback

The setback can be calculated with a formula or can be found in a setback chart available in aircraft maintenance manuals or Source, Maintenance, and Recoverability books (SMRs). (***Figure 14-10***)

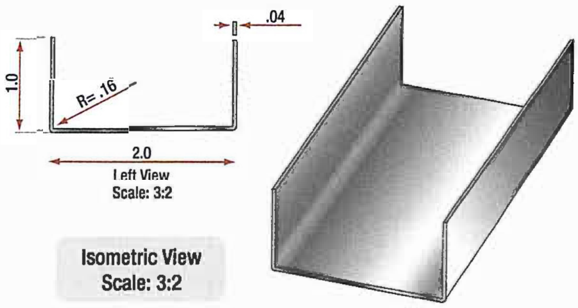


Figure 14-8. U-channel example.

USING A FORMULA TO CALCULATE THE SETBACK

SB = setback
K = K-factor (K is 1 for 90° bends)
R = inside radius of the bend
T = material thickness

Since all of the angles in this example are 90° angles, the setback is calculated as follows:

$$SB = K\,(R + T)$$

$$SB = 1\,(.16 + .40) = .56 \text{ inches}$$

NOTE: K = 1 for a 90° bend. For other than a 90° bend, use a K-factor chart.

USING A SETBACK CHART TO FIND THE SETBACK

The setback chart is a quick way to find the setback and is useful for open and closed bends, because there is no need to calculate or find the K-factor. Several software packages and online calculators are available to calculate the setback. These programs are often used with CAD/CAM programs. (***Figure 14-10***)

- Enter chart at the bottom on the appropriate scale with the sum of the radius and material thickness.
- Read up to the bend angle.
- Find the setback from corresponding scale on the left.

Example:

- Material thickness is 0.063-inch.
- Bend angle is 135°.
- R + T = 0.183-inch.

Find 0.183 at the bottom of the graph. It is found in the middle scale.

Minimum Bend Radius for Aluminum Alloys

Thickness	5052-0 6061-0 5052-H32	7178-0 2024-0 5052-H34 6061-T4 7075-0	6061-T6	7075-T6	2024-T3 2024-T4	2024-T6
.012	.03	.03	.03	.03	.06	.06
.016	.03	.03	.03	.03	.09	.09
.020	.03	.03	.03	.12	.09	.09
.025	.03	.03	.06	.16	.12	.09
.032	.03	.03	.06	.19	.12	.12
.040	.06	.06	.09	.22	.16	.16
.050	.06	.06	.12	.25	.19	.19
.063	.06	.09	.16	.31	.22	.25
.071	.09	.12	.16	.38	.25	.31
.080	.09	.16	.19	.44	.31	.38
.090	.09	.19	.22	.50	.38	.44
.100	.12	.22	.25	.62	.44	.50
.125	.12	.25	.31	.88	.50	.62
.160	.16	.31	.44	1.25	.75	.75
.190	.19	.38	.56	1.38	1.00	1.00
.250	.31	.62	.75	2.00	1.25	1.25
.312	.44	1.25	1.38	2.50	1.50	1.50
.375	.44	1.38	1.50	2.50	1.88	1.88

Bend radius is designated to the inside of the bend. All dimensions are in inches.

Figure 14-9. Minimum bend radius (from the Raytheon Aircraft Structural Inspection and Repair Manual).

- Read up to a bend angle of 135°.
- Locate the setback at the left hand side of the graph in the middle scale (0.435-inch). (***Figure 14-10***)

Step 3: Find the Length of the Flat Line Dimension

The flat line dimension can be found using the formula:

Flat = MLD - SB
MLD = mold line dimension
SB = setback

The flats, or flat portions of the U-channel, are equal to the mold line dimension minus the setback for each of the sides, and the mold line length minus two setbacks for the center flat. Two setbacks need to be subtracted from the center flat because this flat has a bend on either side.

The flat dimension for the sample U-channel is calculated in the following manner:

Flat dimension = MLD - SB
Flat 1 = 1.00-inch - 0.56-inch = 0.44-inch
Flat 2 = 2.00-inch - (2 x 0.56-inch) = 0.88-inch
Flat 3 = 1.00-inch - 0.56-inch = 0.44-inch

Step 4: Find the Bend Allowance

When making a bend or fold in a piece of metal, the bend allowance or length of material required for the bend must be calculated. Bend allowance depends on four factors: degree of bend, radius of the bend, thickness of the metal, and type of metal used.

The radius of the bend is generally proportional to the thickness of the material. Furthermore, the sharper the radius of bend, the less the material that is needed for the bend. The type of material is also important. If the material is soft, it can be bent very sharply; but if it is hard, the radius of bend is greater, and the bend allowance is greater. The degree of bend affects the overall length of the metal, whereas the thickness influences the radius of bend.

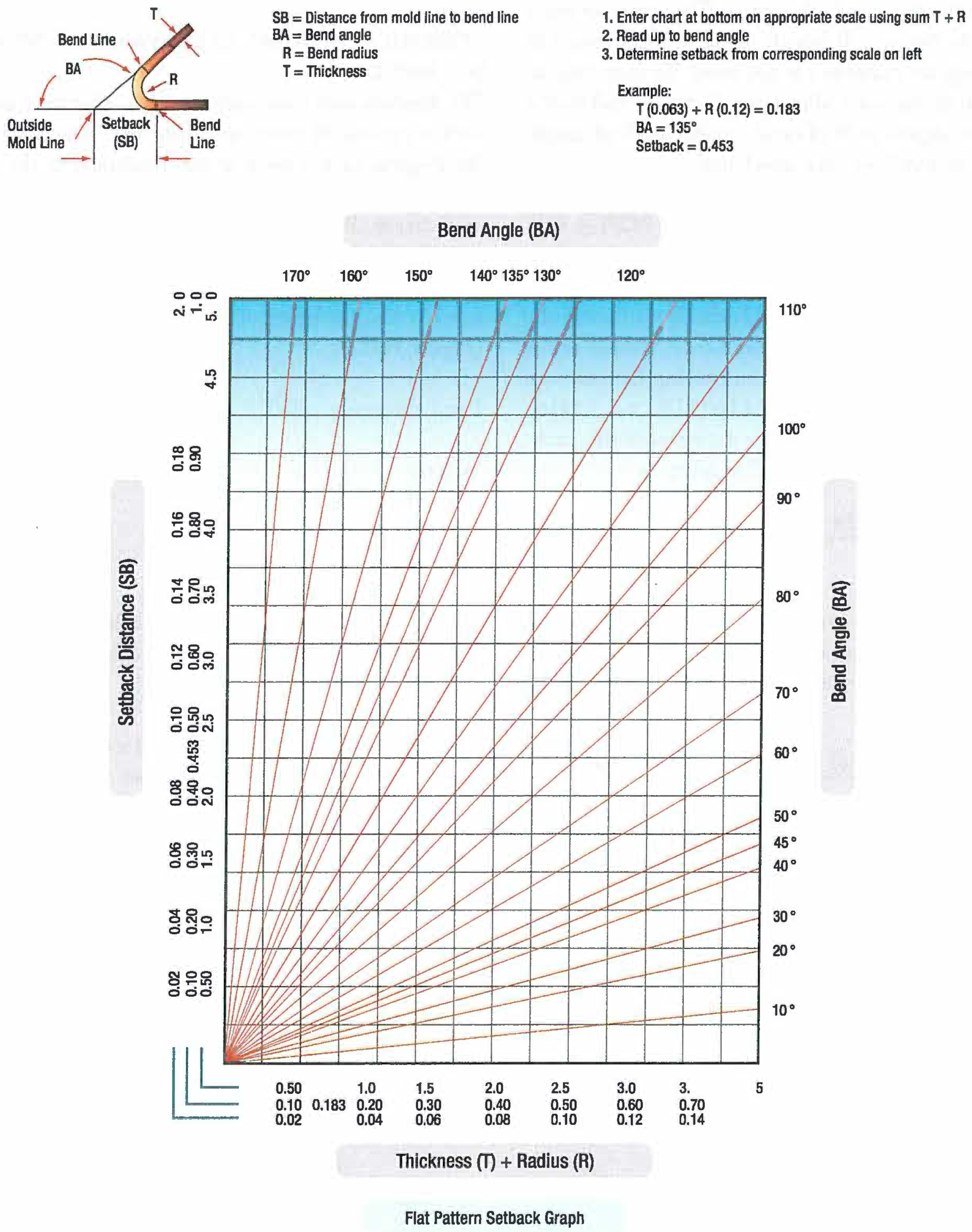


Figure 14-10. Setback chart.

Bending a piece of metal compresses the material on the inside of the curve and stretches the material on the outside of the curve. However, at some distance between these two extremes lies a space which is not affected by either force. This is known as the neutral line or neutral axis and occurs at a distance approximately 0.445 times the metal thickness (0.445 x T) from the inside of the radius of the bend. (***Figure 14-11***)

The length of this neutral axis must be determined so that sufficient material can be provided for the bend. This is called the bend allowance. This amount must be added to the overall length of the layout pattern to ensure adequate material for the bend. To save time in calculation of the bend allowance, formulas and charts for various angles, radii of bends, material thicknesses, and other factors have been developed.

FORMULA 1: BEND ALLOWANCE FOR A 90° BEND

To the radius of bend (R) add ½ the thickness of the metal (½T). This gives R + ½T, or the radius of the circle of the neutral axis. (*Figure 14-12*) Compute the circumference of this circle by multiplying the radius of the neutral line (R + ½T) by 2π (NOTE: π = 3.1416): 2π (R + ½T). Since a 90° bend is a quarter of the circle, divide the circumference by 4. This gives:

$$\frac{2\pi\,(R + \tfrac{1}{2}T)}{4}$$

This is the bend allowance for a 90° bend. To use the formula for a 90° bend having a radius of 1/4 inch for material 0.051- inch thick, substitute in the formula as follows.

$$\text{Bend allowance} = \frac{(2 \times 3.1416)(0.250 + \tfrac{1}{2}(0.051))}{4}$$

$$= \frac{6.2832(0.250 + 0.0255)}{4}$$

$$= \frac{6.2832(0.2755)}{4}$$

$$= 0.4327$$

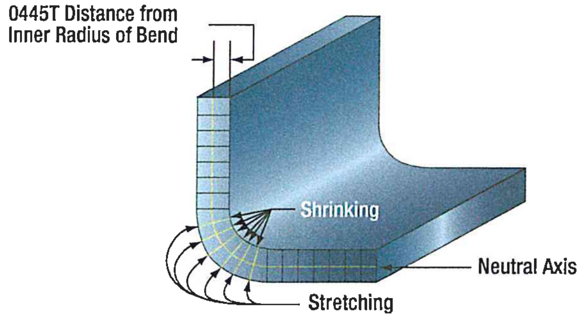


Figure 14-11. Neutral axis and stresses resulting from bending.

The bend allowance, or the length of material required for the bend, is 0.432 7 or 7⁄16 inch.

FORMULA 2: BEND ALLOWANCE FOR A 90° BEND

This formula uses two constant values that have evolved over a period of years as being the relationship of the degrees in the bend to the thickness of the metal when determining the bend allowance for a particular application. By experimentation with actual bends in metals, aircraft engineers have found that accurate bending results could be obtained by using the following formula for any degree of bend from 1° to 180°. (*Figure 14-12*)

Bend allowance = (0.017 43R + 0.00 78T)N

Where:

R = the desired bend radius
T = the thickness of the metal
N = number of degrees of bend

To use this formula for a 90° bend having a radius of .16- inch for material 0.040-inch thick, substitute in the formula as follows:

Bend allowance = (0.0174 3 x 0.16) + (0.007 8 x 0.040) x 90 = 0.27 inches

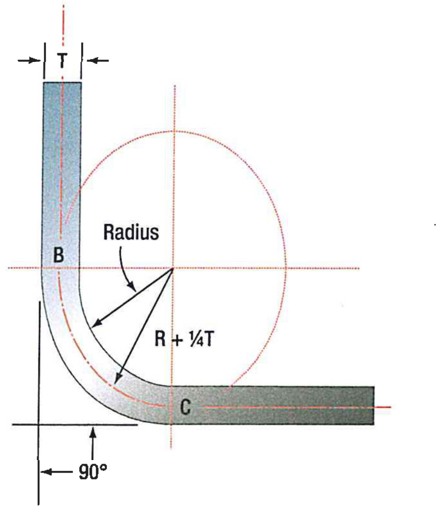


Figure 14-12. Bend allowance for a 90° bend.

USE OF BEND ALLOWANCE CHART FOR A 90° BEND

In ***Figure 14-13***, the radius of bend is shown on the top line, and the metal thickness is shown on the left hand column. The upper number in each cell is the bend allowance for a 90° bend. The lower number in the cell is the bend allowance per 1° of bend. To determine the bend allowance for a 90° bend, simply use the top number in the chart.

Example:
The material thickness of the U-channel is 0.040-inch and the bend radius is 0.16-inch. Reading across the top of the bend allowance chart, find the column for a radius of bend of .156-inch. Now, find the block in this column that is opposite the material thickness (gauge) of 0.040 in the column at the left. The upper number in the cell is (0.273), the correct bend allowance in inches for a 90° bends. Several bend allowance calculation programs are available online. Just enter the material thickness, radius, and degree of bend and the computer program calculates the bend allowance.

Metal Thickness	RADIUS OF BEND, IN INCHES													
	1/32 .031	1/16 .063	3/32 .094	1/8 .125	5/32 .156	3/16 .188	7/32 .219	1/4 .250	9/32 .281	5/16 .313	11/32 .344	3/8 .375	7/16 .438	1/2 .500
.020	.062 .000693	.113 .001251	.161 .001792	.210 .002333	.259 .002874	.309 .003433	.358 .003974	.406 .004515	.455 .005056	.505 .005614	.554 .006155	.603 .006695	.702 .007795	.799 .008877
.025	.066 .000736	.116 .001294	.165 .001835	.214 .002376	.263 .002917	.313 .003476	.362 .004017	.410 .004558	.459 .005098	.509 .005657	.558 .006198	.607 .006739	.705 .007838	.803 .008920
.028	.068 .000759	.119 .001318	.167 .001859	.216 .002400	.265 .002941	.315 .003499	.364 .004040	.412 .004581	.461 .005122	.511 .005680	.560 .006221	.609 .006762	.708 .007862	.805 .007862
.032	.071 .000787	.121 .001345	.170 .001886	.218 .002427	.267 .002968	.317 .003526	.366 .004067	.415 .004608	.463 .005149	.514 .005708	.562 .006249	.611 .006789	.710 .007889	.807 .008971
.038	.075 .00837	.126 .001396	.174 .001937	.223 .002478	.272 .003019	.322 .003577	.371 .004118	.419 .004659	.468 .005200	.518 .005758	.567 .006299	.616 .006840	.715 .007940	.812 .009021
.040	.077 .000853	.127 .001411	.176 .001952	.224 .002493	.273 .003034	.323 .003593	.372 .004134	.421 .004675	.469 .005215	.520 .005774	.568 .006315	.617 .006856	.716 .007955	.813 .009037
.051		.134 .001413	.183 .002034	.232 .002575	.280 .003116	.331 .003675	.379 .004215	.428 .004756	.477 .005297	.527 .005855	.576 .006397	.624 .006934	.723 .008037	.821 .009119
.064		.144 .001595	.192 .002136	.241 .002676	.290 .003218	.340 .003776	.389 .004317	.437 .004858	.486 .005399	.536 .005957	.585 .006498	.634 .007039	.732 .008138	.830 .009220
.072			.198 .002202	.247 .002743	.296 .003284	.436 .003842	.394 .004283	.443 .004924	.492 .005465	.542 .006023	.591 .006564	.639 .007105	.738 .008205	836 .009287
.078			.202 .002249	.251 .002790	.300 .003331	.350 .003889	.399 .004430	.447 .004963	.496 .005512	.546 .006070	.595 .006611	.644 .007152	.745 .008252	.840 .009333
.081			.204 .002272	.253 .002813	.302 .003354	.352 .003912	.401 .004453	.449 .004969	.498 .005535	.548 .006094	.598 .006635	.646 .007176	.745 .008275	.842 .009357
.091			.212 .002350	.260 .002891	.309 .003432	.359 .003990	.408 .004531	.456 .005072	.505 .005613	.555 .006172	.604 .006713	.653 .007254	.752 .008353	.849 .009435
.094			.214 .002374	.262 .002914	.311 .003455	.361 .004014	.410 .004555	.459 .005096	.507 .005637	.558 .006195	.606 .006736	.655 .007277	.754 .008376	.851 .009458
.102				.268 .002977	.317 .003518	.367 .004076	.416 .004617	.464 .005158	.513 .005699	.563 .006257	.812 .006798	.661 .007339	.760 .008439	.857 .009521
.109				.273 .003031	.321 .003572	.372 .004131	.420 .004672	.469 .005213	.518 .005754	.568 .006312	.617 .006853	.665 .008394	.764 .008493	.862 .009575
.125				.284 .003156	.333 .003697	.383 .004256	.432 .004797	.480 .005338	.529 .005678	.579 .006437	.628 .006978	.677 .007519	.776 .008618	.873 .009700
.156					.355 .003939	.405 .004497	.453 .005038	.502 .005579	.551 .006120	.601 .006679	.650 .007220	.698 .007761	.797 .008860	.895 .009942
.188						.417 .004747	.476 .005288	.525 .005829	.573 .006370	.624 .006928	.672 .007469	.721 .008010	.820 .009109	.917 .010191
.250								.568 .006313	.617 .006853	.667 .007412	.716 .007953	.764 .008494	.863 .009593	.961 .010675

Figure 14-13. Bend allowance.

USE OF CHART FOR OTHER THAN A 90° BEND

If the bend is to be other than 90°, use the lower number in the block (the bend allowance for 1°) and compute the bend allowance.

Example: The L-bracket shown in ***Figure 14-14*** is made from 2024-T3 aluminum alloy and the bend is 60° from flat. Note that the bend angle in the figure indicates 120°, but that is the number of degrees between the two flanges and not the bend angle from flat. To find the correct bend angle, use the following formula:

Bend Angle = 180° - Angle between flanges

The actual bend is 60°. To find the correct bend radius for a 60° bend of material 0.040-inches thick, use the following procedure.

1. Go to the left side of the table and find 0.040-inch.
2. Go to the top of the chart and locate the bend radius of 0.16-inch (0.156-inch).
3. Note the bottom number in the block (0.003034).
4. Multiply this number by the bend angle:
   0.003034 x 60 = 0.18204

Step 5: Find the Total Developed Width of the Material

The Total Developed Width (TDW) can be calculated when the dimensions of the flats and the bend allowance are found. The following formula is used to calculate TDW:

TDW = Flats + (bend allowance x number of bends)

For the U-channel example, this gives:

TDW = Flat 1 + Flat 2 + Flat 3 + (2 x BA)
TDW = 0.8 + 1.6 + 0.8 + (2 x 0.27)
TDW = 3.74-inches

Note that the amount of metal needed to make the channel is less than the dimensions of the outside of the channel (total of mold line dimensions is 4 inches). This is because the metal follows the radius of the bend rather than going from mold line to mold line. It is good practice to check that the calculated TDW is smaller than the total mold line dimensions. If the calculated TDW is larger than the mold line dimensions, the math was incorrect.

Step 6: Flat Pattern Lay Out

After a flat pattern layout of all relevant information is made, the material can be cut to the correct size, and the bend tangent lines can be drawn on the material. (***Figure 14-15***)

Step 7: Draw the Sight Lines on the Flat Pattern

The pattern laid out in ***Figure 14-15*** is complete, except for a sight line that needs to be drawn to help position the bend tangent line directly at the point where the bend should start.

Draw a line inside the bend allowance area that is one bend radius away from the bend tangent line that is placed under the brake nose bar. Put the metal in the brake under the clamp and adjust the position of the metal until the sight line is directly below the edge of the radius bar. (***Figure 14-16***)

Now, clamp the brake on the metal and raise the leaf to make the bend. The bend begins exactly on the bend tangent line.

NOTE: A common mistake is to draw the sight line in the middle of the bend allowance area, instead of one radius away from the bend tangent line that is placed under the brake nose bar.

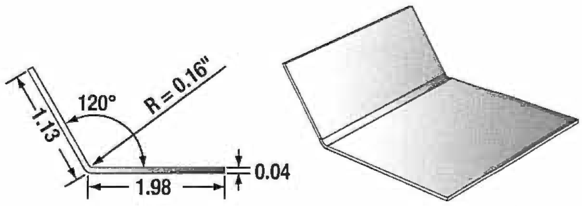


Figure 14-14. Bend allowance for bends less than 90°.

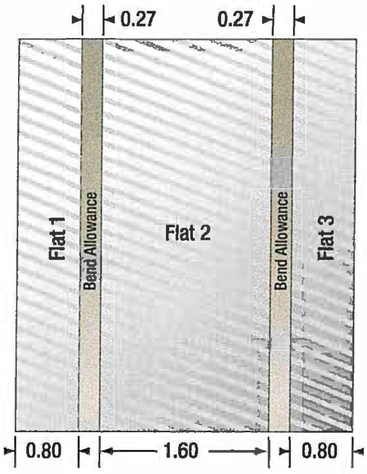


Figure 14-15. Flat pattern layout.

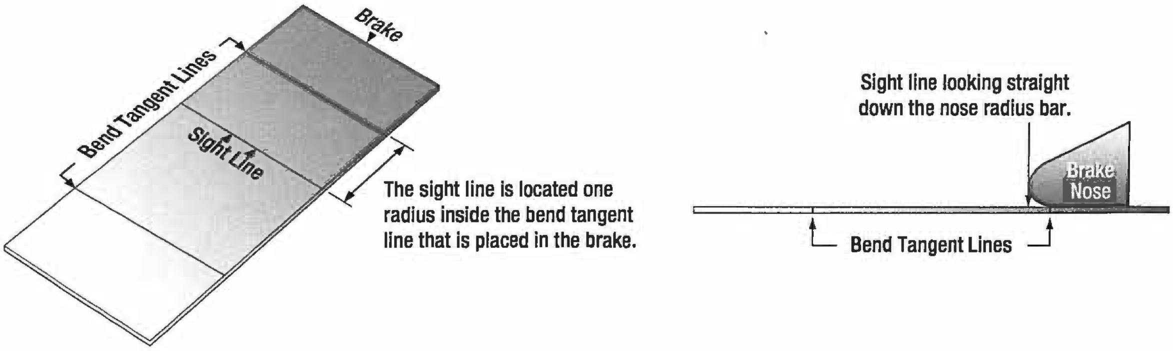


Figure 14-16. Sight line.

USING A J-CHART TO CALCULATE TOTAL DEVELOPED WIDTH

The J-chart, often found in the SRM, can be used to determine bend deduction or setback and the TDW of a flat pattern layout when the inside bend radius, bend angle, and material thickness are known. (*Figure 14-17*) While not as accurate as the traditional layout method, the J-chart provides sufficient information for most applications. The J-chart does not require difficult calculations or memorized formulas because the required information can be found in the repair drawing or can be measured with simple measuring tools.

When using the J-chart, it is helpful to know whether the angle is open (greater than 90°) or closed (less than 90°) because the lower half of the J-chart is for open angles and the upper half is for closed angles.

HOW TO FIND THE TOTAL DEVELOPED WIDTH USING A J-CHART

- Place a straightedge across the chart and connect the bend radius on the top scale with the material thickness on the bottom scale. (*Figure 14-17*)
- Locate the angle on the right hand scale and follow this line horizontally until it meets the straight edge.
- The factor X (bend deduction) is then read on the diagonally curving line.
- Interpolate when the X factor falls between lines.
- Add up the mold line dimensions and subtract the X factor to find the TDW.

Example 1:
Bend radius = 0.22-inch
Material thickness = 0.063-inch
Bend angle = 90°
ML 1 = 2.00/ML 2 = 2.00

Use a straightedge to connect the bend radius (0.22-inch) at the top of the graph with the material thickness at the bottom (0.063-inch). Locate the 90° angle on the right hand scale and follow this line horizontally until it meets the straightedge. Follow the curved line to the left and find 0.17 at the left side. The X factor in the drawing is 0.17-inch. (*Figure 14-18*)

Total developed width = (Mold line 1 + Mold line 2) - X factor

Total developed width = (2 + 2) - .17 = 3.83-inches

Example 2:
Bend radius = 0.25-inch
Material thickness = 0.050-inch
Bend angle = 45°
ML 1 = 2.00/ML 2 = 2.00

Figure 14-19 illustrates a 135° angle, but this is the angle between the two legs. The actual bend from flat position is 45° (180 - 135 = 45). Use a straightedge to connect the bend radius (0.25-inch) at the top of the graph with the material thickness at the bottom (.050-inch). Locate the 45° angle on the right hand scale and follow this line horizontally until it meets the straight edge. Follow the curved line to the left and find 0.035 at the left side. The X factor in the drawing= is 0.035 inch.

Total developed width = (Mold line 1 + Mold line 2) - X factor

Total developed width = (2 + 2) - .035 = 3.965-inch

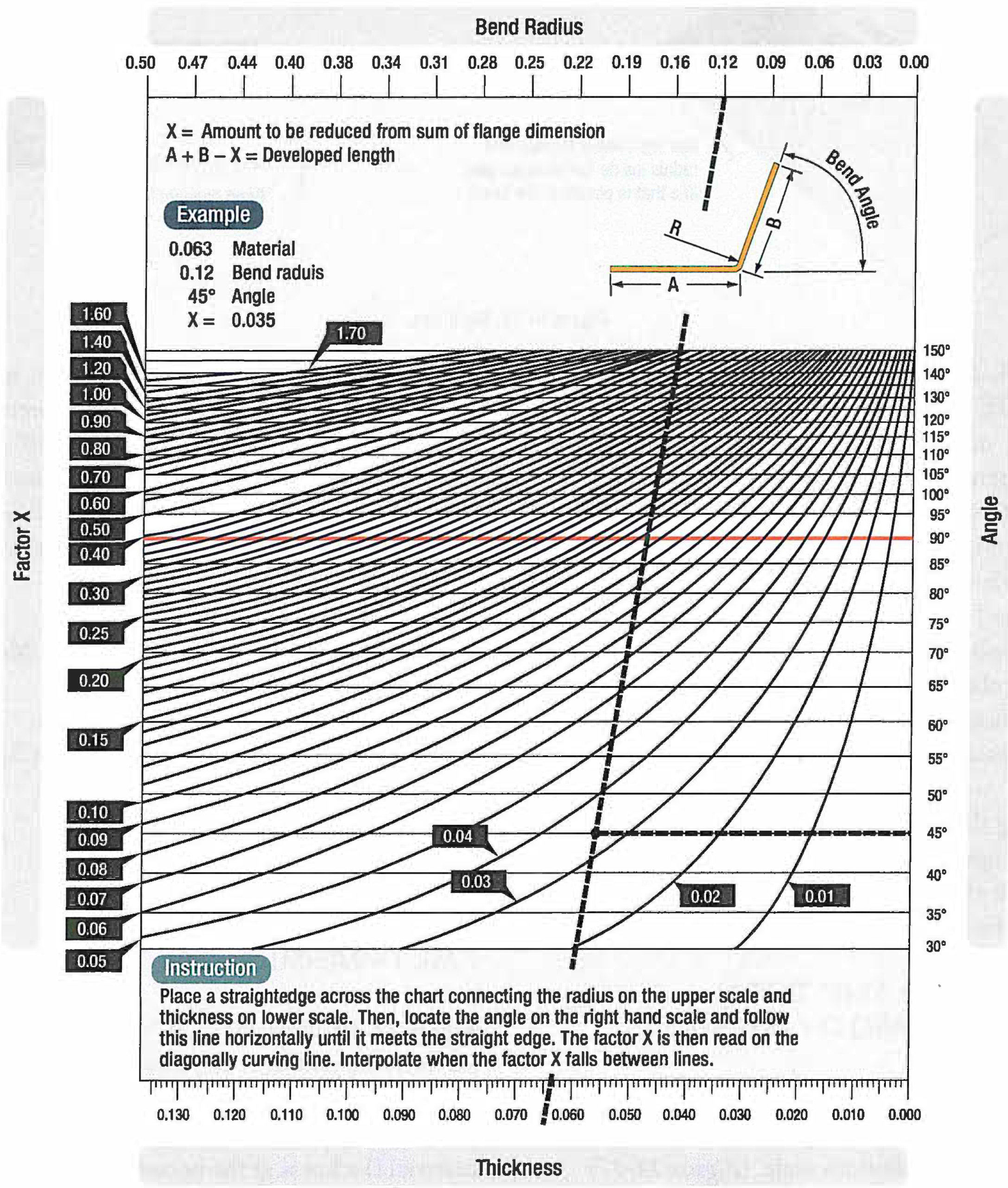


Figure 14-17. J chart.

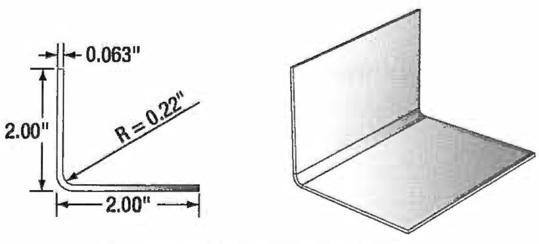


Figure 14-18. Example 1 of J chart.

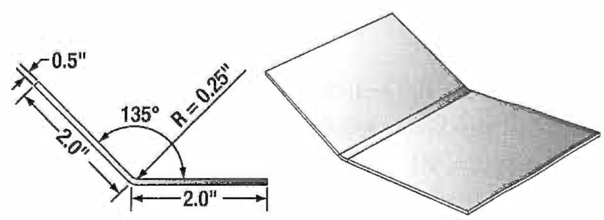


Figure 14-19. Example 2 of J chart.

USING A SHEET METAL BRAKE TO FOLD METAL

The brake set up for box and pan brakes and cornice brakes is identical. (***Figure 14-20***) A proper set up of the sheet metal brake is necessary because accurate bending of sheet metal depends on the thickness and temper of the material to be formed and the required radius of the part.

Any time a different thickness of sheet metal needs to be formed or when a different radius is required to form the part, the operator needs to adjust the sheet metal brake before the brake is used to form the part. For this example, an L-channel made from 2024-T3 aluminum alloy that is 0.032-inch thick will be bent.

Step 1: Adjustment of Bend Radius

> The bend radius necessary to bend a part can be found in the part drawings, but if it is not mentioned in the drawing, consult the SRM for a minimum bend radius chart. This chart lists the smallest radius allowable for each thickness and temper of metal that is normally used. To bend tighter than this radius would jeopardize the integrity of the part. Stresses left in the area of the bend may cause it to fail while in service, even if it does not crack while bending it.

The brake radius bars of a sheet metal brake can be replaced with another brake radius bar with a different diameter. (***Figure 14-21***) For example, a 0.032-inch 2024-T3 L channel needs to be bent with a radius of ⅛-inch and a radius bar with a ⅛-inch radius must be installed. If different brake radius bars are not available, and the installed brake radius bar is smaller than required for the part, it is necessary to bend some nose radius shims. (***Figure 14-22***)

If the radius is so small that it tends to crack annealed aluminum, mild steel is a good choice of material. Experimentation with a small piece of scrap material is necessary to manufacture a thickness that increases the radius to precisely 1⁄16-inch or ⅛-inch. Use radius and fillet gauges to check this dimension. From this point on, each additional shim is added to the radius before it. (***Figure 14-23***)

Example:
If the original nose was 1⁄16-inch and a piece of .063-inch material (1⁄16-inch) was bent around it, the new outside radius is ⅛-inch. If another .063-inch layer (1⁄16-inch) is added, it is now a 3⁄16-inch radius.

If a piece of .032-inch (1⁄32-inch) instead of .063-inch material (1⁄16-inch) is bent around the ⅛-inch radius, a 5⁄32-inch radius results.

Step 2: Adjusting Clamping Pressure

> The next step is setting clamping pressure. Slide a piece of the material with the same thickness as the part to be bent under the brake radius piece. Pull the clamping lever toward the operator to test the pressure. This is an over center type clamp and, when properly set, will not feel springy or spongy when pulled to its fully clamped position. The operator must be able to pull this lever over center with a firm pull and have it bump its limiting stops. On some brakes, this adjustment has to be made on both sides of the brake.

Figure 14-20. Brake radius nose piece adjustment.

Figure 14-21. Interchangeable brake radius bars.

MATERIAL HANDLING

Place test strips on the table 3 inches from each end and one in the center between the bed and the clamp and adjust clamp pressure until it is tight enough to prevent the work pieces from slipping while bending. The clamping pressure can be adjusted with the clamping pressure nut. (*Figure 14-24*)

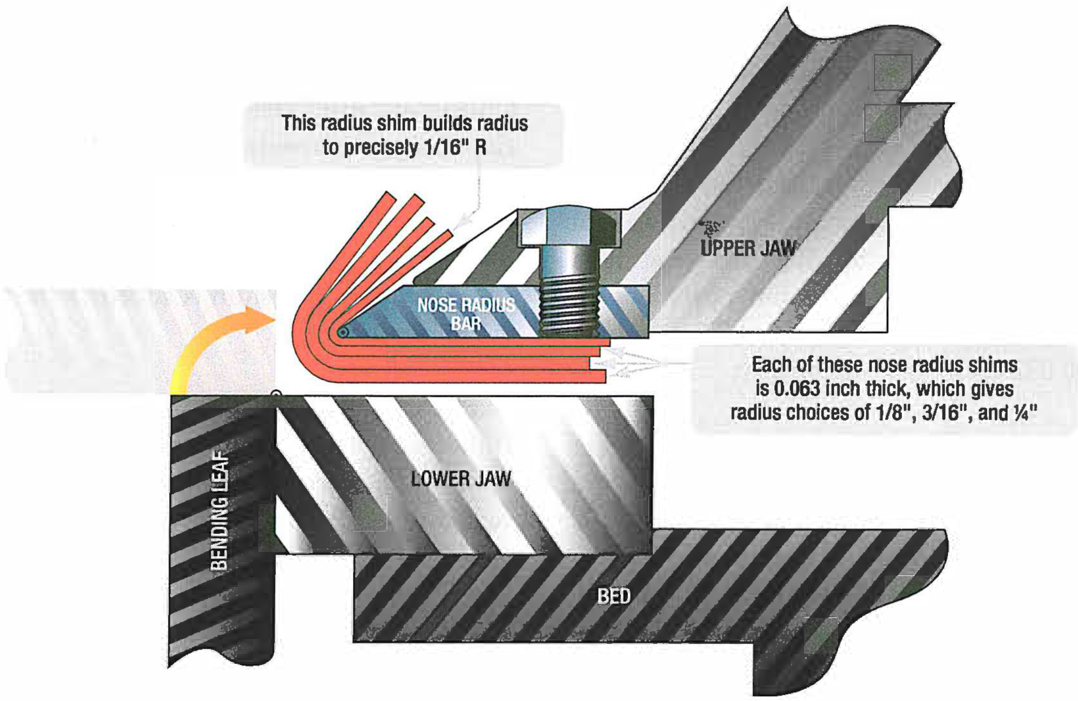


Figure 14-22. Nose radius shims may be used when the brake radius bar is smaller than required.

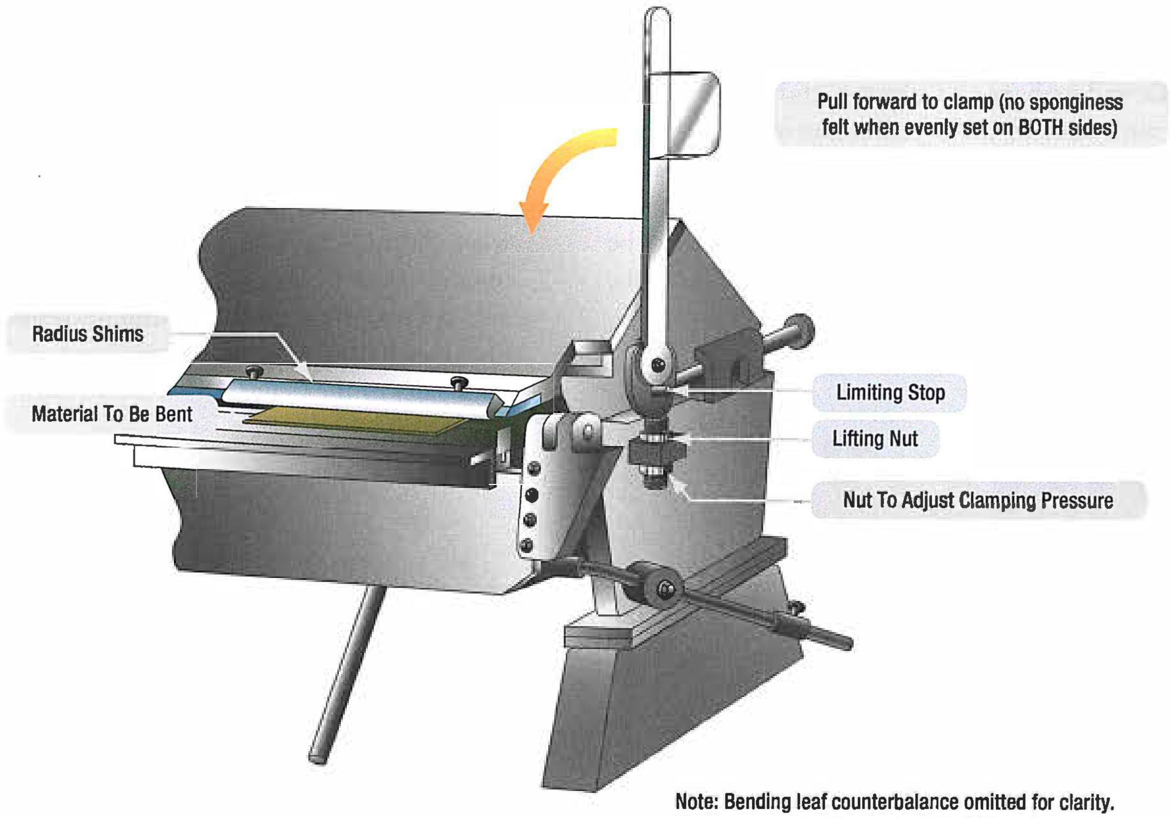


Figure 14-23. General brake overview including radius shims.

Step 3: Adjusting the Nose Gap

Adjust the nose gap by turning the large brake nose gap adjustment knobs at the rear of the upper jaw to achieve its proper alignment. (***Figure 14-24***) The perfect setting is obtained when the bending leaf is held up to the angle of the finished bend and there is one material thickness between the bending leaf and the nose radius piece. Using a piece of material the thickness of the part to be bent as a feeler gauge can help achieve a high degree of accuracy. (***Figures 14-25 and 14-26***) It is essential this nose gap be perfect and even across the length of the part to be bent. Check by clamping two test strips between the bed and the clamp 3-inch from each end of the brake. (***Figure 14-27***) Bend 90° (***Figure 14-28***), remove test strips, and place one on top of the other; they should match. (***Figure 14-29***) If they do not match, adjust the end with the sharper bend back slightly.

FOLDING A BOX

A box can be formed the same way as the U-channel described in the previous paragraphs, but when a sheet metal part has intersecting bend radii, it is necessary to remove material to make room for the material contained in the flanges. This is done by drilling or punching holes at the intersection of the inside bend tangent lines. These holes, called relief holes and whose diameter is approximately twice the bend radius, relieve stresses in the metal as it is bent and prevent the metal from tearing. Relief holes also provide a neatly trimmed corner from which excess material may be trimmed.

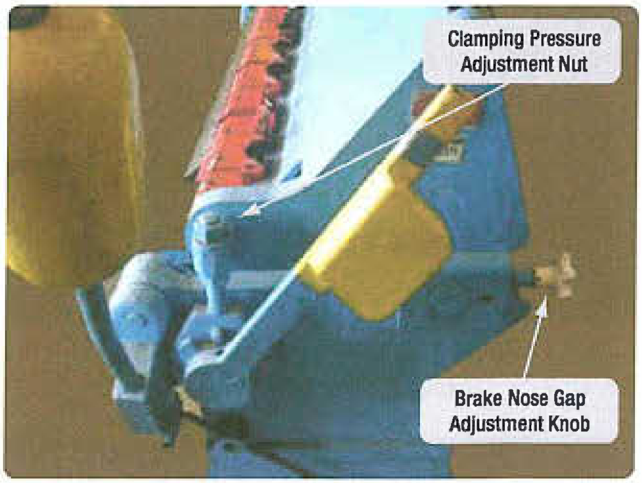


Figure 14-24. Adjust clamping pressure with the clamping pressure nut radius shims.

Figure 14-25. Brake nose gap adjustment with piece of material same thickness as part to be formed.

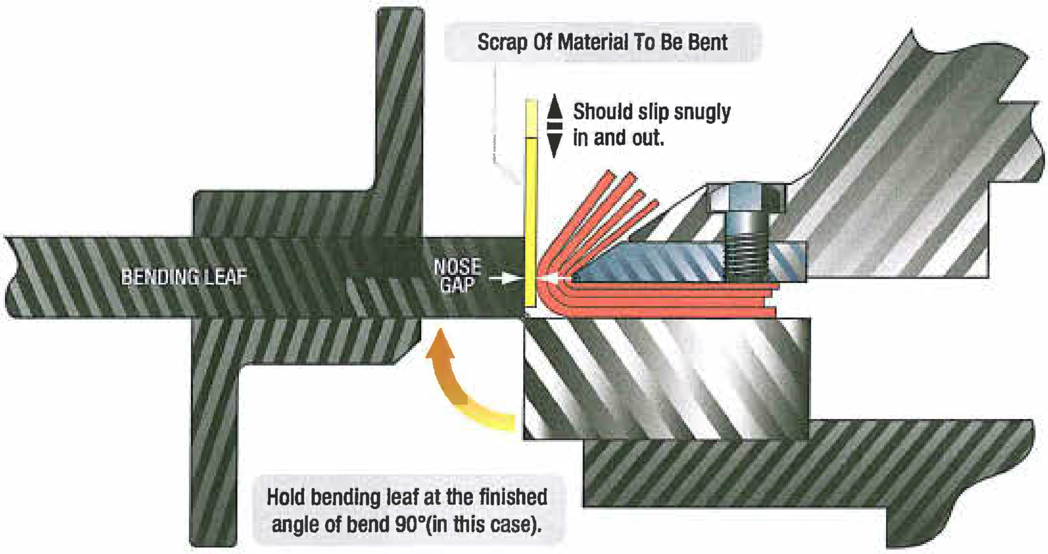


Figure 14-26. Profile illustration of brake nose gap adjustment.

MATERIAL HANDLING

Figure 14-27. Brake alignment with two test strips 3-inches from each end.

Figure 14-28. Brake alignment with two test strips bent at 90°.

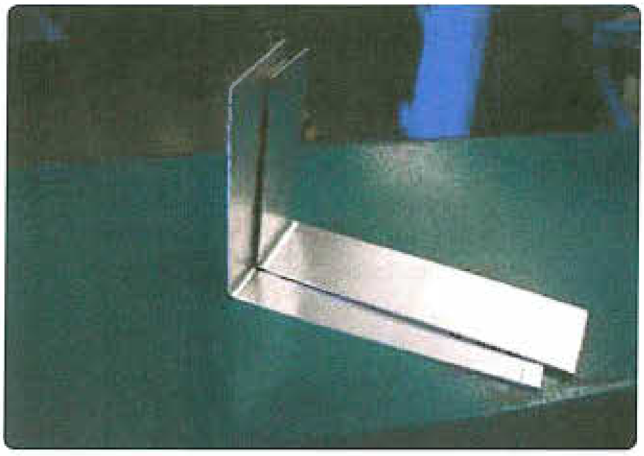


Figure 14-29. Matching test strips.

The larger and smoother the relief hole is, the less likely it will be that a crack will form in the corner. Generally, the radius of the relief hole is specified on the drawing. A box and pan brake, also called a finger brake, is used to bend the box.

Two opposite sides of the box are bent first. Then, the fingers of the brake are adjusted so the folded-up sides ride up in the cracks between the fingers when the leaf is raised to bend the other two sides. The size of relief holes varies with thickness of the material. They should be no less than ⅛-inch in diameter for aluminum alloy sheet stock up to and including 0.064-inch thick, or ³⁄₁₆₀-inch in diameter for stock ranging from 0.072-inch to 0.128-inch thickness. The most common method of determining the diameter of a relief hole is to use the radius of bend for this dimension, provided it is not less than the minimum allowance (⅛-inch).

RELIEF HOLE LOCATION

Relief holes must touch the intersection of the inside bend tangent lines. To allow for possible error in bending, make the relief holes extend 1⁄32-inch to 1⁄16-inch behind the inside bend tangent lines. It is good practice to use the intersection of these lines as the center for the holes. The line on the inside of the curve is cut at an angle toward the relief holes to allow for the stretching of the inside flange.

The positioning of the relief hole is important. (***Figure 14-30***) It should be located so its outer perimeter touches the intersection of the inside bend tangent lines. This keeps any material from interfering with the bend allowance area of the other bend. If these bend allowance areas intersected with each other, there would be substantial compressive stresses that would accumulate in that corner while bending. This could cause the part to crack while bending.

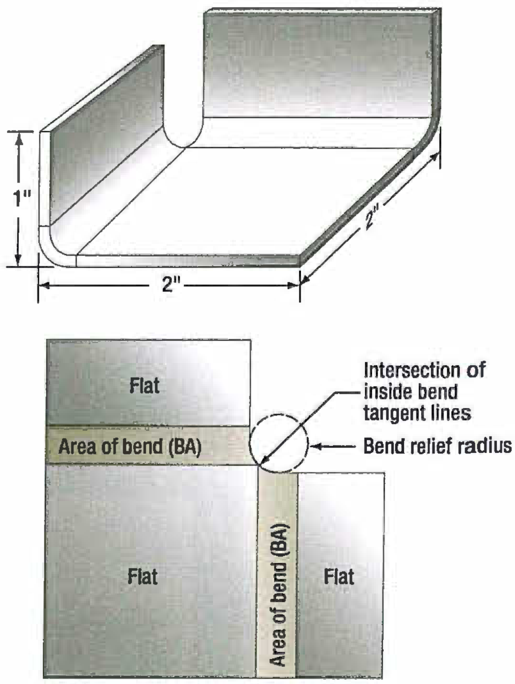


Figure 14-30. Relief hole location adjustment.

LAYOUT METHOD

Lay out the basic part using traditional layout procedures. This determines the width of the flats and the bend allowance. It is the intersection of the inside bend tangent lines that index the bend relief hole position. Bisect these intersected lines and move outward the distance of the radius of the hole on this line. This is the center of the hole. Drill at this point and finish by trimming off the remainder of the corner material. The trim out is often tangent to the radius and perpendicular to the edge. (*Figure 14-31*)

This leaves an open corner. If the corner must be closed, or a slightly longer flange is necessary, then trim out accordingly. If the corner is to be welded, it is necessary to have touching flanges at the corners. The length of the flange should be one material thickness shorter than the finished length of the part so only the insides of the flanges touch.

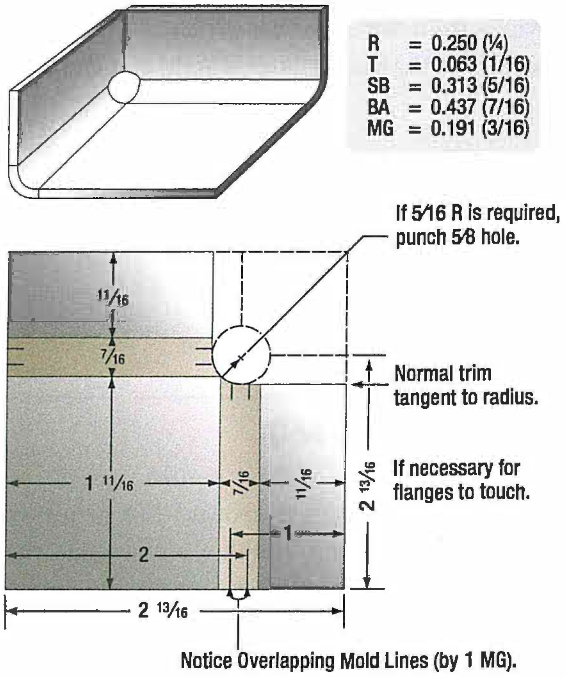


Figure 14-31. Relief hole layout.

OPEN AND CLOSED BENDS

Open and closed bends present unique problems that require more calculations than 90° bends. In the following 45° and a 135° bend examples, the material is 0.050-inch thick and the bend radius is 3⁄16-inch.

OPEN END BEND (LESS THAN 90°)

Figure 14-32 shows an example for a 45° bend.

1. Look up K-factor in K chart. K-factor for 45° is 0.414 21-inch.
2. Calculate setback.
   SB = K(R + T)
   SB = 0.414 21-inch (0.1875-inch + 0.050-inch) = 0.098-inch
3. Calculate bend allowance for 45°. Look up bend allowance for 1° of bend in the bend allowance chart and multiply this by 45.
   0.003 675-inch × 45 = 0.165-inch
4. Calculate flats.
   Flat = Mold line dimension - SB
   Flat 1 = .77-inch - 0.098-inch = 0.672-inch
   Flat 2 = 1.52-inch - 0.098-inch = 1.422-inch
5. Calculate total developed width (TDW).
   TDW = Flats + Bend allowance
   TDW = 0.672-inch + 1.422-inch + 0.165-inch = 2.259-inch.

Observe that the brake reference line is still located one radius from the bend tangent line.

CLOSED END BEND (MORE THAN 90°)

Figure 14-33 shows an example of a 135° bend.

1. Look up K-factor in K chart. K-factor for 135° is 2.414 2-inch.
2. Calculate SB.
   SB = K(R + T)
   SB = 2.414 2-inch (0.187 5-inch + 0.050-inch) = 0.57-inch
3. Calculate bend allowance for 135°. Look up bend allowance for 1° of bend in the bend allowance chart and multiply this by 135.
   0.003 675-inch × 135 = 0.496-inch
4. Calculate flats.
   Flat = Mold line dimension - SB
   Flat 1 = 0.77-inch - 0.57-inch = 0.20-inch
   Flat 2 = 1.52-inch - 0.57-inch = 0.95-inch
5. Calculate TDW.
   TDW = Flats + Bend allowance
   TDW = 0.20 inch + 0.95 inch + 0.496 inch = 1.65 inch.

It is obvious from both examples that a closed bend has a smaller TDW than an open-end bend and the material length needs to be adjusted accordingly.

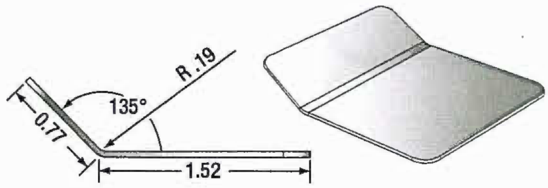


Figure 14-32. Open bend.

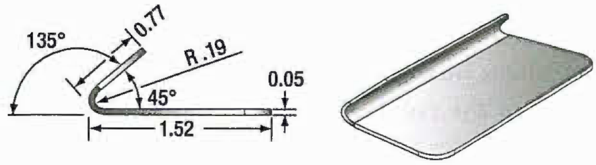


Figure 14-33. Closed bend.

HAND FORMING

All hand forming revolves around the processes of stretching and shrinking metal. As discussed earlier, stretching means to lengthen or increase a particular area of metal while shrinking means to reduce an area. Several methods of stretching and shrinking may be used, depending on the size, shape, and contour of the part being formed.

For example, if a formed or extruded angle is to be curved, either stretch one leg or shrink the other, whichever makes the part fit. In bumping, the material is stretched in the bulge to make it balloon, and in joggling, the material is stretched between the joggles. Material in the edge of lightening holes is often stretched to form a beveled reinforcing ridge around them. The following paragraphs discuss some of these techniques.

STRAIGHT LINE BENDS

The cornice brake and bar folder are ordinarily used to make straight bends. Whenever such machines are not available, comparatively short sections can be bent by hand with the aid of wooden or metal bending blocks. After a blank has been laid out and cut to size, clamp it along the bend line between two wooden forming blocks held in a vise. The wooden forming blocks should have one edge rounded as needed for the desired radius of bend. It should also be curved slightly beyond 90° to allow for spring-back.

Bend the metal that protrudes beyond the bending block to the desired angle by tapping lightly with a rubber, plastic, or rawhide mallet. Start tapping at one end and work back and forth along the edge to make a gradual and even bend. Continue this process until the protruding metal is bent to the desired angle against the forming block. Allow for spring back by driving the material slightly farther than the actual bend. If a large amount of metal extends beyond the forming blocks, maintain hand pressure against the protruding sheet to prevent it from bouncing. Remove any irregularities by holding a straight block of hardwood edgewise against the bend and striking it with heavy blows of a mallet or hammer. If the amount of metal protruding beyond the bending blocks is small, make the entire bend by using the hardwood block and hammer.

FORMED OR EXTRUDED ANGLES

Both formed and extruded types of angles can be curved (not bent sharply) by stretching or shrinking either of the flanges. Curving by stretching one flange is usually preferred since the process requires only a V-block and a mallet and is easily accomplished.

STRETCHING WITH V-BLOCK METHOD

In the stretching method, place the flange to be stretched in the groove of the V-block. (If the flange is to be shrunk, place the flange across the V-block.) Using a round, soft-faced mallet, strike the flange directly over the V portion with light, even blows while gradually forcing it downward into the V. (***Figure 14-34***)

Begin at one end of the flange and form the curve gradually and evenly by moving the strip slowly back and forth, distributing the hammer blows at equal spaces on the flange. Hold the strip firmly to keep it from bouncing when hammered. An overly heavy blow buckles the metal, so keep moving the flange across the V-block, but always lightly strike the spot directly above the V. Lay out a full-sized, accurate pattern on a sheet of paper or plywood and periodically check the accuracy of the curve.

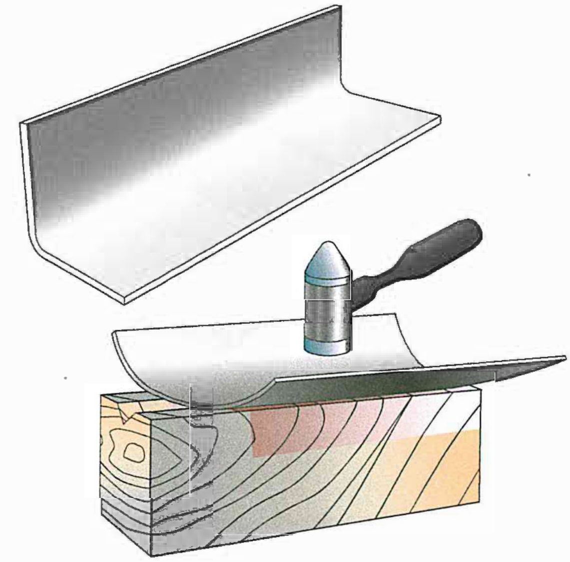


Figure 14-34. V-block forming.

Comparing the angle with the pattern determines exactly how the curve is progressing and just where it needs to be increased or decreased. It is better to get the curve to conform roughly to the desired shape before attempting to finish any one portion, because the finishing or smoothing of the angle may cause some other portion of the angle to change shape. If any part of the angle strip is curved too much, reduce the curve by reversing the angle strip on the V-block, placing the bottom flange up, and striking it with light blows of the mallet.

Try to form the curve with a minimum amount of hammering, for excessive hammering work-hardens the metal. Work hardening can be recognized by a lack of bending response or by springiness in the metal. It can be recognized very readily by an experienced worker. In some cases, the part may have to be annealed during the curving operation. If so, be sure to heat treat the part again before installing it on the aircraft.

SHRINKING WITH V-BLOCK AND SHRINKING BLOCK METHODS

Curving an extruded or formed angle strip by shrinking may be accomplished by either the previously discussed V-block method or the shrinking block method. While the V-block is more satisfactory because it is faster, easier, and affects the metal less, good results can be obtained by the shrinking block method.

In the V-block method, place one flange of the angle strip flat on the V-block with the other flange extending upward. Using the process outlined in the stretching paragraphs, begin at one end of the angle strip and work back and forth making light blows. Strike the edge of the flange at a slight angle to keep the vertical flange from bending outward.

Occasionally, check the curve for accuracy with the pattern. If a sharp curve is made, the angle (cross section of the formed angle) closes slightly. To avoid such closing of the angle, clamp the angle strip to a hardwood board with the hammered flange facing upward using small C-clamps. The jaws of the C-clamps should be covered with masking tape. If the angle has already closed, bring the flange back to the correct angle with a few blows of a mallet or with the aid of a small hardwood block. If any portion of the angle strip is curved too much, reduce it by reversing the angle on the V-block and hammering with a suitable mallet, as explained in the previous paragraph on stretching. After obtaining the proper curve, smooth the entire angle by planishing with a soft-faced mallet.

If the curve in a formed angle is to be quite sharp or if the flanges of the angle are rather broad, the shrinking block method is generally used. In this process, crimp the flange that is to form the inside of the curve.

When making a crimp, hold the crimping pliers so that the jaws are about ⅛-inch apart. By rotating the wrist back and forth, bring the upper jaw of the pliers into contact with the flange, first on one side and then on the other side of the lower jaw. Complete the crimp by working a raised portion into the flange, gradually increasing the twisting motion of the pliers. Do not make the crimp too large because it will be difficult to work out. The size of the crimp depends upon the thickness and softness of the material, but usually about ¼-inch is sufficient. Place several crimps spaced evenly along the desired curve with enough space left between each crimp so that jaws of the shrinking block can easily be attached.

After completing the crimping, place the crimped flange in the shrinking block so that one crimp at a time is located between the jaws. (***Figure 14-35***) Flatten each crimp with light blows of a soft-faced mallet, starting at the apex (the closed end) of the crimp and gradually working toward the edge of the flange. Check the curve of the angle with the pattern periodically during the forming process and again after all the crimps have been worked out. If it is necessary to increase the curve, add more crimps and repeat the process. Space the additional crimps between the original ones so that the metal does not become unduly work hardened at any one point. If the curve needs to be increased or decreased slightly at any point, use the V-block. After obtaining the desired curve, planish the angle strip over a stake or a wooden form.

FLANGED ANGLES

The forming process for the following two flanged angles is slightly more complicated than the previously discussed angles because the bend is shorter (not gradually curved) and necessitates shrinking or stretching in a small or concentrated area. If the flange is to point toward the inside of the bend, the material must be shrunk. If it is to point toward the outside, it must be stretched.

SHRINKING

In forming a flanged angle by shrinking, use wooden forming blocks similar to those shown in ***Figure 14-36*** and proceed as follows:

1. Cut the metal to size, allowing for trimming after forming. Determine the bend allowance for a 90° bend and round the edge of the forming block accordingly.
2. Clamp the material in the form blocks as shown in ***Figure 14-36***, and bend the exposed flange against the block. After bending, tap the blocks slightly. This induces a setting process in the bend.
3. Using a soft-faced shrinking mallet, start hammering near the center and work the flange down gradually toward both ends. The flange tends to buckle at the bend because the material is made to occupy less space. Work the material into several small buckles instead of one large one and work each buckle out gradually by hammering lightly and gradually compressing the material in each buckle. The use of a small hardwood wedge block aids in working out the buckles. (***Figure 14-37***)
4. Planish the flange after it is flattened against the form block and remove small irregularities. If the form blocks are made of hardwood, use a metal planishing hammer. If the forms are made of metal, use a softfaced mallet. Trim the excess material away and file and polish.

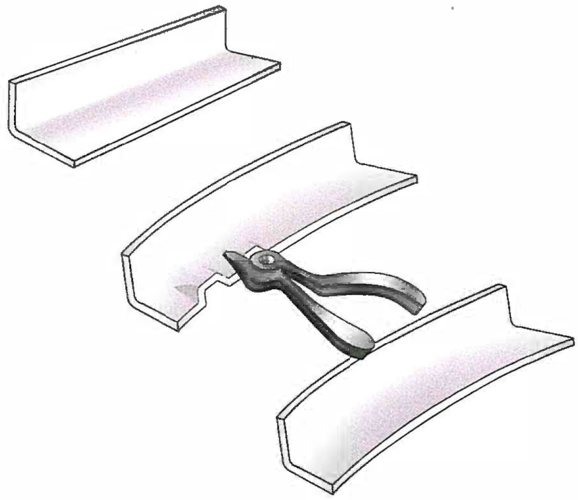


Figure 14-35. Crimping a metal flange in order to form a curve.

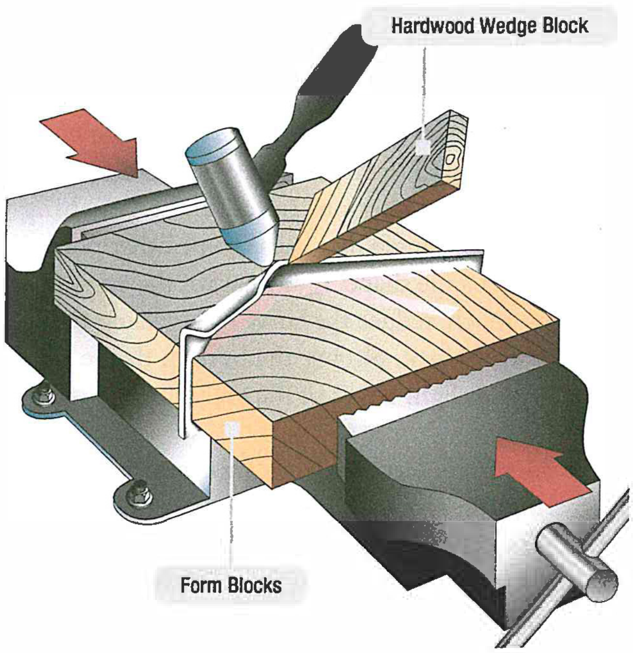


Figure 14-36. Forming a flanged angle using forming blocks.

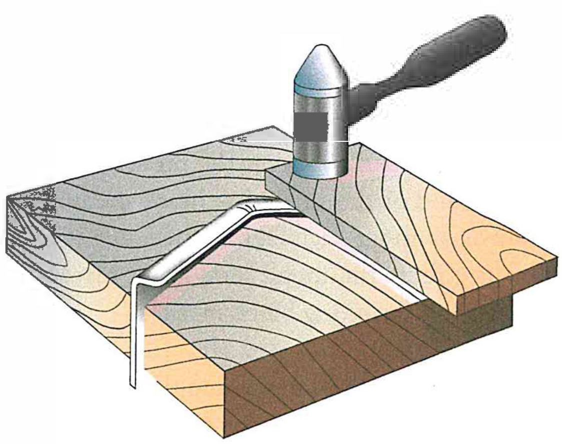


Figure 14-37. Shrinking blocks.

STRETCHING

To form a flanged angle by stretching, use the same forming blocks, wooden wedge block, and mallet as used in the shrinking process and proceed as follows:

1. Cut the material to size (allowing for trim), determine bend allowance for a 90° bend, and round off the edge of the block to conform to the desired radius of bend.
2. Clamp the material in the form blocks. (***Figure 14-38***)
3. Using a soft-faced stretching mallet, start hammering near the ends and work the flange down smoothly and gradually to prevent cracking and splitting. Planish the flange and angle as described in the previous procedure, and trim and smooth the edges, if necessary.

CURVED FLANGED PARTS

Curved flanged parts are usually hand formed with a concave flange, the inside edge, and a convex flange, the outside edge.

The concave flange is formed by stretching, while the convex flange is formed by shrinking. Such parts are shaped with the aid of hardwood or metal forming blocks. (***Figure 14-39***) These blocks are made in pairs and are designed specifically for the shape of the area being formed. These blocks are made in pairs similar to those used for straight angle bends and are identified in the same manner. They differ in that they are made specifically for the particular part to be formed, they fit each other exactly, and they conform to the actual dimensions and contour of the finished article.

The forming blocks may be equipped with small aligning pins to help line up the blocks and to hold the metal in place or they may be held together by C-clamps or a vise. They also may be held together with bolts by drilling through form blocks and the metal, provided the holes do not affect the strength of the finished part. The edges of the forming block are rounded to give the correct radius of bend to the part, and are undercut approximately 5° to allow for spring-back of the metal. This undercut is especially important if the material is hard or if the bend must be accurate.

The nose rib offers a good example of forming a curved flange because it incorporates both stretching and shrinking (by crimping). They usually have a concave flange, the inside edge, and a convex flange, the outside edge. Note the various types of forming represented in the following figures. In the plain nose rib, only one large convex flange is used. (***Figure 14-40***) Because of the great distance around the part and the likelihood of buckles in forming, it is rather difficult to form. The flange and the beaded (raised ridge on sheet metal used to stiffen the piece) portion of this rib provide sufficient strength to make this a good type to use.

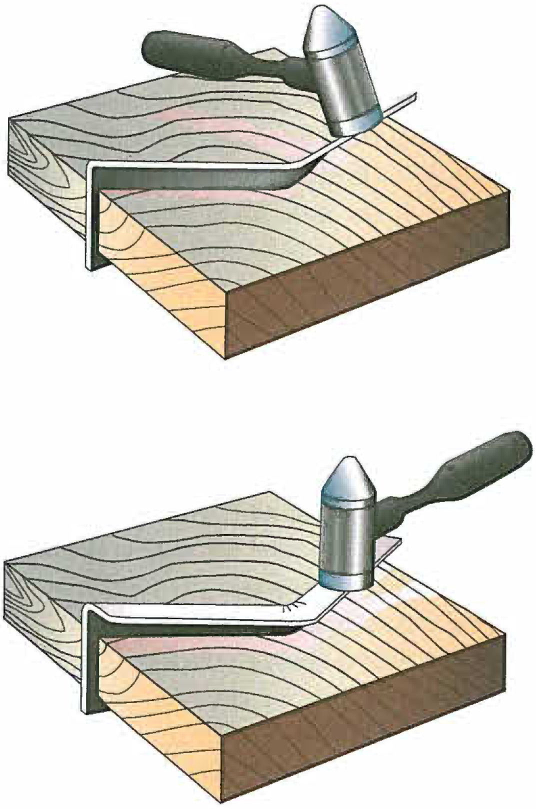


Figure 14-38. Stretching a flanged angle.

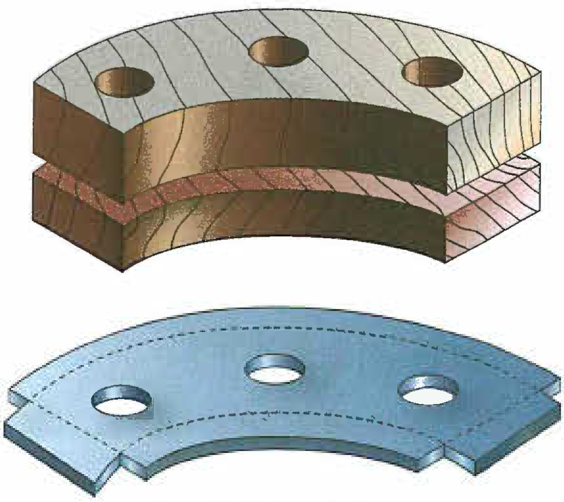


Figure 14-39. Forming blocks.

In ***Figure 14-41***, the concave flange is difficult to form, but the outside flange is broken up into smaller sections by relief holes. In ***Figure 14-42***, note that crimps are placed at equally spaced intervals to absorb material and cause curving, while also giving strength to the part. In ***Figure 14-43***, the nose rib is formed by crimping, beading, putting in relief holes, and using a formed angle riveted on each end. The beads and the formed angles supply strength to the part. The basic steps in forming a curved flange follow: (***Figures 14-44 and 14-45***)

1. Cut the material to size, allowing about ¼ inch excess material for trim and drill holes for alignment pins.
2. Remove all burrs (flagged edges). This reduces the possibility of the material cracking at the edges during the forming process.
3. Locate and drill holes for alignment pins.
4. Place the material between the form blocks and clamp blocks tightly in a vise to prevent the material from moving or shifting. Clamp the work as closely as possible to the particular area being hammered to prevent strain on the form blocks and to keep the metal from slipping.

CONCAVE SURFACES

Bend the flange on the concave curve first. This practice may keep the flange from splitting open or cracking when the metal is stretched. Should this occur, a new piece must be made. Using a plastic or rawhide mallet with a smooth, slightly rounded face, start hammering at the extreme ends of the part and continue toward the center of the bend. This procedure permits some of the metal at the ends of the part to be worked into the center of the curve where it is needed. Continue hammering until the metal is gradually worked down over the entire flange, flush with the form block. After the flange is formed, trim off the excess material and check the part for accuracy. (***Figure 14-44***)

CONVEX SURFACES

Convex surfaces are formed by shrinking the material over a form block. (***Figure 14-45***) Using a wooden or plastic shrinking mallet and a backup or wedge block, start at the center of the curve and work toward both ends. Hammer the flange down over the form, striking the metal with glancing blows at an angle of approximately 45° and with a motion that tends to pull the part away from the radius of the form block.

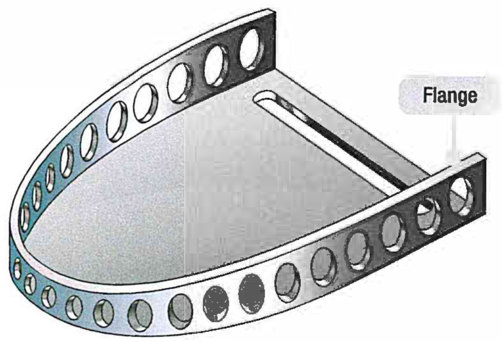


Figure 14-40. Plain nose rib.

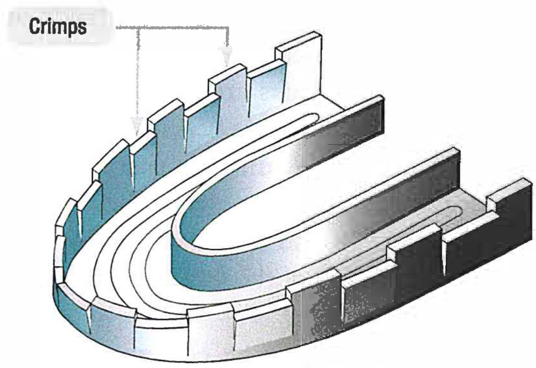


Figure 14-42. Nose rib with crimps.

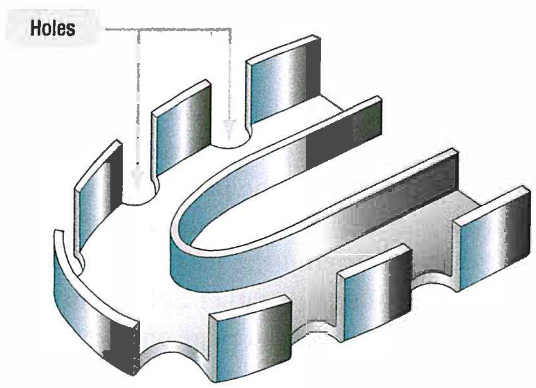


Figure 14-41. Nose rib with relief holes.

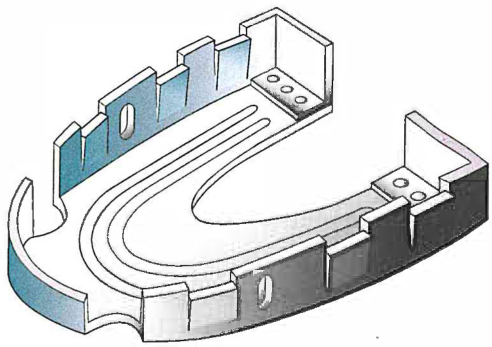


Figure 14-43. Nose rib using a combination of forms.

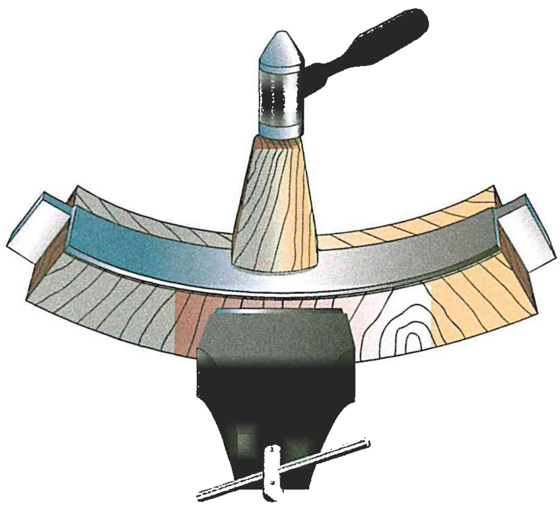


Figure 14-44. Forming a concave flange.

Stretch the metal around the radius bend and remove the buckles gradually by hammering on a wedge block.

Use the backup block to keep the edge of the flange as nearly perpendicular to the form block as possible. The backup block also lessens the possibility of buckles, splits, or cracks. Finally, trim the flanges of excess metal, planish, remove burrs, round the corners (if any), and check the part for accuracy.

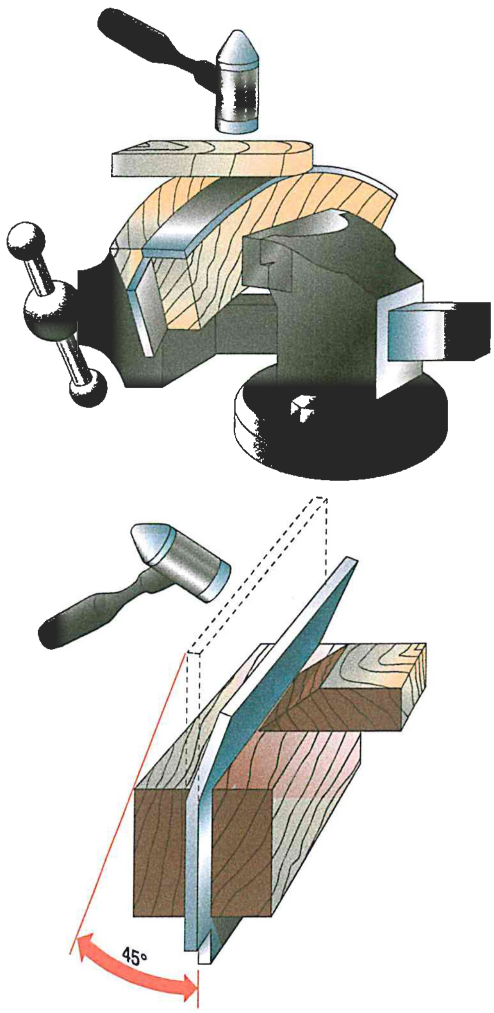


Figure 14-45. Forming a convex flange.

FORMING BY BUMPING

As discussed earlier, bumping involves stretching the sheet metal by bumping it into a form and making it balloon. (***Figure 14-46***) Bumping can be done on a form block or female die, or on a sandbag. Either method requires only one form: a wooden block, a lead die, or a sandbag. The blister, or streamlined cover plate, is an example of a part made by the form block or die method of bumping. Wing fillets are an example of parts that are usually formed by bumping on a sandbag.

FORM BLOCK OR DIE

The wooden block or lead die designed for form block bumping must have the same dimensions and contour as the outside of the blister. To provide enough bucking weight and bearing surface for fastening the metal, the block or die should be at least one inch larger in all dimensions than the form requires.

Follow these procedures to create a form block:

1. Hollow the block out with tools, such as saws, chisels, gouges, files, and rasps.
2. Smooth and finish the block with sandpaper. The inside of the form must be as smooth as possible, because the slightest irregularity shows up on the finished part.
3. Prepare several templates (patterns of the cross section), as shown in ***Figure 14-46*** so that the form can be checked for accuracy.
4. Shape the contour at points 1, 2, and 3.
5. Shape the areas between the template checkpoints to conform the remaining contour to template 4. Shaping of the form block requires particular care because the more nearly accurate it is, the less time it takes to produce a smooth, finished part.

After the form is prepared and checked, perform the bumping as follows:

1. Cut a metal blank to size allowing an extra ½ to 1-inch to permit drawing.
2. Apply a thin coat of light oil to the block and the aluminum to prevent galling (scraping on rough spots).
3. Clamp the material between the block and steel plate. Ensure it is firmly supported yet it can slip a little toward the inside of the form.
4. Clamp the bumping block in a bench vise. Use a soft-faced rubber mallet, or a hardwood drive block with a suitable mallet, to start the bumping near the edges of the form.
5. Work the material down gradually from the edges with light blows of the mallet. Remember, the purpose of bumping is to work the material into shape by stretching rather than forcing it into the form with heavy blows. Always start bumping near the edge of the form. Never start near the center of the blister.
6. Before removing the work from the form, smooth it as much as possible by rubbing it with the rounded end of either a maple block or a stretching mallet.
7. Remove the blister from the bumping block and trim to size.

SANDBAG BUMPING

Sandbag bumping is one of the most difficult methods of hand forming sheet metal because there is no exact forming block to guide the operation. (*Figure 14-47*)

In this method, a depression is made into the sandbag to take the shape of the hammered portion of the metal. The depression or pit has a tendency to shift from the hammering, which necessitates periodic readjustment during the bumping process. The degree of shifting depends largely on the contour or shape of the piece being formed, and whether glancing blows must be struck to stretch, draw, or shrink the metal. When forming by this method, prepare a contour template or some sort of a pattern to serve as a working guide and to ensure accuracy of the finished part.

Make the pattern from ordinary kraft or similar paper, folding it over the part to be duplicated. Cut the paper cover at the points where it would have to be stretched to fit, and attach additional pieces of paper with masking tape to cover the exposed portions. After completely covering the part, trim the pattern to exact size.

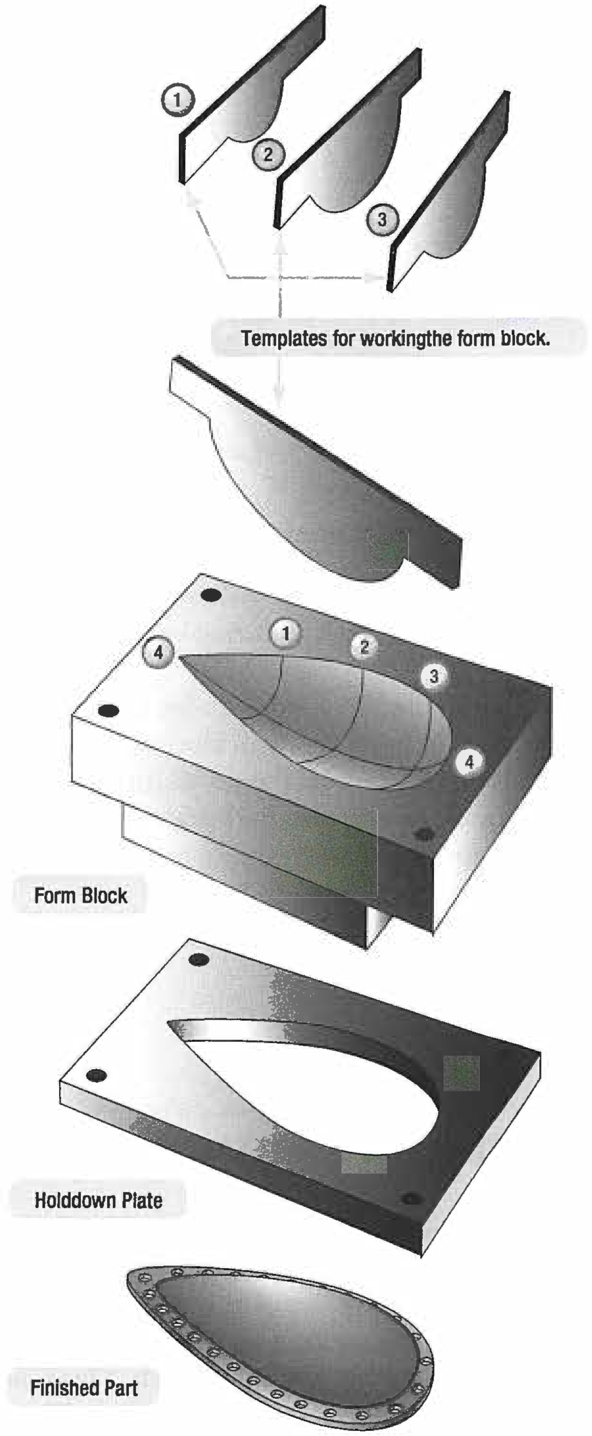


Figure 14-46. Form block bumping.

Open the pattern and spread it out on the metal from which the part is to be formed. Although the pattern does not lie flat, it gives a fairly accurate idea of the approximate shape of the metal to be cut, and the pieced-in sections indicate where the metal is to be stretched. When the pattern has been placed on the material, outline the part and the portions to be stretched using a felt-tipped pen. Add at least 1-inch of excess metal

Figure 14-47. Sandbag bumping.

when cutting the material to size. Trim off the excess metal after bumping the part into shape. If the part to be formed is radially symmetrical, it is fairly easy to shape since a simple contour template can be used as a working guide. The procedure for bumping sheet metal parts on a sandbag follows certain basic steps that can be applied to any part, regardless of its contour or shape.

1. Lay out and cut the contour template to serve as a working guide and to ensure accuracy of the finished part. (This can be made of sheet metal, medium to heavy cardboard, kraft paper, or thin plywood.)
2. Determine the amount of metal needed, lay it out, and cut it to size, allowing at least ½-inch in excess.
3. Place a sandbag on a solid foundation capable of supporting heavy blows and make a pit in the bag with a smooth-faced mallet. Analyze the part to determine the correct radius the pit should have for the forming operation. The pit changes shape with the hammering it receives and must be readjusted accordingly.
4. Select a soft round-faced or bell-shaped mallet with a contour slightly smaller than the contour desired on the sheet metal part. Hold one edge of the metal in the left hand and place the portion to be bumped near the edge of the pit on the sandbag. Strike the metal with light glancing blows.
5. Continue bumping toward the center, revolving the metal, and working gradually inward until the desired shape is obtained. Shape the entire part as a unit.
6. Check the part often for accuracy of shape during the bumping process by applying the template. If wrinkles form, work them out before they become too large.
7. Remove small dents and hammer marks with a suitable stake and planishing hammer or with a hand dolly and planishing hammer.
8. Finally, after bumping is completed, use a pair of dividers to mark around the outside of the object. Trim the edge and file it smooth. Clean and polish the part.

JOGGLING

A joggle, often found at the intersection of stringers and formers, is the offset formed on a part to allow clearance for a sheet or another mating part. Use of the joggle maintains the smooth surface of a joint or splice. The amount of offset is usually small; therefore, the depth of the joggle is generally specified in thousandths of an inch. The thickness of the material to be cleared governs the depth of the joggle. In determining the necessary length of the joggle, allow an extra 1⁄16-inch to give enough added clearance to assure a fit between the joggled, overlapped part. The distance between the two bends of a joggle is called the allowance. This dimension is normally called out on the drawing. However, a general rule of thumb for figuring allowance is four times the thickness of the displacement of flat sheets. For 90° angles, it must be slightly more due to the stress built up at the radius while joggling. For extrusions, the allowance can be as much as 12 times the material thickness, so, it is important to follow the drawing. There are a number of different methods of forming joggles. For example, if the joggle is to be made on a straight flange or flat piece of metal, it can be formed on a cornice break. To form the joggle, use the following procedure:

1. Lay out the boundary lines of the joggle where the bends are to occur on the sheet.
2. Insert the sheet in the brake and bend the metal up approximately 20° to 30°.
3. Release the brake and remove the part.
4. Turn the part over and clamp it in the brake at the second bend line.
5. Bend the part up until the correct height of the joggle is attained.
6. Remove the part from the brake and check the joggle for correct dimensions and clearance.

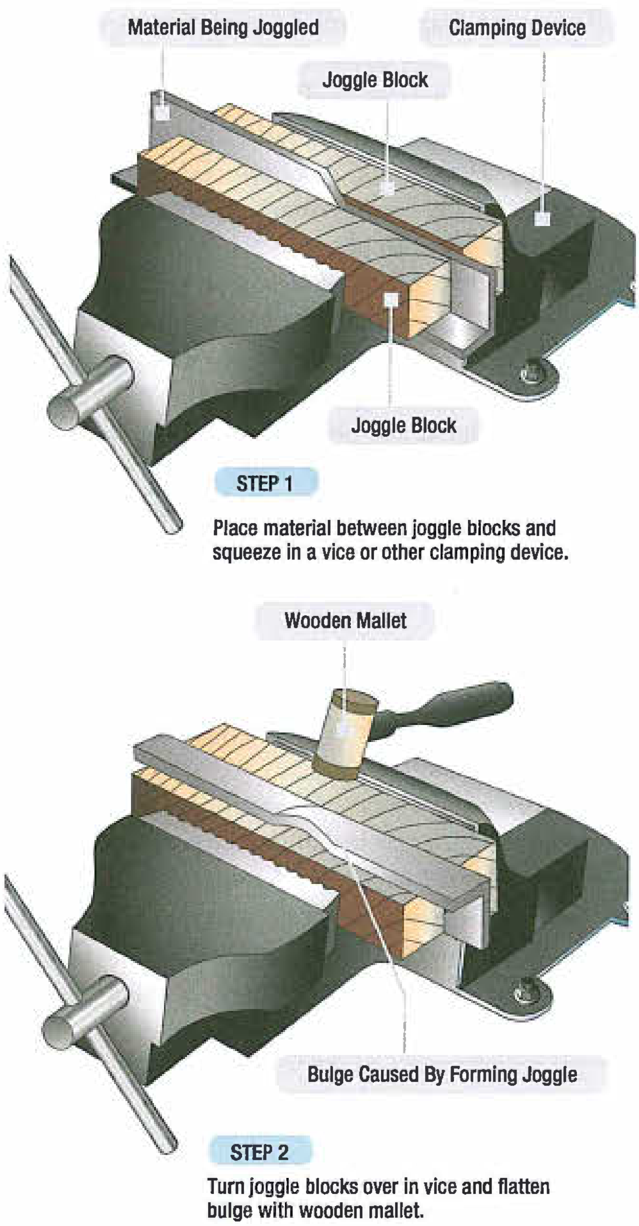


Figure 14-48. Forming joggle using joggle blocks.

When a joggle is necessary on a curved part or a curved flange, forming blocks or dies made of hardwood, steel, or aluminum alloy may be used. The forming procedure consists of placing the part to be joggled between the two joggle blocks and squeezing them in a vice or some other suitable clamping device. After the joggle is formed, the joggle blocks are turned over in the vice and the bulge on the opposite flange is flattened with a wooden or rawhide mallet. (*Figure 14-48*)

Since hardwood is easily worked, dies made of hardwood are satisfactory when the die is to be used only a few times. If a number of similar joggles are to be produced, use steel or aluminum alloy dies. Dies of aluminum alloy are preferred since they are easier to fabricate than those of steel and wear about as long. These dies are sufficiently soft and resilient to permit forming aluminum alloy parts on them without marring, and nicks and scratches are easily removed from their surfaces.

When using joggling dies for the first time, test them for accuracy on a piece of waste stock to avoid the possibility of ruining already fabricated parts. Always keep the surfaces of the blocks free from dirt, filings, and the like, so that the work is not marred. (*Figure 14-49*)

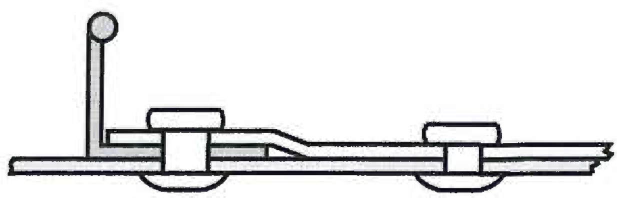


Figure 14-49. Samples of joggled metal.

LIGHTENING HOLES

Lightening holes are cut in rib sections, fuselage frames, and other structural parts to decrease weight. To avoid weakening the member by removal of the material, flanges are often pressed around the holes to strengthen the area from which the material was removed.

Lightening holes should never be cut in any structural part unless authorized. The size of the lightening hole and the width of the flange formed around the hole are determined by design specifications. Margins of safety are considered in the specifications so that the weight of the part can be decreased and still retain the necessary strength. Lightening holes may be cut with a hole saw, a punch, or a fly cutter. The edges are filed smooth to prevent them from cracking or tearing.

FLANGING LIGHTENING HOLES

Form the flange by using a flanging die, or hardwood or metal form blocks. Flanging dies consist of two matching parts: a female and a male die. For flanging soft metal, dies can be of hardwood, such as maple. For hard metal or for more permanent use, they should be made of steel. The pilot guide should be the same size as the hole to be flanged, and the shoulder should be the same width and angle as the desired flange.

When flanging lightening holes, place the material between the mating parts of the die and form it by hammering or squeezing the dies together in a vise or in an arbor press (a small hand operated press). The dies work more smoothly if they are coated with light machine oil. (***Figure 14-50***)


Figure 14-50. Lightening hole die set.

WORKING STAINLESS STEEL

Corrosion-resistant-steel (CRES) sheet is used on some parts of the aircraft when high strength is required. CRES causes magnesium, aluminum, or cadmium to corrode when it touches these metals. To isolate CRES from magnesium and aluminum, apply a finish that gives protection between their mating surfaces. It is important to use a bend radius that is larger than the recommended minimum bend radius to prevent cracking of the material in the bend area.

When working with stainless steel, make sure that the metal does not become unduly scratched or marred. Also, take special precautions when shearing, punching, or drilling this metal. It takes about twice as much pressure to shear or punch stainless steel as it does mild steel. Keep the shear or punch and die adjusted very closely. Too much clearance permits the metal to be drawn over the edge of the die and causes it to become work hardened, resulting in excessive strain on the machine. When drilling stainless steel, use an HSS drill bit ground to an included angle of 135°. Keep the drill speed about one-half that required for drilling mild steel, but never exceed 750 rpm. Keep a uniform pressure on the drill so the feed is constant at all times. Drill the material on a backing plate, such as cast iron, which is hard enough to permit the drill bit to cut completely through the stock without pushing the metal away from the drill point. Spot the drill bit before turning on the power and also make sure that pressure is exerted when the power is turned on.

WORKING INCONEL® ALLOYS 625 AND 718

Inconel® refers to a family of nickel-chromium-iron super alloys typically used in high-temperature applications. Corrosion resistance and the ability to stay strong in high temperatures led to the frequent use of these Inconel® alloys in aircraft powerplant structures. Inconel® alloys 625 and 718 can be cold formed by standard procedures used for steel and stainless steel.

Normal drilling into Inconel® alloys can break drill bits sooner and cause damage to the edge of the hole when the drill bit goes through the metal. If a hand drill is used to drill Inconel® alloys 625 and 718, select a 135° cobalt drill bit. When hand drilling, push hard on the drill, but stay at a constant chip rate. For example, with a No. 30 hole, push the drill with approximately 50 pounds of force. Use the maximum drill rpm as illustrated in

Figure 14-51. A cutting fluid is not necessary when hand drilling.

Drill Size	Maximum RPM
80–30	500
29–U	300
3/8	150

Figure 14-51. Drill size and speed for drilling Inconel®.

The following drilling procedures are recommended:

- Drill pilot holes in loose repair parts with power feed equipment before preassembling them.
- Preassemble the repair parts and drill the pilot holes in the mating structure.
- Enlarge the pilot holes to their completed hole dimension.

When drilling Inconel®, auto feed-type drilling equipment is preferred.

WORKING MAGNESIUM

Warning: Keep magnesium particles away from sources of ignition. Small particles of magnesium burn very easily. In sufficient concentration, these small particles can cause an explosion. If water touches molten magnesium, a steam explosion could occur. Extinguish magnesium fires with dry talc, calcium carbonate, sand, or graphite. Apply the powder on the burning metal to a depth of ½-inch or more. Do not use foam, water, carbon tetrachloride, or carbon dioxide. Magnesium alloys must not touch methyl alcohol.

Magnesium is the world's lightest structural metal. Like many other metals, this silvery-white element is not used in its pure state for stressed application. Instead, magnesium is alloyed with certain other metals (aluminum, zinc, zirconium, manganese, thorium, and rare earth metals) to obtain the strong, lightweight alloys needed for structural uses. When alloyed with these other metals, magnesium, yields alloys with excellent properties and high strength-to-weight ratios. Proper combination of these alloying constituents provide alloys suitable for sand, permanent mold and die castings, forging, extrusions, rolled sheet, and plate with good properties at room temperature, as well as at elevated temperatures.

Light weight is the best known characteristic of magnesium, an important factor in aircraft design. In comparison, aluminum weighs one and one half times more, iron and steel weigh four times more, and copper and nickel alloys weigh five times more. Magnesium alloys can be cut, drilled, and reamed with the same tools that are used on steel or brass, but the cutting edges of the tool must be sharp. Type B rivets (5056-F aluminum alloy) are used when riveting magnesium alloy parts. Magnesium parts are often repaired with clad 2024-T3 aluminum alloy.

While magnesium alloys can usually be fabricated by methods similar to those used on other metals, remember that many of the details of shop practice cannot be applied. Magnesium alloys are difficult to fabricate at room temperature; therefore, most operations must be performed at high temperatures. This requires preheating of the metal or dies, or both. Magnesium alloy sheets may be cut by blade shears, blanking dies, routers, or saws. Hand or circular saws are usually used for cutting extrusions to length. Conventional shears and nibblers should never be used for cutting magnesium alloy sheet because they produce a rough, cracked edge.

Shearing and blanking of magnesium alloys require close tool tolerances. A maximum clearance of 3 to 5 percent of the sheet thickness is recommended. The top blade of the shears should be ground with an included angle of 45° to 60°. The shear angle on a punch should be from 2° to 3°, with a 1° clearance angle on the die. For blanking, the shear angle on the die should be from 2° to 3° with a 1° clearance angle on the punch. Hold-down pressures should be used when possible. Cold shearing should not be accomplished on a hard-rolled sheet thicker than 0.064-inch or annealed sheet thicker than ⅛-inch. Shaving is used to smooth the rough, flaky edges of a magnesium sheet that has been sheared. This operation consists of removing approximately 1⁄32-inch by a second shearing.

Hot shearing is sometimes used to obtain an improved sheared edge. This is necessary for heavy sheet and plate stock. Annealed sheet may be heated to 600 °F, but hard rolled sheet must be held under 400 °F, depending on the alloy used. Thermal expansion makes it necessary to allow for shrinkage after cooling, which entails adding a small amount of material to the cold metal dimensions before fabrication.

Sawing is the only method used in cutting plate stock more than ½-inch thick. Band saw raker-set blades of 4 to 6 tooth pitch are recommended for cutting plate stock or heavy extrusions. Small and medium extrusions are more easily cut on a circular cutoff saw having six teeth per inch. Sheet stock can be cut on handsaws having raker-set or straight-set teeth with an 8-tooth pitch. Band saws should be equipped with non-sparking blade guides to eliminate the danger of sparks igniting the magnesium alloy filings.

Cold working most magnesium alloys at room temperature is very limited, because they work harden rapidly and do not lend themselves to any severe cold forming. Some simple bending operations may be performed on sheet material, but the radius of bend must be at least 7 times the thickness of the sheet for soft material and 12 times the thickness of the sheet for hard material. A radius of 2 or 3 times the thickness of the sheet can be used if the material is heated for the forming operation.

Since wrought magnesium alloys tend to crack after they are cold-worked, the best results are obtained if the metal is heated to 450 °F before any forming operations are attempted. Parts formed at the lower temperature range are stronger because the higher temperature range has an annealing effect on the metal.

The disadvantages of hot working magnesium are:
1. Heating the dies and the material is expensive and troublesome.
2. There are problems in lubricating and handling materials at these temperatures.

The advantages to hot working magnesium are:
1. It is more easily formed when hot than are other metals.
2. Spring-back is reduced, resulting in greater dimensional accuracy.

When heating magnesium and its alloys, watch the temperature carefully as the metal is easily burned. Overheating also causes small molten pools to form within the metal. In either case, the metal is ruined. To prevent burning, magnesium must be protected with a sulfur dioxide atmosphere while being heated. Proper bending around a short radius requires the removal of sharp corners and burrs near the bend line. Layouts should be made with a carpenter's soft pencil because any marring of the surface may result in fatigue cracks.

Press brakes can be used for making bends with short radii. Die and rubber methods should be used where bends are to be made at right angles, which complicate the use of a brake. Roll forming may be accomplished cold on equipment designed for forming aluminum. The most common method of forming and shallow drawing of magnesium is to use a rubber pad as the female die. This rubber pad is held in an inverted steel pan that is lowered by a hydraulic press ram. The press exerts pressure on the metal and bends it to the shape of the male die.

The machining characteristics of magnesium alloys are excellent, making possible the use of maximum speeds of the machine tools with heavy cuts and high feed rates. Power requirements for machining magnesium alloys are about one-sixth of those for mild steel.

Filings, shavings, and chips from machining operations should be kept in covered metal containers because of the danger of combustion. Do not use magnesium alloys in liquid deicing and water injection systems or in the integral fuel tank areas.

WORKING TITANIUM

Keep titanium particles away from sources of ignition. Small particles of titanium burn very easily. In sufficient concentration, these small particles can cause an explosion. If water touches molten titanium, a steam explosion could occur. Extinguish titanium fires with dry talc, calcium carbonate, sand, or graphite. Apply the powder on the burning metal to a depth of ½-inch or more. Do not use foam, water, carbon tetrachloride, or carbon dioxide.

DESCRIPTION OF TITANIUM

Titanium in its mineral state, is the fourth most abundant structural metal in the earth's crust. It is light weight, nonmagnetic, strong, corrosion resistant, and ductile. Titanium lies between the aluminum alloys and stainless steel in modulus, density, and strength at intermediate temperatures. Titanium is 30 percent stronger than steel, but is nearly 50 percent lighter. It is 60 percent heavier than aluminum, but twice as strong.

Titanium and its alloys are used chiefly for parts that require good corrosion resistance, moderate strength up to 600 °F (315 °C), and light weight. Commercially pure titanium sheet may be formed by hydropress, stretch press, brake roll forming, drop hammer, or other similar operations. It is more difficult to form than annealed stainless steel. Titanium can also be worked by grinding, drilling, sawing, and the types of working used on other metals. Titanium must be isolated from magnesium, aluminum, or alloy steel because galvanic corrosion or oxidation of the other metals occurs upon contact.

Monel® rivets or standard close-tolerance steel fasteners should be used when installing titanium parts. The alloy sheet can be formed, to a limited extent, at room temperature. The forming of titanium alloys is divided into three classes:

- Cold forming with no stress relief
- Cold forming with stress relief
- Elevated temperature forming (built-in stress relief)

Over 5 percent of all titanium in the United States is produced in the form of the alloy Ti 6Al-4V, which is known as the workhorse of the titanium industry. Used in aircraft turbine engine components and aircraft structural components, Ti 6Al-4V is approximately 3 times stronger than pure titanium. But, this most widely used titanium alloy, is hard to form. The following are procedures for cold forming titanium 6Al-4V annealed with stress relief (room temperature forming):

1. It is important to use a minimum radius chart when forming titanium because an excessively small radius introduces excess stress to the bend area.
2. Stress relieves the part as follows: heat the part to a temperature above 1 250 °F (677 °C), but below 1 450 °F (788 °C). Keep the part at this temperature for more than 30 minutes but less than 10 hours.
3. A powerful press brake is required to form titanium parts. Regular hand-operated box and pan brakes cannot form titanium sheet material.
4. A power slip roller is often used if the repair patch needs to be curved to fit the contour of the aircraft.

Titanium can be difficult to drill, but standard high-speed drill bits may be used if the bits are sharp, if sufficient force is applied, and if a low-speed drill motor is used. If the drill bit is dull, or if it is allowed to ride in a partially drilled hole, an overheated condition is created, making further drilling extremely difficult. Therefore, keep holes as shallow as possible; use short, sharp drill bits of approved design; and flood the area with large amounts of cutting fluid to facilitate drilling or reaming.

When working titanium, it is recommended that you use carbide or 8 percent cobalt drill bits, reamers, and countersinks. Ensure the drill or reamer is rotating to prevent scoring the side of the hole when removing either of them from a hole. Use a hand drill only when positive-power-feed drills are not available. The following guidelines are used for drilling titanium:

- The largest diameter hole that can be drilled in a single step is 0.156 3-inch because a large force is required. Larger diameter drill bits do not cut satisfactorily when much force is used. Drill bits that do not cut satisfactorily cause damage to the hole.
- Holes with a diameter of 0.187 5-inch and larger can be hand drilled if the operator:
  - Starts with a hole with a diameter of 0.156 3-inch
  - Increases the diameter of the hole in 0.031 3-inch or 0.0625-inch increments.
- Cobalt vanadium drill bits last much longer than HSS bits.

- The recommended drill motor rpm settings for hand drilling titanium are listed in ***Figure 14-52***.
- The life of a drill bit is shorter when drilling titanium than when drilling steel. Do not use a blunt drill bit or let a drill bit rub the surface of the metal and not cut it. If one of these conditions occurs, the titanium surface becomes work hardened, and it is very difficult to start the drill again.
- When hand drilling two or more titanium parts at the same time, clamp them together tightly. To clamp them together, use temporary bolts, Cleco clamps, or tooling clamps. Put the clamps around the area to drill and as near the area as possible.
- When hand drilling thin or flexible parts, put a support (such as a block of wood) behind the part.
- Titanium has a low thermal conductivity. When it becomes hot, other metals become easily attached to it. Particles of titanium often become welded to the sharp edges of the drill bit if the drill speed is too high. When drilling large plates or extrusions, use a water soluble coolant or sulphurized oil.

Hole Size (inches)	Drill Speed (rpm)
0.0625	920 to 1830 rpm
0.125	460 to 920 rpm
0.1875	230 to 460 rpm

Figure 14-52. Hole size and drill speed for drilling titanium.

NOTE: The intimate metal-to-metal contact in the metal working process creates heat and friction that must be reduced or the tools and the sheet metal used in the process are quickly damaged and/or destroyed. Coolants, also called cutting fluids, are used to reduce the friction at the interface of the tool and sheet metal by transferring heat away from the tool and sheet metal. Thus, the use of cutting fluids increases productivity, extends tool life, and results in a higher quality of workmanship.

INSPECTION OF SHEET METAL WORK

When visually inspecting sheet metal work for damage, remember that there may be other kinds of damage than that caused by impact from foreign objects or collision. A rough landing may overload one of the landing gear, causing it to become sprung; this would be classified as load damage. During inspection and sizing up of the repair job, consider how far the damage caused by the sprung shock strut extends to supporting structural members.

A shock occurring at one end of a member is transmitted throughout its length; therefore, closely inspect all rivets, bolts, and attaching structures along the complete member for any evidence of damage. Make a close examination for rivets that have partially failed and for holes that have been elongated.

Whether specific damage is suspected or not, an aircraft structure must occasionally be inspected for structural integrity. The following paragraphs provide general guidelines for this inspection. When inspecting the structure of an aircraft, it is very important to watch for evidence of corrosion on the inside. This is most likely to occur in pockets and corners where moisture and salt spray may accumulate; therefore, drain holes must always be kept clean.

While an injury to the skin covering caused by impact with an object is plainly evident, a defect, such as distortion or failure of the substructure, may not be apparent until some evidence develops on the surface, such as canted, buckled or wrinkled covering, and loose rivets or working rivets. A working rivet is one that has movement under structural stress, but has not loosened to the extent that movement can be observed. This situation can sometimes be noted by a dark, greasy residue or deterioration of paint and primers around rivet heads. External indications of internal injury must be watched for and correctly interpreted. When found,an investigation of the substructure in the vicinity should be made and corrective action taken.

Warped wings are usually indicated by the presence of parallel skin wrinkles running diagonally across the wings and extending over a major area. This condition may develop from unusually violent maneuvers, extremely rough air, or extra hard landings. While there may be no actual rupture of any part of the structure, it may be distorted and weakened. Similar failures may also occur in fuselages. Small cracks in the skin covering may be caused by vibration and they are frequently found leading away from rivets.

Aluminum alloy surfaces having chipped protective coating, scratches, or worn spots that expose the surface of the metal should be recoated at once, as corrosion may develop rapidly. The same principle is applied to aluminum clad (Alclad™) surfaces. Scratches, which penetrate the pure aluminum surface layer, permit corrosion to take place in the alloy beneath.

A simple visual inspection cannot accurately determine if suspected cracks in major structural members actually exist or the full extent of the visible cracks. Eddy current and ultrasonic inspection techniques are used to find hidden damage.

INSPECTION OF RIVETED JOINTS

Inspection consists of examining both the shop and manufactured heads and the surrounding skin and structural parts for deformities.

During the repair of an aircraft structural part, examine adjacent parts to determine the condition of neighboring rivets. The presence of chipped or cracked paint around the heads may indicate shifted or loose rivets. If the heads are tipped or if rivets are loose, they show up in groups of several consecutive rivets and are probably tipped in the same direction. If heads that appear to be tipped are not in groups and are not tipped in the same direction, tipping may have occurred during some previous installation.

Inspect rivets that are known to have been critically loaded, but that show no visible distortion, by drilling off the head and carefully punching out the shank. If upon examination, the shank appears joggled and the holes in the sheet misaligned, the rivet has failed in shear. In that case, determine what is causing the stress and take necessary corrective action. Countersunk rivets that show head slippage within the countersink or dimple, indicating either sheet bearing failure or rivet shear failure, must be replaced.

Joggles in removed rivet shanks indicate partial shear failure. Replace these rivets with the next larger size. Also, if the rivet holes show elongation, replace the rivets with the next larger size. Sheet failures, such as tear-outs, cracks between rivets, and the like, usually indicate damaged rivets, and the complete repair of the joint may require replacement of the rivets with the next larger size.

The presence of a black residue around the rivets is not an indication of looseness, but it is an indication of movement (fretting). The residue, which is aluminum oxide, is formed by a small amount of relative motion between the rivet and the adjacent surface. This is called fretting corrosion, or smoking, because the aluminum dust quickly forms a dark, dirty looking trail, like a smoke trail. Sometimes, the thinning of the moving pieces can propagate a crack. If a rivet is suspected of being defective, this residue may be removed with a general purpose abrasive hand pad, such as those manufactured by Scotch Brite™, and the surface inspected for signs of pitting or cracking. Although the condition indicates the component is under significant stress, it does not necessarily precipitate cracking. (***Figure 14-53***)

Airframe cracking is not necessarily caused by defective rivets. It is common practice in the industry to size rivet patterns assuming one or more of the rivets is not effective. This means that a loose rivet would not necessarily overload adjacent rivets to the point of cracking. Rivet head cracking are acceptable under the following conditions:

- The depth of the crack is less than ⅛ of the shank diameter.
- The width of the crack is less than 1⁄16 of the shank diameter.
- The length of the crack is confined to an area on the head within a circle having a maximum diameter of 1¼ times the shank diameter.
- Cracks should not intersect, which creates the potential for the loss of a portion of a head.

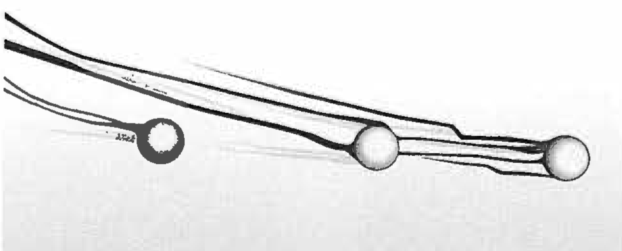


Figure 14-53. Smoking rivet.

INSPECTION FOR CORROSION

Corrosion is the gradual deterioration of metal due to a chemical or electrochemical reaction with its environment. The reaction can be triggered by the atmosphere, moisture, or other agents. When inspecting the structure of an aircraft, it is important to watch for evidence of corrosion on both the outside and inside. Corrosion on the inside is most likely to occur in pockets and corners where moisture and salt spray may accumulate; therefore, drain holes must always be kept clean. Also inspect the surrounding members for evidence of corrosion.

COMPOSITE AND NON-METALLIC

BONDING PRACTICES

Composite materials can be used to structurally repair, restore, or enhance aluminum, steel, and titanium components.

Bonded composite doublers have the ability to slow or stop fatigue crack growth, replace lost structural area due to corrosion grind-outs, and structurally enhance areas with small and negative margins. This technology has often been referred to as a combination of metal bonding and conventional on-aircraft composite bonded repair. Boron prepreg tape with an epoxy resin is most often used for this application.

Fabrication and repair using non-metallic and composite materials is thoroughly discussed in *Module 06*. Bonding practices are an integral part of both. Refer to *Module 06, Sub-Module 03* for complete information on this subject. Level 2 learning is required of B1 technicians on bonding practices.

ENVIRONMENTAL CONDITIONS

Control of the repair environment is directly related to the integrity and endurance of the repair. Cleanliness is critical. Bonded areas must be kept clean for full potential of adhesion to be realized. Precured laminates undergoing secondary bonding usually have a thin nylon or fiberglass peel ply cured onto the bonding surfaces. While the peel ply sometimes hampers nondestructive inspection of the precured laminate, it has been found to be the most effective means of ensuring surface cleanliness prior to bonding. When the peel ply is stripped away, a pristine surface becomes available. Light scuff sanding removes high resin peak impressions produced by the peel ply weave which, if they fracture, create cracks in the bond line.

Bonded repair of or with composite materials is done at room temperature or elevated temperature. Elevated temperatures are preferred with most repair methods which produce the highest quality bond. Small parts repaired off the aircraft can be placed in an autoclave or walk-in curing oven to control the repair environment. On-aircraft repairs may require the use of a heat bonder, heat lamps, hot air or heat blanket usage to elevate and maintain the proper temperature while the bonded repair cures. Thermal surveys of the area to be repaired are conducted to ascertain the heat sink effect of adjacent structures. Compensation in heating is made so that an even prescribed cure temperature can be reached and held during bond curing.

Vacuum bagging is common to remove air and volatiles from the plies of a repair layup. Pressure might also be applied if possible.

A complete discussion of the various considerations and techniques used to control the repair environment when working with composite materials is available in *Module 06, Sub-Module 03* of this series. Refer to this section for more information. Be aware that Level 2 learning is required of B1 technicians on bonding practices, environmental conditions and inspection of composite and non-metallic repairs.

INSPECTION OF COMPOSITES

Composite structures should be inspected for delamination, which is separation of the various plies, debonding of the skin from the core, and evidence of moisture and corrosion. Previously discussed methods including ultrasonic, acoustic emission, and radiographic inspections may be used as recommended by the aircraft manufacturer. The simplest method used in testing composite structures is the tap test.

TAP TESTING

Tap testing, also referred to as the ring test or coin test, is widely used as a quick evaluation of any accessible surface to detect the presence of delamination or debonding. The testing procedure consists of lightly tapping the surface with a light hammer (maximum weight of 2 ounces), a coin or other suitable device. The acoustic response or "ring" is compared to that of a known good area.

A "flat" or "dead" response indicates an area of concern. Tap testing is limited to finding defects in relatively thin skins, less than 0.080" thick. On honeycomb structures, both sides need to be tested. Tap testing on only one side would not detect debonding on the opposite side.

ELECTRICAL CONDUCTIVITY

Composite structures are not inherently electrically conductive. Some aircraft, because of their relatively low speed and type of use, are not affected by electrical issues. Manufacturers of other aircraft, such as high-speed high-performance jets, are required to utilize various methods of incorporating aluminum into their structures to make them conductive. The aluminum is embedded within the plies of the lay-ups either as a thin wire mesh, screen, foil, or spray.

When damaged sections of the structure are repaired, care must be taken to ensure that the conductive path be restored. Not only is it necessary to include the conductive material in the repair, but the continuity of the electrical path from the original conductive material to the replacement conductor and back to the original must be maintained. Electrical conductivity may be checked by use of an ohmmeter. Specific manufacturer's instructions must be carefully followed.

Question: 14-1
________________ is accomplished by either stretching or shrinking the material in a certain area to produce curves, flanges, and various irregular shapes.

Question: 14-2
In layout and forming, the length of the curved portion of the neutral line is known as the ________________.

Question: 14-3
Generally speaking, the ________________ a material is, the more sharply it can be bent (the smaller the radius of bend).

Question: 14-4
State the formula for the bend allowance of a 90° bend.

Question: 14-5
A ________________ is used to determine bend deduction or setback and the TDW of a flat pattern layout when the inside bend radius, bend angle, and material thickness are known.

Question: 14-6
________________ whose diameter is approximately twice the bend radius, relieve stresses in the metal as it is bent and prevent the metal from tearing.

Question: 14-7
An ________________ end bend is less than 90° degrees.

Question: 14-8
Curving an extruded or formed angle strip by shrinking may be accomplished by either V-block method or the ________________ block method.

ANSWERS

Answer: 14-1
Forming.

Answer: 14-2
bend allowance.

Answer: 14-3
thinner.

Answer: 14-4

$$\frac{2\pi (R + ½T)}{4}$$

Answer: 14-5
J-chart.

Answer: 14-6
Relief holes.

Answer: 14-7
open.

Answer: 14-8
shrinking.

Question: 14-9
When forming curved flanged parts, the concave flange is formed by _________________, while the convex flange is formed by _________________.

Question: 14-10
_________________ can be done on a form block or female die, or on a sandbag.

Question: 14-11
Lightening holes are cut in rib sections, fuselage frames, and other structural parts to _________________.

Question: 14-12
_________________ is 30 percent stronger than steel, but is nearly 50 percent lighter; it is 60 percent heavier than aluminum, but twice as strong.

Question: 14-13
The presence of a black residue around rivets is not an indication of looseness, but it is an indication of _________________.

Question: 14-14
_________________ testing, also referred to as the ring test or coin test, is widely used as a quick evaluation of any accessible surface to detect the presence of delamination or debonding.

ANSWERS

Answer: 14-9
stretching.
shrinking.

Answer: 14-10
Bumping.

Answer: 14-11
decrease weight.

Answer: 14-12
Titanium.

Answer: 14-13
movement (fretting).

Answer: 14-14
Tap.

MAINTENANCE PRACTICES

WELDING, BRAZING, SOLDERING AND BONDING

SUB-MODULE 15

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 15 WELDING, BRAZING, SOLDERING AND BONDING Knowledge Requirements		
7.15 - Welding, Brazing, Soldering and Bonding		
(a) Soldering methods; inspection of soldered joints.	2	2
(b) Welding and brazing methods; Inspection of welded and brazed joints; Bonding methods and inspection of bonded joints.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

BRAZING AND SOLDERING

TORCH BRAZING OF STEEL

The definition of joining two pieces of metal by brazing typically meant using brass or bronze as the filler metal which adhered to both pieces. However, that definition has been expanded to include any metal joining process in which the bonding material is a nonferrous metal or alloy with a melting point higher than 800 °F, but lower than that of the metals being joined. Brazing requires less heat than welding and can be used to join metals that may be damaged by high heat. However, because the strength of a brazed joint is not as great as that of a welded joint, brazing is not used for critical structural repairs on aircraft. Also, any metal part that is subjected to a sustained high temperature should not be brazed.

Brazing is applicable for joining a variety of metals, including brass, copper, bronze and nickel alloys, cast iron, malleable iron, wrought iron, galvanized iron and steel, carbon steel, and alloy steels. Brazing can also be used to join dissimilar metals, such as copper to steel or steel to cast iron.

When metals are joined by brazing, the base metal parts are not melted. The brazing metal adheres to the base metal by molecular attraction and inter-granular penetration; it does not fuse and amalgamate with them.

In brazing, the edges of the pieces to be joined are usually beveled as in welding steel. The surrounding surfaces must be cleaned of dirt and rust. Parts to be brazed must be securely fastened together to prevent any relative movement. The strongest brazed joint is one in which the molten filler metal is drawn in by capillary action, requiring a close fit.

A brazing flux is necessary to obtain a good union between the base metal and the filler metal. It destroys the oxides and floats them to the surface, leaving a clean metal surface free from oxidation. A brazing rod can be purchased with a flux coating already applied, or any one of the numerous fluxes available on the market for specific application may be used. Most fluxes contain a mixture of borax and boric acid.

The base metal should be preheated slowly with a neutral soft flame until it reaches the flowing temperature of the filler metal. If a filler rod that is not pre-coated with flux is used, heat about 2 inches of the rod end with the torch to a dark purple color and dip it into the flux. Enough flux adheres to the rod that it is unnecessary to spread it over the surface of the metal. Apply the flux-coated rod to the red-hot metal with a brushing motion, using the side of the rod; the brass flows freely into the steel. Keep the torch heat on the base metal to melt the filler rod. Do not melt the rod with the torch. Continue to add the rod as the brazing progresses, with a rhythmic dipping action so that the bead is built to a uniform width and height. The job should be completed rapidly and with the fewest possible passes of the rod and torch.

Notice that some metals are good conductors of heat and dissipate the heat more rapidly away from the joint. Other metals are poor conductors that tend to retain the heat and overheat readily. Controlling the temperature of the base metal is extremely important. The base metal must be hot enough for the brazing filler to flow, but never overheated to the filler boiling point. This causes the joint to be porous and brittle.

The key to even heating of the joint area is to watch the appearance of the flux. The flux should change appearance uniformly when even heat is being applied. This is especially important when joining two metals of different mass or conductivity. The brazing rod melts when applied to the red-hot base metal and runs into the joint by capillary attraction. (Note that molten brazing filler metal tends to flow toward the area of higher temperature.) In a torch heated assembly, the outer metal surfaces are slightly hotter than the interior joint surfaces. The filler metal should be deposited directly adjacent to the joint. Where possible, the heat should be applied to the assembly on the side opposite to where the filler is applied because the filler metal tends to flow toward the source of greater heat.

After the brazing is complete, the assembly or component must be cleaned. Since most brazing fluxes are water soluble, a hot water rinse (120 °F or hotter) and a wire brush remove the flux. If the flux was overheated during the brazing process, it usually turns green or black. In this case, the flux needs to be removed with a mild acid solution recommended by the manufacturer of the flux in use.

TORCH BRAZING OF ALUMINUM

Torch brazing of aluminum is done using similar methods as brazing of other materials. The brazing material itself is an aluminum/silicon alloy having a slightly lower melting temperature than the base material. Aluminum brazing occurs at temperatures over 875 °F, but below the melting point of the parent metal. This is performed with a specific aluminum brazing flux. Brazing is best suited to joint configurations that have large surface areas in contact, such as the lap, or for fitting fuel tank bungs and fittings. Either acetylene or hydrogen may be used as fuel gas, both being used for production work for many years. Using eye protection that reduces the sodium flare, such as the TM2000 lens, is recommended.

When using acetylene, the tip size is usually the same, or one size smaller than that used for welding of aluminum. A 1–2X reducing flame is used to form a slightly cooler flame, and the torch is held back at a greater distance using the outer envelope as the heat source rather than the inner cone. Prepare the flux and apply in the same manner as the aluminum welding flux, fluxing both the base metal and filler material. Heat the parts with the outer envelope of the flame, watching for the flux to begin to liquefy; the filler may be applied at that point. The filler should flow easily. If the part gets overheated, the flux turns brown or grey. If this happens, re-clean and re-flux the part before continuing. Brazing is more easily accomplished on 1100, 3003, and 6061 aluminum alloys. 5052 alloy is more difficult; proper cleaning and practice are vital. There are brazing products sold that have the flux contained in hollow spaces in the filler metal itself, which typically work only on 1100, 3003, and 6061 as the flux is not strong enough for use on 5052. Cleaning after brazing is accomplished the same as with oxy-fuel welding of aluminum, using hot water and a clean stainless brush. The flux is corrosive, so every effort should be made to remove it thoroughly and quickly after the brazing is completed.

SOLDERING

Soft solder is chiefly used to join copper and brass where a leak proof joint is desired, and sometimes for fitting joints to promote rigidity and prevent corrosion. Soft soldering is generally performed only in minor repair jobs. Soft solder is also used to join electrical connections. It forms a strong union with low electrical resistance. Soft soldering does not require the heat of an oxy-fuel gas torch and can be performed using a small propane or MAPP® torch, an electrical soldering iron, or in some cases, a soldering copper, that is heated by an outside source, such as an oven or torch. The soft solders are chiefly alloys of tin and lead. The percentages of tin and lead vary considerably in the various solders with a corresponding change in their melting points ranging from 293 °F to 592 °F. Half-and-half (50/50) is the most common general-purpose solder. It contains equal portions of tin and lead and melts at approximately 360 °F.

To get the best results for heat transfer when using an electrical soldering iron or a soldering copper, the tip must be clean and have a layer of solder on it. This is usually referred to as being tinned. The hot iron or copper should be fluxed and the solder wiped across the tip to form a bright, thin layer of solder. Flux is used with soft solder for the same reasons as with brazing. It cleans the surface area to be joined and promotes the flow by capillary action into the joint. Most fluxes should be cleaned away after the job is completed because they cause corrosion. Electrical connections should be soldered only with soft solder containing rosin. Rosin does not corrode the electrical connection.

ALUMINUM SOLDERING

The soldering of aluminum is much like the soldering of other metals. The use of special aluminum solders is required, along with the necessary flux. Aluminum soldering occurs at temperatures below 875 °F. Soldering can be accomplished using the oxy-acetylene, oxy-hydrogen, or even an air propane torch setup. A neutral flame is used in the case of either oxy-acetylene or oxy-hydrogen. Depending on the solder and flux type, most common aluminum alloys can be soldered. Being of lower melting temperature, a tip one or two sizes smaller than required for welding is used, along with a soft flame setting.

Joint configurations for aluminum soldering follow the same guidelines as any other base material. Lap joints are preferred to tee or butt joints due to the larger surface contact area. However parts, such as heat exchanger tubes, are a common exception to this.

Normally, the parts are cleaned as for welding or brazing, and the flux is applied according to manufacturer's instructions. The parts are evenly heated with the outer envelope of the flame to avoid overheating the flux, and the solder is applied in a fashion similar to that for other base metals. Cleaning after soldering may not be required to prevent oxidation because some fluxes are not corrosive. However, it is always advisable to remove all flux residues after soldering.

Aluminum soldering is commonly used in such applications as the repair of heat exchanger or radiator cores originally using a soldered joint. It is not, however, to be used as a direct replacement repair for brazing or welding.

SILVER SOLDERING

The principle use of silver solder in aircraft work is in the fabrication of high-pressure oxygen lines and other parts that must withstand vibration and high temperatures. Silver solder is used extensively to join copper and its alloys, nickel and silver, as well as various combinations of these metals and thin steel parts. Silver soldering produces joints of higher strength than those produced by other brazing processes.

Flux must be used in all silver soldering operations to ensure the base metal is chemically clean. The flux removes the film of oxide from the base metal and allows the silver solder to adhere to it.

All silver solder joints must be physically, as well as chemically, clean. The joint must be free of dirt, grease, oil, and/or paint. After removing the dirt, grease, etc., any oxide (rust and/or corrosion) should be removed by grinding or filing the piece until bright metal can be seen. During the soldering operation, the flux continues to keep the oxide away from the metal and aid in the flow of the solder.

The three recommended types of joint for silver soldering are lap, flanged, and edge. With these, the metal is formed to furnish a seam wider than the base metal thickness and provide the type of joint that holds up under all types of loads. (*Figure 15-1*)

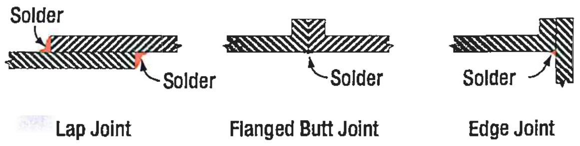


Figure 15-1. Silver solder joints.

The oxy-acetylene flame for silver soldering should be a soft neutral or slightly reducing flame. That is, a flame with a slight excess of acetylene. During both preheating and application of the solder, the tip of the inner cone of the flame should be held about ½-inch from the work. The flame should be kept moving so that the metal does not overheat.

When both parts of the base metal are at the correct temperature, the flux flows and solder can be applied directly adjacent to the edge of the seam. It is necessary to simultaneously direct the flame over the seam and keep it moving so that the base metal remains at an even temperature.

INSPECTION OF SOLDERED AND BRAZED JOINTS

Since soldered and brazed joints are not typically used in structural applications, a visual inspection is usually sufficient to determine if the joint is sound, not cracked, or formed properly. There should not be any attempt to fill gaps between the metals joined by soldering with solder or brazing rod. Solder is not as strong as the metals it joins thus joints with too much solder are inherently weak. Soldered and brazed joints should be close fitting and should be clean of any oxidation or excess material from the soldering process.

AIRCRAFT WELDING

Welding can be traced back to the Bronze Age, but it was not until the 19th century that welding as we know it today was invented. Some of the first successful commercially manufactured aircraft were constructed from welded steel tube frames.

As the technology and manufacturing processes evolved in the aircraft and aerospace industry, lighter metals, such as aluminum, magnesium, and titanium, were used in their construction. New processes and methods of welding these metals were developed. This chapter provides some of the basic information needed to understand and initiate the various welding methods and processes.

Traditionally, welding is defined as a process that joins metal by melting or hammering the work pieces until they are united together. With the right equipment and instruction, almost anyone with some basic mechanical skill, dexterity, and practice can learn to weld.

There are three general types of welding: gas, electric arc, and electric resistance. Each type of welding has several variations, some of which are used in the construction of aircraft. Additionally, there are some new welding processes that have been developed in recent years that are highlighted for the purpose of information.

This chapter addresses the welding equipment, methods, and various techniques used during the repair of aircraft and fabrication of component parts, including the processes of brazing and soldering of various metals.

TYPES OF WELDING

GAS WELDING

Gas welding is accomplished by heating the ends or edges of metal parts to a molten state with a high temperature flame. The oxy-acetylene flame, with a temperature of approximately 6 300 °Fahrenheit (F), is produced with a torch burning acetylene and mixing it with pure oxygen. Hydrogen may be used in place of acetylene for aluminum welding, but the heat output is reduced to about 4 000 °F. Gas welding was the method most commonly used in production on aircraft materials under 3⁄16-inch in thickness until the mid 1950s, when it was replaced by electric welding for economic (not engineering) reasons. Gas welding continues to be a very popular and proven method for repair operations.

Nearly all gas welding in aircraft fabrication is performed with oxy-acetylene welding equipment consisting of:

- Two cylinders, acetylene and oxygen.
- Acetylene and oxygen pressure regulators and cylinder pressure gauges.
- Two lengths of colored hose (red for acetylene and green for oxygen) with adapter connections for the regulators and torch.
- A welding torch with an internal mixing head, various size tips, and hose connections.
- Welding goggles fitted with appropriate lenses.
- A flint or spark lighter.
- Special wrench for acetylene tank valve.
- An appropriately-rated fire extinguisher.
- Safety chain for securing tanks in cart.

The equipment may be permanently installed in a shop, but most welding outfits are of the portable type. (***Figure 15-2***)

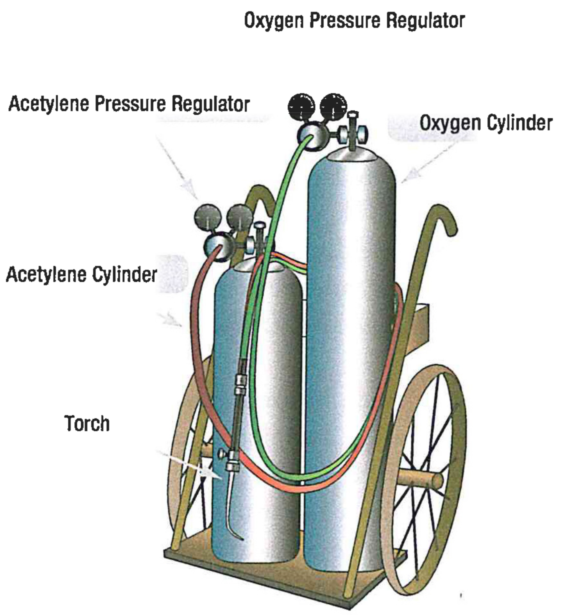


Figure 15-2. Portable oxy-acetylene welding outfit.

ELECTRIC ARC WELDING

Electric arc welding is used extensively by the aircraft industry in both the manufacture and repair of aircraft.

It can be used satisfactorily to join all weldable metals, provided that the proper processes and materials are used. The four types of electric arc welding are addressed in the following paragraphs.

SHIELDED METAL ARC WELDING (SMAW)

Shielded metal arc welding (SMAW) is the most common type of welding and is usually referred to as "stick" welding. The equipment consists of a metal wire rod coated with a welding flux that is clamped in an electrode holder that is connected by a heavy electrical cable to a low voltage and high current in either alternating current (AC) or direct current (DC),

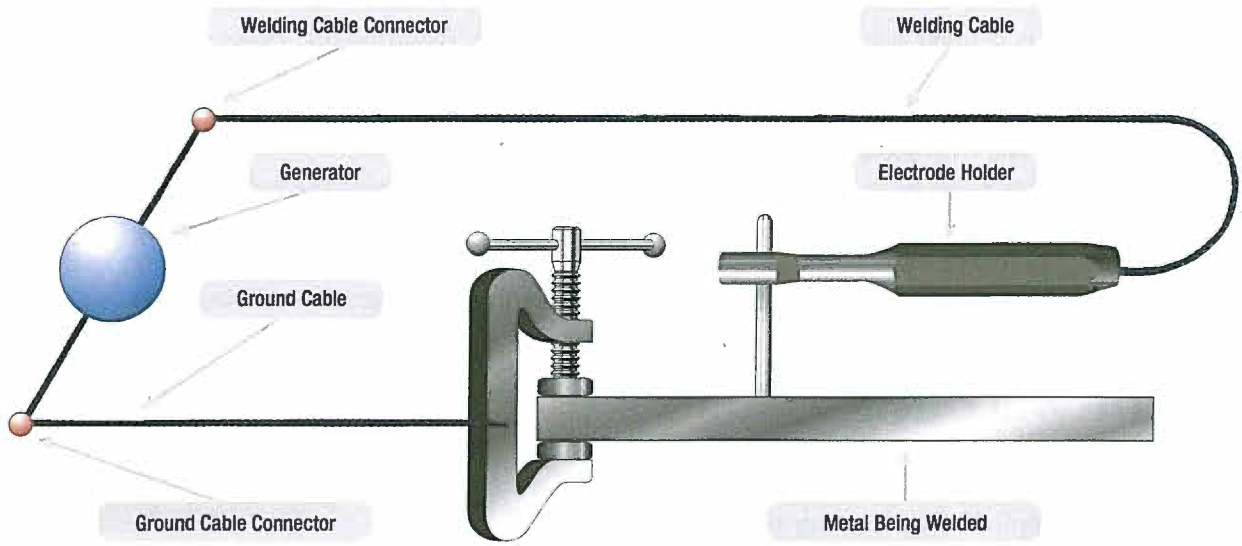


Figure 15-3. Typical arc welding circuit.

depending on the type of welding being done. An arc is struck between the rod and the work and produces heat in excess of 10 000 °F, which melts both the material and the rod. The welding circuit consists of a welding machine, two leads, an electrode holder, an electrode, and the work to be welded. (***Figure 15-3***)

When the electrode is touched to the metal to be welded, the circuit is complete and the current flows. The electrode is then withdrawn from the metal approximately ¼ inch to form an air gap between the metal and the electrode. If the correct gap is maintained, the current bridges the gap to form a sustained electric spark called the arc. This action melts the electrode and the coating of flux.


Figure 15-4. Stick welder–Shielded Metal Arc Welder (SMAW).

As the flux melts, it releases an inert gas that shields the molten puddle from oxygen in the air to prevent oxidation. The molten flux covers the weld and hardens to an airtight slag that protects the weld bead as it cools. Some aircraft manufacturers, such as Stinson, used this process for the welding of 4130 steel fuselage structures. This was followed by heat treatment in an oven to stress relieve and normalize the structure.

Shown in ***Figure 15-4*** is a typical arc welding machine with cables, ground clamp, and electrode holder.

GAS METAL ARC WELDING (GMAW)

Gas metal arc welding (GMAW) was formerly called Metal Inert Gas (MIG) welding. It is an improvement over stick welding because an uncoated wire electrode is fed into and through the torch and an inert gas, such as argon, helium, or carbon dioxide, flows out around the wire to protect the puddle from oxygen. The power supply is connected to the torch and the work, and the arc produces the intense heat needed to melt the work and the electrode. (***Figure 15-5***)

Low-voltage high-current DC is typically used with GMAW welding. ***Figure 15-6*** shows the equipment required for a typical MIG welding setup.

This method of welding can be used for large volume manufacturing and production work; it is not well suited to repair work because weld quality cannot be easily determined without destructive testing. ***Figure 15-7*** depicts a typical power source used for MIG welding.

Figure 15-5. Metal inert gas (MIG) welding process.

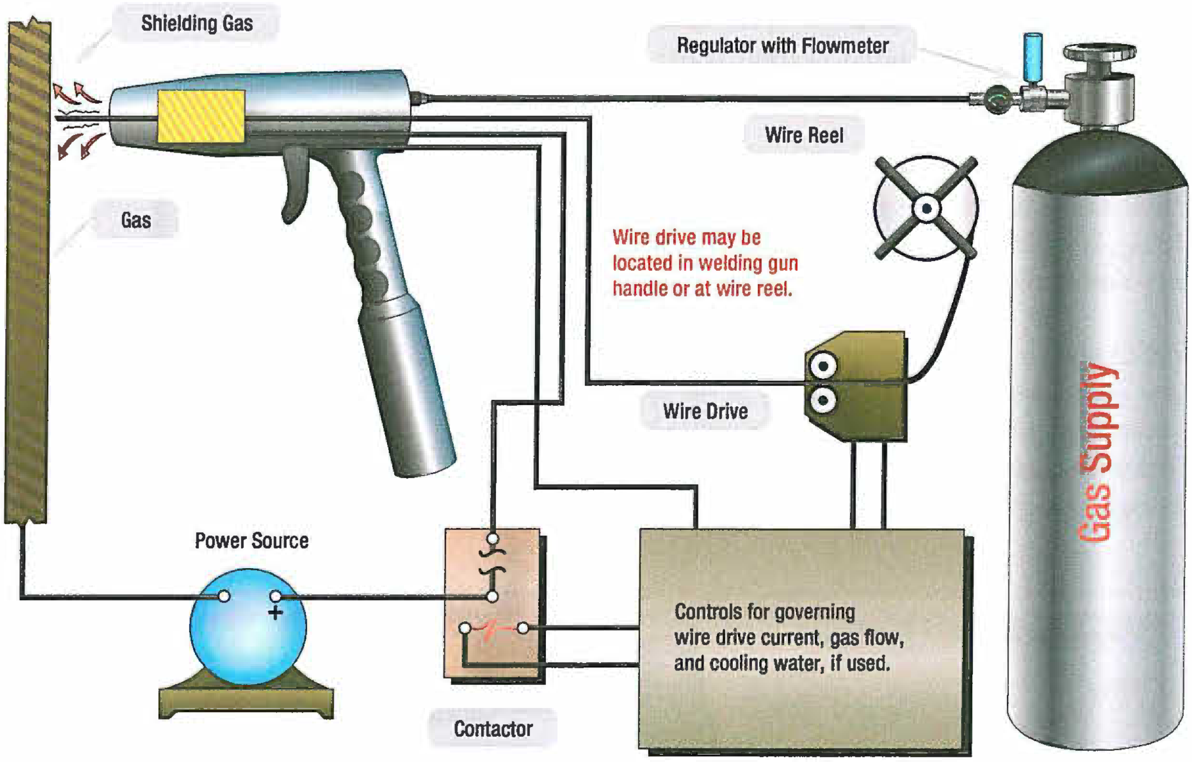


Figure 15-6. MIG welding equipment.

GAS TUNGSTEN ARC WELDING (GTAW)

Gas tungsten arc welding (GTAW) is a method of electric arc welding that fills most of the needs in aircraft maintenance and repair when proper procedures and materials are used. It is the preferred method to use on stainless steel, magnesium, and most forms of thick aluminum.

It is more commonly known as Tungsten Inert Gas (TIG) welding and by the trade names of Heliarc or Heliweld. These names were derived from the inert helium gas that was originally used. The first two methods of electric arc welding that were addressed used a consumable electrode that produced the filler for the weld.

In TIG welding, the electrode is a tungsten rod that forms the path for the high amperage arc between it and the work to melt the metal at over 5 400 °F. The electrode is not consumed and used as filler so a filler rod is manually fed into the molten puddle in almost the same manner as when using an oxy-acetylene torch. A stream of inert gas, such as argon or helium, flows out around the electrode and envelopes the arc, thereby preventing the formation of oxides in the molten puddle. (*Figure 15-8*)

The versatility of a TIG welder is increased by the choice of the power supply being used. DC of either polarity or AC may be used. (*Figure 15-9*)

- Either select the welder setting to DC straight polarity (the work being the positive and the torch being negative) when welding mild steel, stainless steel, and titanium; or
- Select AC for welding aluminum and magnesium.

Figure 15-10 is a typical power source for TIG welding along with a torch, foot operated current control, regulator for inert gas, and assorted power cables.

ELECTRIC RESISTANCE WELDING

Electric resistance welding, either spot welding or seam welding, is typically used to join thin sheet metal components during the manufacturing process.

SPOT WELDING

Two copper electrodes are held in the jaws of the spot welding machine, and the material to be welded is clamped between them. Pressure is applied to hold the electrodes tightly together and electrical current flows through the electrodes and the material. The resistance of the material being welded is so much higher than that of the copper electrodes that enough heat is generated to melt the metal. The pressure on the electrodes forces the molten spots in the two pieces of metal to unite, and

Figure 15-7. MIG welder–gas metal arc welder (GMAW).

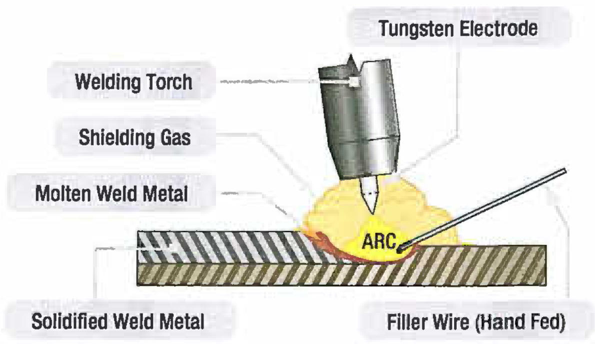


Figure 15-8. Tungsten inert gas (TIG) welding process.

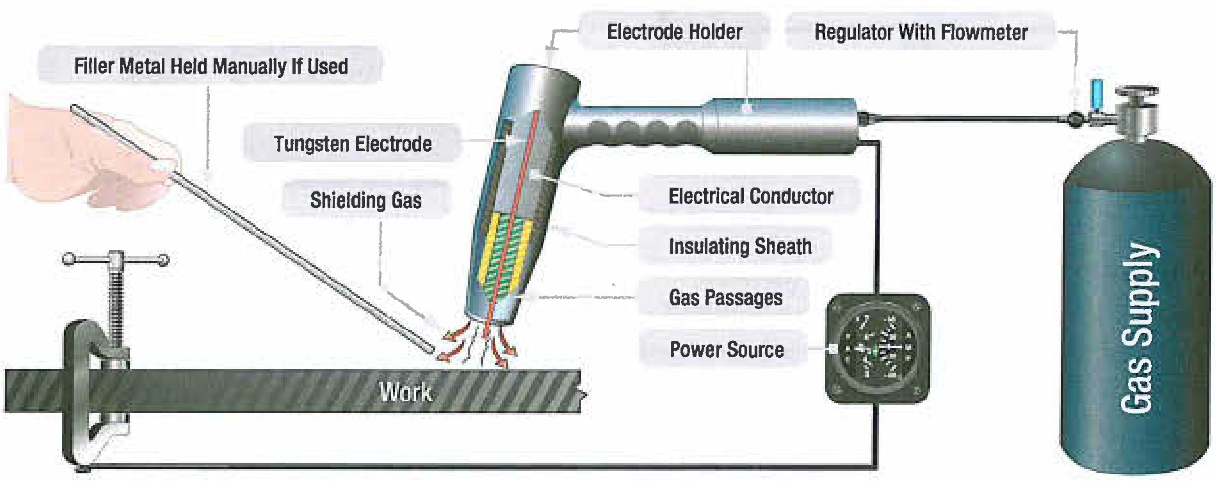


Figure 15-9. Typical setup for TIG welding.

this pressure is held after the current stops flowing long enough for the metal to solidify. The amount of current, pressure, and dwell time are all carefully controlled and matched to the type of material and the thickness to produce the correct spot welds. (***Figure 15-11***)

SEAM WELDING

Rather than having to release the electrodes and move the material to form a series of spot welds, a seam-welding machine is used to manufacture fuel tanks and other components where a continuous weld is needed. Two copper wheels replace the bar-shaped electrodes. The metal to be welded is moved between them, and electric pulses create spots of molten metal that overlap to form the continuous seam.

PLASMA ARC WELDING (PAW)

Plasma arc welding (PAW) was developed in 1964 as a method of bringing better control to the arc welding process. PAW provides an advanced level of control and accuracy using automated equipment to produce high quality welds in miniature and precision applications. Furthermore, PAW is equally suited to manual operation and can be performed by a person using skills similar to those for GTAW.

In the plasma welding torch, a non-consumable tungsten electrode is located within a fine-bore copper nozzle. A pilot arc is initiated between the torch electrode and nozzle tip. This arc is then transferred to the metal being welded. (***Figure 15-12***)

By forcing the plasma gas and arc through a constricted orifice, the torch delivers a high concentration of heat to a small area. The plasma process produces exceptionally high quality welds. (***Figure 15-13***)

Plasma gas is normally argon. The torch also uses a secondary gas, such as argon/helium or argon/nitrogen, that assists in shielding the molten weld puddle and minimizing oxidation of the weld.

Like GTAW, the PAW process can be used to weld most commercial metals, and it can be used for a wide variety of metal thicknesses. On thin material, from foil to ⅛-inch, the process is desirable because of the low heat input. The process provides relatively constant heat input because arc length variations are not very critical. On material thicknesses greater than ⅛-inch, and using

Figure 15-10. TIG welder–gas tungsten arc welder (GTAW).

Figure 15-11. Spot welding thin sheet metal.

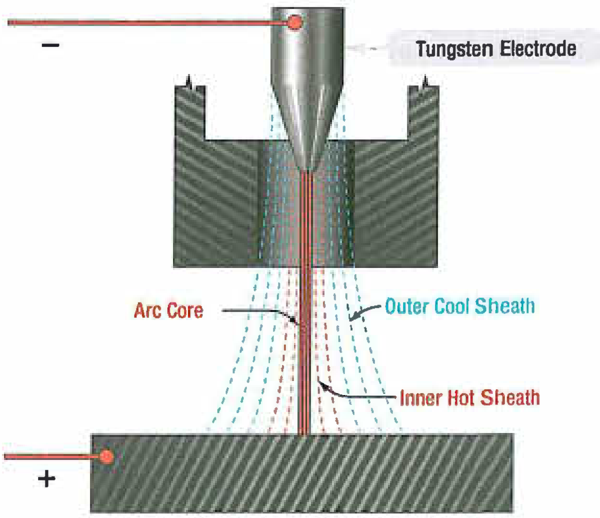


Figure 15-12. The plasma welding process.

Figure 15-13. Plasma arc.

automated equipment, a keyhole technique is often used to produce full penetration single-path welds. In the keyhole technique, the plasma completely penetrates the work piece. The molten weld metal flows to the rear of the keyhole and solidifies as the torch moves on. The high quality welds produced are characterized by deep, narrow penetration and a small weld face.

When PAW is performed manually, the process requires a high degree of welding skills similar to that required for GTAW. However, the equipment is more complex and requires a high degree of knowledge to set up and use. The equipment required for PAW includes a welding machine, a special plasma arc control system, the plasma welding torch (water-cooled), the source of plasma and shielding gas, and filler material, when required. Because of the cost associated with this equipment, this process is very limited outside of manufacturing facilities.

PLASMA ARC CUTTING

When a plasma cutting torch is used, the gas is usually compressed air. The plasma cutting machine works by constricting an electrical arc in a nozzle and forcing the ionized gas through it. This heats the gas that melts the metal which is blown away by the air pressure. By increasing air pressure and intensifying the arc with higher voltages, the cutter is capable of blasting through thicker metals and blowing away the dross with minimal cleanup.

Plasma arc systems can cut all electrically conductive metals, including aluminum and stainless steel. These two metals cannot be cut by oxy-fuel cutting systems because they have an oxide layer that prevents oxidation from occurring. Plasma cutting works well on thin metals and can successfully cut brass and copper in excess of two inches thick.

Plasma cutting machines can rapidly and precisely cut through, gouge, or pierce any electrically conductive metal without preheating. The plasma cutter produces a precise kerf (cut) width and a small heat-affected zone that prevents warping and damage.

GAS WELDING AND CUTTING EQUIPMENT

WELDING GASES

ACETYLENE

This is the primary fuel for oxy-fuel welding and cutting. It is chemically very unstable, and is stored in special cylinders designed to keep the gas dissolved. The cylinders are packed with a porous material and then saturated with acetone. When the acetylene is added to the cylinder, it dissolves. In this solution, it becomes stable. Pure acetylene stored in a free state explodes from a slight shock at 29.4 pounds per square inch (psi). The acetylene pressure gauge should never be set higher than 15 psi for welding or cutting.

ARGON

Argon is a colorless, odorless, tasteless, and nontoxic inert gas. Inert gas cannot combine with other elements. It has a very low chemical reactivity and low thermal conductivity. It is used as a gas shield for the electrode in MIG, TIG, and plasma welding equipment.

HELIUM

Helium is a colorless, odorless, tasteless, and nontoxic inert gas. Its boiling and melting points are the lowest of the elements and it normally exists only in gas form. It is used as a protective gas shield for many industrial uses including electric arc welding.

HYDROGEN

Hydrogen is a colorless, odorless, tasteless, and highly flammable gas. It can be used at a higher pressure than acetylene and is used for underwater welding and cutting. It also can be used for aluminum welding using the oxy-hydrogen process.

OXYGEN

Oxygen is a colorless, odorless, and nonflammable gas. It is used in the welding process to increase the combustion rate which increases the flame temperature of flammable gas.

PRESSURE REGULATORS

A pressure regulator is attached to a gas cylinder and is used to lower the cylinder pressure to the desired working pressure. Regulators have two gauges, one indicating the pressure in the cylinder and the second showing the working pressure. By turning the adjustment knob in or out, a spring operating a flexible diaphragm opens or closes a valve in the regulator. Turning the knob in causes the flow and pressure to increase; backing it out decreases the flow and pressure.

There are two types of regulators: single stage and two stage. They perform the same function but the two-stage regulator maintains a more constant outlet pressure and flow as the cylinder volume and pressure drops. Two-stage regulators can be identified by a larger, second pressure chamber under the regulator knob. (*Figures 5-14 and 5-15*)

Figure 15-14. Single-stage acetylene regulator. Note the maximum 15-psi working pressure. The notched groove cylinder connection nut indicates a left hand thread.

Figure 15-15. Two-stage oxygen regulator. No groove on the cylinder connection nut indicates a right hand thread.

WELDING HOSE

A welding hose connects the regulators to the torch. It is typically a double hose joined together during manufacture. The acetylene hose is red and has left hand threads indicated by a groove cut into the connection nut. The oxygen hose is green and has right hand threads indicated by the absence of a groove on the connection nut.

Welding hoses are produced in different sizes from ¼ inch to ½ inch inside diameter (ID). The hose should be marked for light, standard, and heavy duty service plus a grade indicating whether it has an oil- and/or flame-resistant cover. The hose should have the date of manufacture, maximum working pressure of 200 psi, and indicate that it meets specification IP-90 of the Rubber Manufacturers Association and the Compressed Gas Association for rubber welding hoses. Grade-R hose should only be used with acetylene gas. A T-grade hose must be used with propane, MAPP®, and all other fuel gases.

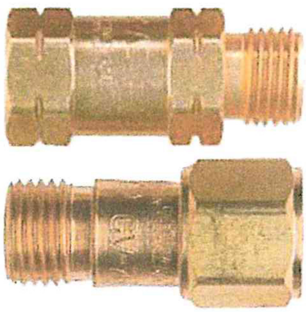


Figure 15-16. Check valves.

CHECK VALVES AND FLASHBACK ARRESTORS

The check valve stops the reverse flow of the gas and can be installed either between the regulator and the hose or the hose and the torch. (*Figure 15-16*) Excessive overheating of cutting, welding, and heating tips can cause flashback conditions. A flashback can be caused when a tip is overheated and the gas ignites before passing out of the tip. The flame is then burning internally rather than on the outside of the tip and is usually identified by a shrill hissing or squealing noise.

A flashback arrestor installed on each hose prevents a high pressure flame or oxygen-fuel mixture from being pushed back into either cylinder causing an explosion. The flashback arrestors incorporate a check valve that stops the reverse flow of gas and the advancement of a flashback fire. (*Figure 15-17*)

TORCHES

EQUAL PRESSURE TORCH

The equal pressure torch is the most commonly used torch for oxy-acetylene welding. It has a mixing chamber and uses acetylene fuel at 1-15 psi. The flame is easy to adjust and there is less chance of flashback with this torch. There are several small lightweight torches of this type that are ideal for aviation welding projects.

The Smith Airline™ and the Meco Midget™ torches are small enough to be used in close confined areas, lightweight enough to reduce fatigue during long welding sessions yet, with the appropriate tips, are capable of welding 0.250-inch steel.

INJECTOR TORCH

The injector torch uses fuel gas at pressures between just above 0 and 2 psi. This torch is typically used with propane and propylene gas. High-pressure oxygen comes through a small nozzle inside the torch head and pulls the fuel gas along with it via a venturi effect. The low-pressure injector torch is more prone to flashback.

CUTTING TORCH

The cutting torch is an attachment added to the torch handle that allows the cutting of metal. The cutting process is fundamentally the rapid burning or oxidizing of the metal in a localized area. The metal is heated to a bright red color (1 400 °F to 1 600 °F), which is the kindling temperature, using only the preheat jets. Then, a jet of high pressure oxygen released by the lever on the cutting attachment is directed against the heated metal. This oxygen blast combines with the hot metal and forms an intensely hot oxide. The molten oxide is blown down the sides of the cut, heating the metal in its path to the kindling temperature as the torch is moved along the line of the desired cut. The heated metal also burns to an oxide that is blown away on the underside of the piece. (*Figure 15-18*)

TORCH TIPS

The torch tip delivers and controls the final flow of gases. It is important that you use the correct tip with the proper gas pressures for the work to be welded satisfactorily. The size of the tip opening—not the temperature—determines the amount of heat applied to the work.

If an excessively small tip is used, the heat provided is insufficient to produce penetration to the proper depth. If the tip is too large, the heat is too great, and holes are burned in the metal. Torch tip sizes are designated by numbers. The manufacturer can provide a chart with recommended sizes for welding specific thicknesses of metal. With use, a torch tip becomes clogged with carbon deposits. If it is allowed to contact the molten pool, particles of slag may clog the tip.

This may cause a backfire, which is a momentary backward flow of the gases at the torch tip. A backfire is rarely dangerous, but molten metal may be splattered when the flame pops. Tips should be cleaned with the proper size tip cleaner to avoid enlarging the tip opening.

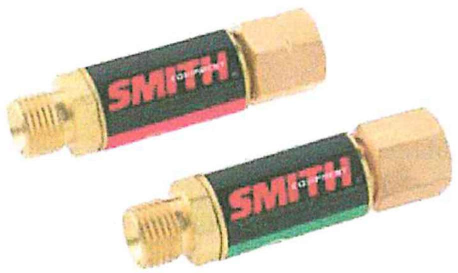


Figure 15-17. Flashback arrestors.

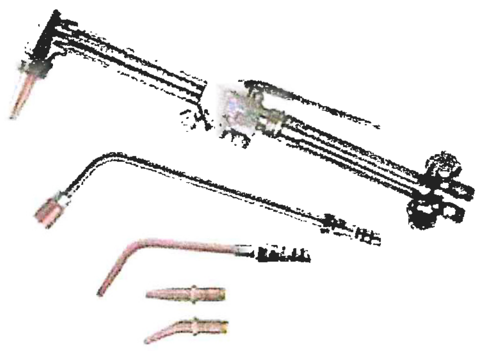


Figure 15-18. Torch handle with cutting, heating, and welding tips.

WELDING EYEWEAR

Protective eyewear for use with oxy-fuel welding outfits is available in several styles and must be worn to protect the welder's eyes from the bright flame and flying sparks. This eyewear is not for use with arc welding equipment. Some of the styles available have individual lenses and include goggles that employ a head piece and/or an elastic head strap to keep them snug around the eyes for protection from the occasional showering spark. (*Figure 15-19*)

Figure 15-19. Welding goggles.

Another popular style is the rectangular eye shield that takes a standard 2-inch by 4.25-inch lens. This style is available with an elastic strap but is far more comfortable and better fitting when attached to a proper fitting adjustable headgear. It can be worn over prescription glasses, provides protection from flying sparks, and accepts a variety of standard shade and color lenses. A clear safety glass lens is added in front of the shaded lens to protect it from damage. (*Figure 15-20*)

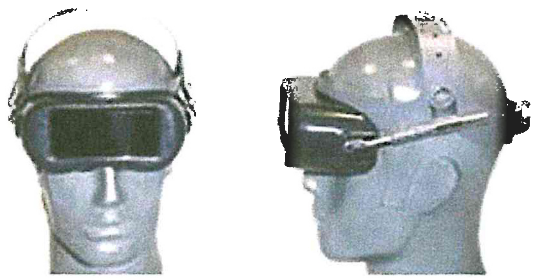


Figure 15-20. Gas welding eye shield attached to adjustable headgear.

It was standard practice in the past to select a lens shade for gas welding based on the brightness of flame emitting from the torch. The darkest shade of lens showing a clear definition of the work was normally the most desirable. However, when flux was used for brazing and welding, the torch heat caused the sodium in the flux to give off a brilliant yellow-orange flare, hiding a clear view of the weld area and causing many eye problems.

Various types of lens and colors were tried for periods of time without much success. It was not until the late 1980s that TM Technologies developed and patented a new green glass designed especially for aluminum oxy-fuel welding. It not only eliminated the sodium orange flare completely, but also provided the necessary protection from ultraviolet, infrared, and blue light to meet the requirements of the American National Standards Institute (ANSI) Z87-1989 Safety Standards for a special purpose lens. This lens can be used for welding and brazing all metals using an oxy-fuel torch.

TORCH LIGHTERS

Torch lighters are called friction lighters or flint strikers. The lighter consists of a file-shaped piece of steel, usually recessed in a cup-like device, and a replaceable flint, which, when drawn across the steel, produces a shower of sparks to light the fuel gas. An open flame or match should never be used to light a torch because accumulated gas may envelop the hand and, when ignited, cause a severe burn. (*Figure 15-21*)

FILLER ROD

The use of the proper type of filler rod is very important for oxy-acetylene welding. This material adds not only reinforcement to the weld area, but also desired properties to the finished weld. By selecting the proper rod, tensile strength or ductility can be secured in a weld. Similarly, the proper rod can help retain the desired amount of corrosion resistance. In some cases, a suitable rod with a lower melting point helps to avoid cracks caused by expansion and contraction.

Welding rods may be classified as ferrous or nonferrous. Ferrous rods include carbon and alloy steel rods, as well as cast-iron rods. Nonferrous rods include brass, aluminum, magnesium, copper, silver, and their various alloys. Welding rods are manufactured in standard 36-inch lengths and in diameters from 1⁄16-inch to 3⁄8-inch. The diameter of the rod to be used is governed by the thickness of the metals to be joined. If the rod is too small, it cannot conduct heat away from the puddle rapidly enough, and a burned hole results. A rod too large in diameter draws heat away and chills the puddle, resulting in poor penetration of the joined metal. All filler rods should be cleaned prior to use.

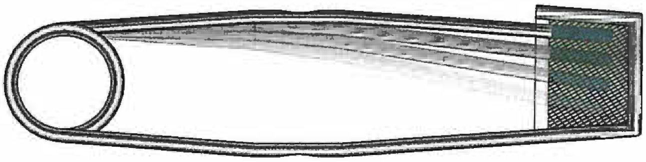


Figure 15-21. Torch lighter.

EQUIPMENT SETUP

Setting up acetylene welding equipment in preparation for welding should be accomplished in a systematic and definite order to avoid costly damage to equipment and compromising the safety of personnel.

GAS CYLINDERS

All cylinders should be stored and transported in the upright position, especially acetylene cylinders, because they contain an absorbent material saturated with liquid acetone. If the cylinder were laid on its side, allowing the acetone to enter and contaminate the regulator, hose, and torch, fuel starvation and a resultant flashback in the system could result. If an acetylene cylinder must be placed on its side for a period of time, it must be stored in the upright position for at least twice as long before being used. Gas cylinders should be secured, usually with a chain, in a permanent location or in a suitable mobile cart. The cylinder's protective steel cap should not be removed until the cylinder is put into service.

REGULATORS

Prior to installing the regulator on a gas cylinder, open the cylinder shutoff valve for an instant to blow out any foreign material that may be lodged in the outlet. Close the valve and wipe off the connection with a clean oil-free cloth. Connect the acetylene pressure regulator to the acetylene cylinder and tighten the left hand nut. Connect the oxygen pressure regulator to the oxygen cylinder and tighten the right hand nut. The connection fittings are brass and do not require a lot of torque to prevent them from leaking. At this time, check to ensure the adjusting screw on each pressure regulator is backed out by turning counterclockwise until it turns freely.

HOSES

Connect the red hose with the left hand threads to the acetylene pressure regulator and the green hose with the right hand threads to the oxygen pressure regulator. This is the location, between the regulator and hose, in which flashback arrestors should be installed. Because the fittings are brass and easily damaged, tighten only enough to prevent leakage.

Stand off to the side and away from the face of the gauges in case they blow out. Now, very slowly open the oxygen cylinder valve and read the cylinder gauge to check the contents in the tank. The oxygen cylinder shutoff valve has a double seat valve and should be opened fully against its stop to seat the valve and prevent a leak. The acetylene cylinder shutoff valve should be slowly opened just enough to get the cylinder pressure reading on the regulator and then one half of a turn more. This allows a quick shutoff, if needed.

NOTE: As a recommended safety practice, the cylinders should not be depleted in content below 20 psi. This prevents the possible reverse flow of gas from the opposite tank. Both hoses should be blown out before attaching to the torch. This is accomplished for each cylinder by turning the pressure adjusting screw in (clockwise) until the gas escapes, and then quickly backing the screw out (counterclockwise) to shut off the flow. This should be done in a well ventilated open space, free from sparks, flames, or other sources of ignition.

TORCH CONNECTION

Connect the red hose with the left hand thread connector nut to the left hand thread fitting on the torch. Connect the green hose with the right hand thread connector nut to the right hand thread fitting on the torch. Close the valves on the torch handle and check all connections for leaks, as follows:

- Turn in the adjusting screw on the oxygen pressure regulator until the working pressure indicates 10 psi. Turn in the adjusting screw on the acetylene pressure regulator until the working pressure indicates 5 psi.

- Back out adjusting screws on the regulators and verify that the working pressure remains steady. If it drops and pressure is lost, a leak is indicated between the regulator and torch.
- A general tightening of all connections should fix the leak. Repeat a check of the system.
- If a leak is still indicated by a loss in working pressure, a mixture of soapy water on all the connections reveals the source of the leak. Never check for a leak with a flame because a serious explosion could occur.

TIP SIZE SELECTION

Welding and cutting tips are available in a variety of sizes for almost any job, and are identified by number. The higher the number is, the bigger the hole in the tip is allowing more heat to be directed onto the metal and allowing thicker metal to be welded or cut.

Welding tips have one hole and cutting tips have a number of holes. The cutting tip has one large hole in the center for the cutting oxygen and a number of smaller holes around it that supply fuel, gas, and oxygen for the preheating flame. The selection of the tip size is very important, not only for the quality of the weld and/or the efficiency of the cutting process, but for the overall operation of the welding equipment and safety of the personnel using it.

Starvation occurs if torch tips are operated at less than the required volume of gas, leading to tip overheating and possible flashbacks. Incorrect tip size and obstructed tip orifices can also cause overheating and/or flashback conditions. All fuel cylinders have a limited capacity to deliver gas to the tip. That capacity is further limited by the gas contents remaining in the cylinder and the temperature of the cylinder.

The following provides some recommended procedures to guard against overheating and flashbacks:

- Refer to the manufacturer's recommendations for tip size based on the metal's thickness.
- Use the recommended gas pressure settings for the tip size being used.
- Provide the correct volume of gas as recommended for each tip size.
- Do not use an excessively long hose, one with multiple splices, or one that may be too small in diameter and restrict the flow of gas.

NOTE: Acetylene is limited to a maximum continuous withdrawal rate of one-seventh of the cylinder's rated capacity when full. For example, an acetylene cylinder that has a capacity of 330 cubic feet has a maximum withdrawal of 47 cubic feet per hour. This is determined by dividing 330 (cylinder capacity) by 7 (one-seventh of the cylinder capacity).

As a safety precaution, it is recommended that flashback arrestors be installed between the regulators and the gas supply hoses of all welding outfits. ***Figure 15-22*** shows recommended tip sizes of different manufacturers, for welding various thickness of metals.

REGULATOR WORKING PRESSURE ADJUSTMENT

The working pressure should be set according to the manufacturer's recommendation for the tip size that is being used to weld or cut. This is a recommended method that works for most welding and cutting operations.

In a well ventilated area, open the acetylene valve on the torch and turn the adjusting screw on the acetylene pressure regulator clockwise until the desired pressure is set. Close the acetylene valve on the torch. Then, set the oxygen pressure in the same manner by opening the oxygen valve on the torch and turning the adjusting screw clockwise on the oxygen regulator until desired pressure is set. Then, close the oxygen valve on the torch handle. With the working pressures set, the welding or cutting operation can be initiated.

LIGHTING AND ADJUSTING THE TORCH

With the proper working pressures set for the acetylene and oxygen, open the torch acetylene valve a quarter to a half turn. Direct the torch away from the body and ignite the acetylene gas with the flint striker. Open the acetylene valve until the black sooty smoke disappears from the flame. The pure acetylene flame is long, bushy, and has a yellowish color. Open the torch oxygen valve slowly and the flame shortens and turns to a bluish-white color that forms a bright inner luminous cone surrounded by an outer flame envelope. This is a neutral flame that should be set before either a carburizing or oxidizing flame mixture is set.

Welding Tip Size Conversion Chart									
Wire Drill	Decimal Inch	Metric Equiv. (mm)	Smiths™ AW1A	Henrob/ Dillion	Harris 15	Victor J Series	Meco N Midget™	Aluminum Thickness (in)	Steel Thickness (in)
97	0.0059	0.150						Foil	Foil
85	0.0110	0.279							
80	0.0135	0.343		#00			#00		
76	0.0200	0.508	AW200				#0		
75	0.0220	0.559		#0	#0	#000			.015
74	0.0225	0.572	AW20					.025	
73	0.0240	0.610					0.5		
72	0.0250	0.635		0.5					
71	0.0260	0.660	AW201		1				
70	0.0280	0.711				#00	1		.032
69	0.0292	0.742	AW202						
67	0.0320	0.813	AW203				1.5	.040	
66	0.0340	0.864		1					
65	0.0350	0.889			2	#0	2	.050	.046
63	0.0370	0.940	AW204				2.5		
60	0.0400	1.016				1			
59	0.0410	1.041		1.5					
58	0.0420	1.067			3		3		.062
57	0.0430	1.092	AW205						
56	0.0465	1.181	AW206			2	4	.063	
55	0.0520	1.321		2	4				.093
54	0.0550	1.397	AW207				4.5		
53	0.0595	1.511			5	3			.125
52	0.0635	1.613	AW208				5	.100	
51	0.0670	1.702			6				.187
49	0.0730	1.854	AW209	2.5		4	5.5		
48	0.0760	1.930			7			.188	.250
47	0.0780	1.981					6		
45	0.0820	2.083			8				.312
44	0.0860	2.184	AW210				6.5	.25	
43	0.0890	2.261			9	5	7		.375
42	0.0930	2.362		3					
40	0.0980	2.489			10				
36	0.1060	2.692				6			
35	0.1100	2.794			13				

Figure 15-22. Chart of recommended tip sizes for welding various thicknesses of metal.

FLAME TYPES

The three types of flame commonly used for welding are neutral, carburizing, and oxidizing. Each serves a specific purpose. (*Figure 15-23*)

NEUTRAL FLAME

The neutral flame burns at approximately 5 850 °F at the tip of the inner luminous cone and is produced by a balanced mixture of acetylene and oxygen supplied by the torch. The neutral flame is used for most welding because it does not alter the composition of the base metal. When using this flame on steel, the molten metal puddle is quiet and clear, and the metal flows to give a thoroughly fused weld without burning or sparking.

CARBURIZING FLAME

The carburizing flame burns at approximately 5 700 °F at the tip of the inner core. It is also referred to as a reducing flame because it tends to reduce the amount of oxygen in the iron oxides. The flame burns with a coarse rushing sound, and has a bluish-white inner cone, a white center cone, and a light blue outer cone.

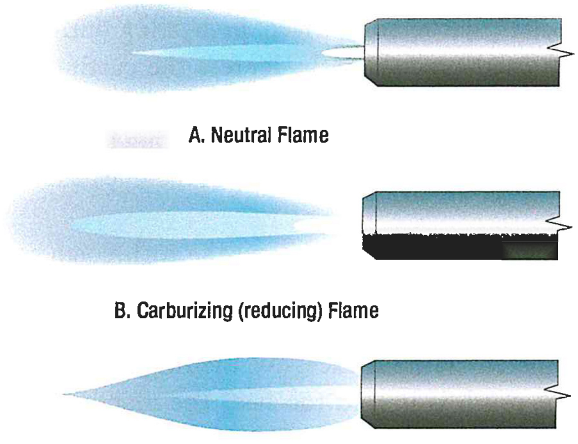


Figure 15-23. Oxy-acetylene flames.

The flame is produced by burning more acetylene than oxygen, and can be recognized by the greenish feathery tip at the end of the cone. The longer the feather, the more acetylene is in the mix. For most welding operations, the length of the feather should be about twice the length of the inner cone. The carburizing flame is best used for welding high-carbon steels, for hard facing, and for welding such nonferrous alloys as aluminum, nickel, and Monel.

OXIDIZING FLAME

The oxidizing flame burns at approximately 6 300 °F and is produced by burning an excess of oxygen. It takes about two parts of oxygen to one part acetylene to produce this flame. It can be identified by the shorter outer flame and the small, white, inner cone. To obtain this flame, start with a neutral flame and then open the oxygen valve until the inner cone is about one-tenth of its original length. The oxidizing flame makes a hissing sound, and the inner cone is somewhat pointed and purplish in color at the tip.

The oxidizing flame does have some specific uses. A slightly oxidizing flame is used for bronze welding (brazing) of steel and cast iron. A stronger oxidizing flame is used for fusion welding of brass and bronze. If an oxidizing flame is used on steel, it causes the molten metal to foam, give off sparks, and burn.

SOFT OR HARSH FLAMES

With each size of tip, a neutral, carbonizing or oxidizing flame can be obtained. It is also possible to obtain a soft or harsh flame by decreasing or increasing the working pressure of both gases (observing the maximum working pressure of 15 psi for acetylene gas).

For some work, it may be desirable to have a soft or low velocity flame without a reduction of thermal output. This can be achieved by reducing the working pressure using a larger tip and closing the torch valves until the neutral flame is quiet and steady. It is especially desirable to use a soft flame when welding aluminum to avoid blowing holes in the metal when the puddle is formed.

TORCH HANDLING

It should be cautioned that improper adjustment or handling of the torch may cause the flame to backfire or, in rare cases, to flashback. A backfire is a momentary backward flow of gases at the torch tip that causes the flame to go out. A backfire may be caused by touching the tip against the work, overheating the tip, by operating the torch at other than recommended pressures, by a loose tip or head, or by dirt or slag in the end of the tip, and may cause molten metal to be splattered when the flame pops.

A flashback is dangerous because it is the burning of gases within the torch. It is usually caused by loose connections, improper pressures, or overheating of the torch. A shrill hissing or squealing noise accompanies a flashback, and unless the gases are turned off immediately, the flame may burn back through the hose and regulators causing great damage and personal injury. The cause of the flashback should always be determined and the problem corrected before relighting the torch. All gas welding outfits should have a flashback arrestor.

OXY-ACETYLENE CUTTING

Cutting ferrous metals by the oxy-acetylene process is primarily the rapid burning or oxidizing of the metal in a localized area. This is a quick and inexpensive way to cut iron and steel where a finished edge is not required. ***Figure 15-24*** shows an example of a cutting torch. It has the conventional oxygen and acetylene valves in the torch handle that control the flow of the two gases to the cutting head. It also has an oxygen valve below the oxygen lever on the cutting head so that a finer adjustment of the flame can be obtained.

The size of the cutting tip is determined by the thickness of the metal to be cut. Set the regulators to the recommended working pressures for the cutting torch based on the tip size selected. Before beginning any cutting operation, the area should be clear of all combustible material and the proper protective equipment should be worn by personnel engaged in the cutting operation.

The flame for the torch in ***Figure 15-24*** is set by first closing the oxygen valve below the cutting lever and fully opening the oxygen valve on the handle. (This supplies the high pressure oxygen blast when the cutting lever is actuated.) The acetylene valve on the handle is then opened and the torch is lit with a striker. The acetylene flame is increased until the black soot is gone. Then, open the oxygen valve below the cutting lever and adjust the flame to neutral. If more heat is needed, open the valves to add more acetylene and oxygen. Actuate the cutting lever and readjust the preheat flame to neutral if necessary.

The metal is heated to a bright red color (1400 °F - 1600 °F, which is the kindling or ignition temperature) by the preheat orifices in the tip of the cutting torch. Then, a jet of high-pressure oxygen is directed against it by pressing the oxygen lever on the torch. This oxygen blast combines with the red-hot metal and forms an intensely hot molten oxide that is blown down the sides of the cut. As the torch is moved along the intended cut line, this action continues heating the metal in its path to the kindling temperature. The metal, thus heated, also burns to an oxide that is blown away to the underside of the piece.

Proper instruction and practice provides the knowledge and skill to become proficient in the technique needed to cut with a torch. Hold the torch in either hand, whichever is most comfortable. Use the thumb of that hand to operate the oxygen cutting lever. Use the other hand to rest the torch on and steady it along the cut line.

Begin at the edge of the metal and hold the tip perpendicular to the surface, preheating until the spot turns bright red. Lightly depress the cutting lever to allow a shower of sparks and molten metal to blow through the cut. Fully depress the cutting lever and move the torch slowly in the direction of the intended cut.

Practice and experience allow the technician to learn how to judge the speed at which to move the torch. It should be just fast enough to allow the cut to penetrate completely without excessive melting around the cut. If the torch is moved too fast, the metal will not be preheated enough, and the cutting action stops. If this happens, release the cutting lever, preheat the cut to bright red, depress the lever, and continue with the cut.

SHUTTING DOWN THE GAS WELDING EQUIPMENT

Shutting down the welding equipment is fairly simple when some basic steps are followed:

- Turn off the flame by closing the acetylene valve on the torch first. This shuts the flame off quickly. Then, close the oxygen valve on the torch handle. Also, close the oxygen valve on cutting torch, if applicable.
- If the equipment is not used in the immediate future (approximately the next 30 minutes), the valves on the acetylene and oxygen cylinders should be closed and pressure relieved from the hoses.
- In a well-ventilated area, open the acetylene valve on the torch and allow the gas to escape to the outside atmosphere, and then close the valve.
- Open the oxygen valve on the torch, allow the gas to escape, and then close the valve.
- Close both the acetylene and oxygen regulators by backing out the adjusting screw counterclockwise until loose.
- Carefully coil the hose to prevent kinking and store it to prevent damage to the torch and tip.

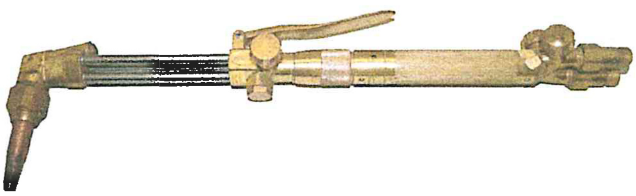


Figure 15-24. Cutting torch with additional tools.

GAS WELDING PROCEDURES AND TECHNIQUES

The material to be welded, the thickness of the metal, the type of joint, and the position of the weld dictates the procedure and technique to be used.

When light-gauge metal is welded, the torch is usually held with the hose draped over the wrist. (***Figure 15-25***) To weld heavy materials, the more common grip may provide better control of the torch. (***Figure 15-26***)

The torch should be held in the most comfortable position that allows the tip to be in line with the joint to be welded, and inclined between 30° and 60° from the perpendicular. This position preheats the edges just ahead of the molten puddle. The best angle depends on the type of weld, the amount of preheating required, and the thickness and type of metal. The thicker the metal, the more vertical the torch must be for proper heat penetration. The white cone of the flame should be held about ⅛-inch from the surface of the metal.

Welding can be performed by pointing the torch flame in the direction that the weld is progressing. This is referred to as forehand welding, and is the most commonly used method for lighter tubing and sheet metal. The filler rod is kept ahead of the tip in the direction the weld is going and is added to the puddle.

For welding thick metals or heavy plate, a technique called backhand welding can be used. In this method, the torch flame is pointed back toward the finished weld and the filler rod is added between the flame and the weld. This method provides a greater concentration of heat for welding thicker metals and would rarely be used in aircraft maintenance.

PUDDLE

If the torch is held in the correct position, a small puddle of molten metal forms. The puddle should be centered in the joint and composed of equal parts of those pieces being welded. After the puddle appears, the tip should be moved in a semicircular arc or circular motion equally between the pieces to ensure an even distribution of heat.

ADDING FILLER ROD TO THE PUDDLE

As the metal melts and the puddle forms, filler rod is needed to replace the metal that flows out from around the joint. The rod is added to the puddle in the amount that provides for the completed fillet to be built up about one-fourth the thickness of the base metal. The filler rod selected should be compatible with the base metal being welded.

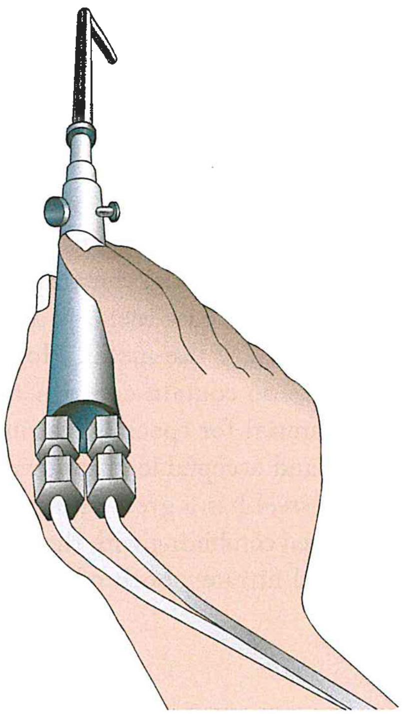


Figure 15-25. Hand position for light-gauge materials.

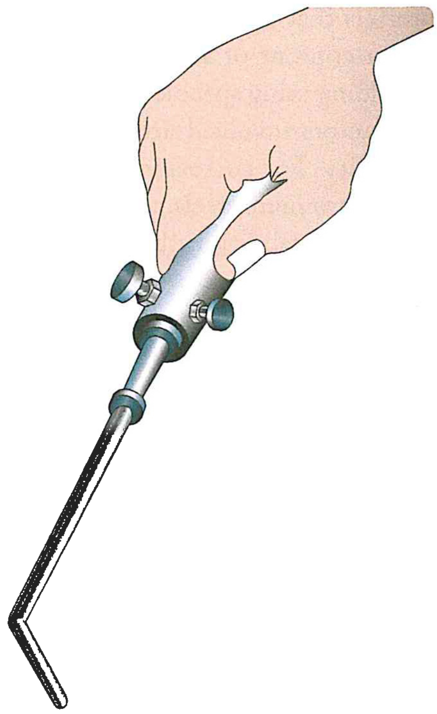


Figure 15-26. Hand position for heavy-gauge materials.

CORRECT FORMING OF A WELD

The form of the weld metal has considerable bearing upon the strength and fatigue resistance of a joint. The strength of an improperly made weld is usually less than the strength for which the joint was designed. Low-strength welds are generally the result of insufficient penetration; undercutting of the base metal at the toe of the weld; poor fusion of the weld metal with the base metal; trapped oxides, slag, or gas pockets in the weld; overlap of the weld metal on the base metal; too much or too little reinforcement; or overheating of the weld.

CHARACTERISTICS OF A GOOD WELD

A completed weld should have the following characteristics:

1. The seam should be smooth, the bead ripples evenly spaced, and of a uniform thickness.
2. The weld should be built up, slightly convex, thus providing extra thickness at the joint.
3. The weld should taper off smoothly into the base metal.
4. No oxide should be formed on the base metal close to the weld.
5. The weld should show no signs of blowholes, porosity, or projecting globules.
6. The base metal should show no signs of burns, pits, cracks, or distortion.

Although a clean, smooth weld is desirable, this characteristic does not necessarily mean that the weld is a good one; it may be dangerously weak inside. However, when a weld is rough, uneven, and pitted, it is almost always unsatisfactory inside. Welds should never be filed to give them a better appearance, since filing deprives the weld of part of its strength. Welds should never be filled with solder, brazing material, or filler of any sort.

When it is necessary to reweld a joint, all old weld material must be removed before the operation is begun. It must be remembered that reheating the area may cause the base metal to lose some of its strength and become brittle. This should not be confused with a postweld heat treatment that does not raise the metal to a high enough temperature to cause harm to the base material.

OXY-ACETYLENE WELDING OF FERROUS METALS

STEEL (INCLUDING SAE 4 130)

Low-carbon steel, low-alloy steel (e.g., 4 130), cast steel, and wrought iron are easily welded with the oxy-acetylene flame. Low-carbon and low-alloy steels are the ferrous materials that are gas welded most frequently. As the carbon content of steel increases, it may be repaired by welding using specific procedures for various alloy types. Factors involved are the carbon content and hardenability. For corrosion-resistant and heat-resistant nickel chromium steels, the allowed weldability depends upon their stability, carbon content, and reheat treatment.

The Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI) provide a designation system that is an accepted standard for the industry in the United States. SAE 4130 is an alloy steel that is an ideal material for constructing fuselages and framework on small aircraft; it is also used for motorcycle and high-end bicycle frames and race car frames and roll cages. The tubing has high tensile strength, malleability, and is easy to weld.

The number '4130' is also an AISI 4-digit code that defines the approximate chemical composition of the steel. The '41' indicates a low-alloy steel containing chromium and molybdenum (chromoly) and the '30' designates a carbon content of 0.3 percent. 4130 steel also contains small amounts of manganese, phosphorus, sulfur, and silicon, but like all steels, it contains mostly iron.

In order to make a good weld, the carbon content of the steel must not be altered to any appreciable degree, nor can other atmospheric chemical constituents be added to or subtracted from the base metal without seriously altering the properties of the metal. However, many welding filler wires do contain constituents different from the base material for specific reasons, which is perfectly normal and acceptable if approved materials are used. Molten steel has a great affinity for carbon, oxygen, and nitrogen combining with the molten puddle to form oxides and nitrates, both of which lower the strength of steel.

When welding with an oxy-acetylene flame, the inclusion of impurities can be minimized by observing the following precautions:

- Maintain an exact neutral flame for most steels and a slight excess of acetylene when welding alloys with a high nickel or chromium content, such as stainless steel.
- Maintain a soft flame and control the puddle.
- Maintain a flame sufficient to penetrate the metal and manipulate it so that the molten metal is protected from the air by the outer envelope of flame.
- Keep the hot end of the welding rod in the weld pool or within the flame envelope.
- When the weld is complete and still in the red heat, circle the outer envelope of the torch around the entire weldment to bring it evenly to a dull red. Slowly back the torch away from the weldment to ensure a slow cooling rate.

CHROME MOLYBDENUM

The welding technique for chrome molybdenum (chromemoly) is practically the same as that for carbon steels, except for sections over 3/16-inch thick. The surrounding area must be preheated to a temperature between 300 °F and 400 °F before beginning to weld. If this is not done, the sudden quenching of the weld area after the weld is complete may cause a brittle grain structure of untempered martensite that must be eliminated with post-weld heat treatments. Untempered martensite is a glass-like structure that takes the place of the normally ductile steel structure and makes the steel prone to cracking, usually near the edge of the weld. This preheating also helps to alleviate some of the distortion caused by welding along with using proper practices found in other sections of this chapter.

A soft neutral flame should be used for welding and must be maintained during the process. If the flame is not kept neutral, an oxidizing flame may cause oxide inclusions and fissures. A carburizing flame makes the metal more hardenable by raising the carbon content. The volume of the flame must be sufficient to melt the base metal, but not hot enough to overheat the base metal and cause oxide inclusions or a loss of metal thickness. The filler rod should be compatible with the base metal. If the weld requires high strength, special low alloy filler is used, and the piece is heat treated after welding. It may be advantageous to TIG weld 4130 chromemoly sections over 0.093-inch thickness followed by a proper postweld heat treatment as this can result in less overall distortion. However, do not eliminate the postweld heat treatment as doing so could severely limit the fatigue life of the weldment due to the formed martensitic grain structure.

STAINLESS STEEL

The procedure for welding stainless steel is basically the same as that for carbon steels. There are, however, some special precautions you must take to obtain the best results. Only stainless steel used for nonstructural members of aircraft can be welded satisfactorily. The stainless steel used for structural components is cold worked or cold rolled and, if heated, loses some of its strength. Nonstructural stainless steel is obtained in sheet and tubing form and is often used for exhaust collectors, stacks, or manifolds. Oxygen combines very readily with this metal in the molten state, and you must take extreme care to prevent this from occurring.

A slightly carburizing flame is recommended for welding stainless steel. The flame should be adjusted so that a feather of excess acetylene, about 1/16-inch long, forms around the inner cone. Too much acetylene, however, adds carbon to the metal and causes it to lose its resistance to corrosion. The torch tip size should be one or two sizes smaller than that prescribed for a similar gauge of low carbon steel. The smaller tip lessens the chances of overheating and subsequent loss of the corrosion-resistant qualities of the metal. To prevent the formation of chromium oxide, a specially compounded flux for stainless steel, should be used. The flux, when mixed with water, can be spread on the underside of the joint and on the filler rod. Since oxidation must be avoided as much as possible, use sufficient flux. The filler rod used should be of the same composition as the base metal.

When welding, hold the filler rod within the envelope of the torch flame so that the rod is melted in place or melted at the same time as the base metal. Add the filler rod by allowing it to flow into the molten pool. Do not stir the weld pool, because air enters the weld and increases oxidation. Avoid rewelding any portion or welding on the reverse side of the weld, which results in warping and overheating of the metal.

Another method used to keep oxygen from reaching the metal is to surround the weld with a blanket of inert gas. This is done by using a TIG welder to perform welding of stainless steel. It is a recommended method for excellent weld results and does not require the application of flux and its subsequent cleanup.

OXY-ACETYLENE WELDING OF NON-FERROUS METALS

Nonferrous metals are those that contain no iron. Examples of nonferrous metals are lead, copper, silver, magnesium, and the most important in aircraft construction, aluminum. Some of these metals are lighter than the ferrous metals, but in most cases, they are not as strong. Aluminum manufacturers have compensated for the lack of strength of pure aluminum by alloying it with other metals or by cold working it. For still greater strength, some aluminum alloys are also heat treated.

ALUMINUM WELDING

Gas welding of certain aluminum alloys can be accomplished successfully, but it requires some practice and the appropriate equipment to produce a successful weld. Before attempting to weld aluminum for the first time, become familiar with how the metal reacts under the welding flame.

A good example for practice and to see how aluminum reacts to a welding flame, heat a piece of aluminum sheet on a welding bench. Hold a torch with a neutral flame perpendicular to the sheet and bring the tip of the inner cone almost in contact with the metal. Observe that the metal suddenly melts away, almost without any indication, and leaves a hole in the metal. Now repeat the operation, only this time hold the torch at an angle of about 30° to the surface. This allows for better control of the heat and allows the surface metal to melt without forming a hole. Practice by slowly moving the flame along the surface until the puddle can be controlled without melting holes. Once that is mastered, practice on flanged joints by tacking and welding without filler rod. Then, try welding a butt joint using flux and filler rod. Practice and experience provides the visual indication of the melting aluminum so that a satisfactory weld can be performed.

Aluminum gas welding is usually confined to material between 0.031-inch and 0.125-inch in thickness. The weldable aluminum alloys used in aircraft construction are 1100, 3003, 4043, and 5052. Alloy numbers 6053, 6061, and 6151 can also be welded, but since these alloys are in the heat-treated condition, welding should not be done unless the parts can be reheat treated.

Proper preparation prior to welding any metal is essential to produce a satisfactory weld. This preparation is especially critical during oxy-acetylene welding of aluminum. Select the proper torch tip for the thickness of metal being welded. Tip selection for aluminum is always one size larger than one would normally choose for the same thickness in a steel sheet. A rule of thumb: ¾ metal thickness = tip orifice.

Set the proper regulator pressure using the following method for oxy-acetylene welding of aluminum. This method has been used by all aircraft factories since World War II. Start by slowly opening the valve on the oxygen cylinder all the way until it stops to seat the upper packing. Now, barely crack open the acetylene cylinder valve until the needle on the gauge jumps up, then open one-quarter turn more. Check the regulators to ensure the adjusting screws are turned counterclockwise all the way out and loose. Now, open both torch valves wide open, about two full turns (varies with the torch model).

Turn the acetylene regulator by adjusting the screw until the torch blows a light puff at a two-inch distance. Now, hold the torch away from the body and light it with the striker, adjusting the flame to a bright yellow bushy flame with the regulator screw. Add oxygen by slowly turning in the oxygen regulator screw to get a loud blue flame with a bright inner cone, perhaps a bit of the "fuel-rich" feather or carburizing secondary cone. By alternately turning in each of the torch valves a little bit, the flame setting can be lowered to what is needed to either tack or weld.

Special safety eyewear must also be used to protect the welder and provide a clear view through the yellow-orange flare given off by the incandescing flux. Special purpose green-glass lens have been designed and patented especially for aluminum oxy-fuel welding by TM Technologies. These lenses cut the sodium orange flare completely and provide the necessary protection from ultraviolet, infrared, blue light, and impact. They meet safety standard ANSI Z87-1989 for a special-purpose lens.

Apply flux either to the material, the filler, or both if needed. The aluminum welding flux is a white powder mixed one part powder to two parts clean spring or mineral water. (Do not use distilled water.) Mix a paste that can be brushed on the metal. Heating the filler or the part with the torch before applying the flux helps the flux dry quickly and not pop off when the torch heat approaches. Proper safety precautions, such as eye protection, adequate ventilation, and avoiding the fumes, are recommended.

The material to be welded must be free of oil or grease. It should be cleaned with a solvent; the best being denatured isopropyl (rubbing) alcohol. A stainless toothbrush should be used to scrub off the invisible aluminum oxide film just prior to welding, but after cleaning with alcohol.

Always clean the filler rod or filler wire prior to use with alcohol and a clean cloth. Make the best possible fit-up for joints to avoid large gaps and select the appropriate filler metal that is compatible with the base metal. The filler should not be a larger diameter than the pieces to be welded. (*Figure 15-27*)

Begin by tacking the pieces. The tacks should be applied 1-1½ inches apart. Tacks are done hot and fast by melting the edges of the metal together, if they are touching, or by adding filler to the melting edges when there is a gap. Tacking requires a hotter flame than welding. So, if the thickness of the metal being welded is known, set the length of the inner cone of the flame roughly three to four metal thicknesses in length for tacking. (Example: .063 aluminum sheet = 3⁄16-¼ inch inner cone.)

Once the edges are tacked, begin welding by either starting at the second tack and continuing on, or starting the weld one inch in from the end and then welding back to the edge of the sheet. Allow this initial skip-weld to chill and solidify. Then, begin to weld from the previous starting point and continue all the way to the end. Decrease the heat at the end of the seam to allow the accumulated heat to dissipate. The last inch or so is tricky and must be dabbed to prevent blow-through. (Dabbing is the adding of filler metal in the molten pool while controlling the heat on the metal by raising and lowering the torch.) Weld bead appearance, or making ringlets, is caused by the movement of the torch and dabbing the filler metal. If the torch and add filler metal is moved at the same time, the ringlet is more pronounced. A good weld has a bead that is not too proud and has penetration that is complete.

Immediately after welding, the flux must be cleaned by using hot (180 °F) water and the stainless steel brush, followed by liberal rinsing with fresh water. If only the filler was fluxed, the amount of cleanup is minimal. All flux residues must be removed from voids and pinholes. If any particular area is suspect to hidden flux, pass a neutral flame over it and a yellow-orange incandescence will betray hiding residues. Proper scrubbing with an

Filler Metal Selection Chart

Base Metals	1100 3003	5005	5052	5086 DO NOT GAS WELD	6061
6061	4043 (a) 4047	4043 (a) 5183 5356 5556 5554 (d) 5654 (c)	5356 5183 5554 5556 5654 (d) 4043 (a)	5356 5183 5356 5556 5654 (c)	4043 (a) 4047 5556 5183 5554 (d)
5086 DO NOT GAS WELD	5356 4043 (a)	5356 5183 5556	5356 5183 5556	5356 5183 5556	
5052	5183 5356 5556 4043 (a,b)	4043 (a) 5183 5356 5556 4047	5654 (c) 5183 5356 5556 5554 (d) 4043 (a)		
5005	5183 5356 5556 4043 (a,b)	5183 5356 4043 (a,b)			
1100 3003	1110 4043 (a)				

For explanation of (a. b. c. d) see below

(a) 4043, because of its Si content, is less susceptible to hot cracking but has less ductility and may crack when planished.
(b) For applications at sustained temperatures above ISOF because of intergranular corrosion.
(c) Low temperature service at ISOF and below.
(d) 5554 is suitable for elevated temperatures.

NOTE: When choosing between 5356, 5183, 5556, be aware that 5356 is the weakest and 5556 is the strongest, with 5183 in between. Also, 4047 has more Si than 4043, therefore less sensitivity to hot cracking, slightly higher weld shear strength, and less ductility.

Figure 15-27. Filler metal selection chart.

etching solution and waiting no longer than 20 minutes to prime and seal avoids the lifting, peeling, or blistering of the finished topcoat.

MAGNESIUM WELDING

Gas welding of magnesium is very similar to welding aluminum using the same equipment. Joint design also follows similar practice to aluminum welding. Care must be taken to avoid designs that may trap flux after the welding is completed, with butt and edge welds being preferred. Of special interest is the high expansion rate of magnesium-based alloys, and the special attention that must be given to avoid stresses being set up in the parts. Rigid fixtures should be avoided; use careful planning to eliminate distortion.

In most cases, filler material should match the base material in alloy. When welding two different magnesium alloys together, the material manufacturer should be consulted for recommendations. Aluminum should never be welded to magnesium. As in aluminum welding, a flux is required to break down the surface oxides and ensure a sound weld. Fluxes sold specifically for the purpose of fusion welding magnesium are available in powder form and are mixed with water in the same manner as for aluminum welding. Use the minimum amount of flux necessary to reduce the corrosive effects and cleaning time required after the weld is finished. The sodium-flare reducing eye protection used for aluminum welding is of the same benefit on magnesium welding.

Welding is done with a neutral flame setting using the same tip size for aluminum welding. The welding technique follows the same pattern as aluminum with the welding being completed in a single pass on sheet gauge material. Generally, the TIG process has replaced gas welding of magnesium due to the elimination of the corrosive flux and its inherent limitations on joint design.

GAS METAL ARC WELDING (TIG WELDING)

The TIG process as it is known today is a combination of the work done by General Electric in the 1920s to develop the basic process, the work done by Northrop in the 1940s to develop the torch itself, and the use of helium shielding gas and a tungsten electrode. The process was developed for welding magnesium in the Northrop XP-56 flying wing to eliminate the corrosion and porosity issues with the atomic hydrogen process they had been using with a boron flux. It was not readily used on other materials until the late 1950s when it found merit in welding space-age super alloys. It was also later used on other metals, such as aluminum and steel, to a much greater degree.

Modern TIG welding machines are offered in DC, AC, or with AC/DC configurations, and use either transformer or inverter-based technology. Typically, a machine capable of AC output is required for aluminum. The TIG torch itself has changed little since the first Northrop patent. TIG welding is similar to oxy-fuel welding in that the heat source (torch) is manipulated with one hand, and the filler, if used, is manipulated with the other. A distinct difference is to control the heat input to the metal. The heat control may be preset and fixed by a machine setting or variable by use of a foot pedal or torch mounted control.

Several types of tungsten electrode are used with the TIG welder. Thoriated and zirconiated electrodes have better electron emission characteristics than pure tungsten, making them more suitable for DC operations on transformer-based machines, or either AC or DC with the newer inverter-based machines. Pure tungsten provides a better current balance with AC welding with a transformer based machine, which is advantageous when welding aluminum and magnesium. The equipment manufacturers' suggestions for tungsten type and form should be followed as this is an ever changing part of the TIG technology.

The shape of the electrode used in the TIG welding torch is an important factor in the quality and penetration of the weld. The tip of the electrode should be shaped on a dedicated grinding stone or a special-purpose tungsten grinder to avoid contaminating the electrode. The grinding should be done longitudinally, not radially, with the direction of stone travel away from the tip. ***Figure 15-28*** shows the effects of a sharp versus blunt electrode with transformer-based machines.

When in doubt, consult the machine manufacturer for the latest up-to-date suggestions on tungsten preparation or if problems arise.

Sharper Electrode	Blunter Electrode
Easy Arc Starting	Usually Harder To Start The Arc
Handles Less Amperage	Handles More Amperage
Wider Arc Shape	Narrower Arc Shape
Good Arc Stability	Potential For Arc Wander
Less Weld Penetration	Better Weld Penetration
Shorter Electrode Life	Longer Electrode Life

Figure 15-28. Effects of sharp and blunt electrodes.

The general guidelines for weld quality, joint fit prior to welding, jigging, and controlling warp all apply to this process in the same regard as any other welding method. Of particular note are the additional process steps that sometimes must be taken to perform a quality weld; these are dealt within their appropriate sections.

TIG WELDING 4130 STEEL TUBING

Welding 4130 with TIG is not much different than welding other steels as far as technique is concerned. The following information generally addresses material under 0.120-inch thick.

Clean the steel of any oil or grease and use a stainless steel wire brush to clean the work piece prior to welding. This is to prevent porosity and hydrogen embrittlement during the welding process. The TIG process is highly susceptible to these problems, much more so than oxy-acetylene welding, so care must be taken to ensure all oils and paint are removed from all surfaces of the parts to be welded.

Use a TIG welder with high-frequency starting to eliminate arc strikes. Do not weld where there is any breeze or draft; the welds should be allowed to cool slowly. Preheating is not necessary for tubing of less than 0.120-inch wall thickness; however, postweld tempering (stress relieving) is still recommended to prevent the possible brittleness of the area surrounding the weld due to the untempered martensite formations caused by the rapid cooling of the weld inherent to the TIG process.

If you use 4130 filler rod, preheat the work before welding and heat treat afterward to avoid cracking. In a critical situation such as this, engineering should be done to determine preheat and postweld heat treatment needed for the particular application.

Weld at a slower speed, make sufficiently large fillets, and make them flat or slightly convex, not concave. After the welding is complete, allow the weldment to cool to room temperature. Using an oxy-acetylene torch set to a neutral flame, heat the entire weldment evenly to 1 100 °F-1 200 °F; hold this temperature for about 45 minutes per inch of metal thickness. The temperature is generally accepted to be a dull red in ambient lighting. Note that for most tubing sections, the temperature needs to be held for only a minute or two. This process is found in most materials engineering handbooks written by The American Society for Materials (ASM) and other engineering sources. When working on a critical component, seek engineering help if there is any doubt.

TIG WELDING STAINLESS STEEL

Stainless steels, or more precisely, corrosion-resisting steels, are a family of iron-based metals that contain chromium in amounts ranging from 10 percent to about 30 percent. Nickel is added to some of the stainless steels, which reduces the thermal conductivity and decreases the electrical conductivity. The chromium-nickel steels belong in the AISI 300 series of stainless steels. They are nonmagnetic and have austenitic microstructure. These steels are used extensively in aircraft in which strength or resistance to corrosion at high temperature is required.

All of the austenitic stainless steels are weldable with most welding processes, with the exception of AISI 303, which contains high sulfur, and AISI 303Se, which contains selenium to improve its machinability.

The austenitic stainless steels are slightly more difficult to weld than mild-carbon steel. They have lower melting temperatures, and a lower coefficient of thermal conductivity, so welding current can be lower. This helps on thinner materials because these stainless steels have a higher coefficient of thermal expansion, requiring special precautions and procedures to be used to reduce warping and distortion. Any of the distortion-reducing techniques, such as skip welding or back-step welding, should be used. Fixtures and/or jigs should be used where possible. Tack welds should be applied twice as often as normal.

The selection of the filler metal alloy for welding the stainless steel is based on the composition of the base metal. Filler metal alloys for welding austenitic type stainless include AISI No. 309, 310, 316, 317, and 347. It is possible to weld several different stainless base metals with the same filler metal alloy. Follow the manufacturer's recommendations.

Clean the base metal just prior to welding to prevent the formation of oxides. Clean the surface and joint edges with a non-chlorinated solvent, and brush with a stainless steel wire brush to remove the oxides. Clean the filler material in the same manner.

To form a weld bead, move the torch along the joint at a steady speed using the forehand method. Dip the filler metal into the center of the weld puddle to ensure adequate shielding from the gas.

The base metal needs protection during the welding process by either an inert gas shield, or a backing flux, on both sides of the weld. Back purging uses a separate supply of shielding gas to purge the backside of the weld of any ambient air. Normally, this requires sealing off the tubular structures or using other various forms of shields and tapes to contain the shielding gas. A special flux may also be used on the inside of tubular structures in place of a back purge. This is especially advantageous with exhaust system repairs in which sealing off the entire system is time consuming. The flux is the same as is used for the oxy-acetylene welding process on stainless materials.

TIG WELDING ALUMINUM

TIG welding of aluminum uses similar techniques and filler materials as oxy-fuel welding. Consult with the particular welding machine manufacturer for recommendations on tungsten type and size, as well as basic machine settings for a particular weldment because this varies with specific machine types. Typically, the machine is set to an AC output waveform because it causes a cleaning action that breaks up surface oxides. Argon or helium shielding gas may be used, but argon is preferred because it uses less by volume than helium. Argon is a heavier gas than helium, providing better cover, and it provides a better cleaning action when welding aluminum.

Filler metal selection is the same as used with the oxy-fuel process; however, the use of a flux is not needed as the shielding gas prevents the formation of aluminum oxide on the surface of the weld pool, and the AC waveform breaks up any oxides already on the material. Cleaning of the base metal and filler follows the same guidelines as for oxy-fuel welding. When welding tanks of any kind, it is a good practice to back-purge the inside of the tank with a shielding gas. This promotes a sound weld with a smooth inner bead profile that can help lessen pinhole leaks and future fatigue failures.

Welding is done with similar torch and filler metal angles as in oxy-fuel welding. The tip on the tungsten is held a short distance (1⁄16 - 1⁄8 inch) from the surface of the material, taking care not to ever let the molten pool contact the tungsten and contaminate it. Contamination of the tungsten must be dealt with by removal of the aluminum from the tungsten and regrinding the tip to the factory recommended profile.

TIG WELDING MAGNESIUM

Magnesium alloys can be welded successfully using the same type joints and preparation that are used for steel or aluminum. However, because of its high thermal conductivity and coefficient of thermal expansion, which combine to cause severe stresses, distortion, and cracking, extra precautions must be taken. Parts must be clamped in a fixture or jig. Smaller welding beads, faster welding speed, and the use of a lower melting point and lower shrinkage filler rods are recommended.

DC, both straight or reverse polarity, and AC, with superimposed high frequency for arc stabilization, are commonly used for welding magnesium. DC reverse polarity provides better cleaning action of the metal and is preferred for manual welding operations.

AC power sources should be equipped with a primary contactor operated by a control switch on the torch or a foot control for starting or stopping the arc. Otherwise, the arcing that occurs while the electrode approaches or draws away from the work piece may result in burned spots on the work. Argon is the most commonly used shielding gas for manual welding operations. Helium is the preferred gas for automated welding because it produces a more stable arc than argon and permits the use of slightly longer arc lengths. Zirconiated, thoriated, and pure tungsten electrodes are used for TIG welding magnesium alloys.

The welding technique for magnesium is similar to that used for other non-ferrous metals. The arc should be maintained at about ⁵⁄₁₆ inch. Tack welds should be used to maintain fit and prevent distortion. To prevent weld cracking, weld from the middle of a joint towards the end, and use starting and run off plates to start and end the weld. Minimize the number of stops during welding. After a stop, the weld should be restarted about ½-inch from the end of the previous weld. When possible, make the weld in one uninterrupted pass.

TIG WELDING TITANIUM

The techniques for welding titanium are similar to those required for nickel-based alloys and stainless steels. To produce a satisfactory weld, emphasis is placed on the surface cleanliness and the use of inert gas to shield the weld area. A clean environment is one of the requirements to weld titanium.

TIG welding of titanium is performed using DC straight polarity. A water-cooled torch, equipped with a ¾-inch ceramic cup and a gas lens, is recommended. The gas lens provides a uniform, non-turbulent inert gas flow. Thoriated tungsten electrodes are recommended for TIG welding of titanium. The smallest diameter electrode that can carry the required current should be used. A remote contactor controlled by the operator should be employed to allow the arc to be broken without removing the torch from the cooling weld metal, allowing the shielding gas to cover the weld until the temperature drops.

Most titanium welding is performed in an open fabrication shop. Chamber welding is still in use on a limited basis, but field welding is common. A separate area should be set aside and isolated from any dirt producing operations, such as grinding or painting. Additionally, the welding area should be free of air drafts and the humidity should be controlled.

Molten titanium weld metal must be totally shielded from contamination by air. Molten titanium reacts readily with oxygen, nitrogen, and hydrogen; exposure to these elements in air or in surface contaminants during welding can adversely affect titanium weld properties and cause weld embrittlement. Argon is preferred for manual welding because of better arc stability characteristics.

Helium is used in automated welding and when heavier base metals or deeper penetration is required.

Care must be taken to ensure that the heat affected zones and the root side of the titanium welds are shielded until the weld metal temperature drops below 800 °F. This can be accomplished using shielding gas in three separate gas streams during welding.

1. The first shielding of the molten puddle and adjacent surfaces is provided by the flow of gas through the torch. Manufacturer recommendations should be followed for electrodes, tip grinding, cup size, and gas flow rates.
2. The secondary, or trailing, shield of gas protects the solidified weld metal and the heat affected zone until the temperature drops. Trailing shields are custom-made to fit a specific torch and a particular welding operation.
3. The third, or backup, flow is provided by a shielding device that can take many forms. On straight seam welds, it may be a grooved copper backing bar clamped behind the seam allowing the gas flow in the groove and serving as a heat sink. Irregular areas may be enclosed with aluminum tents taped to the backside of welds and purged with the inert gas.

Titanium weld joints are similar to those employed with other metals. Before welding, the weld joint surfaces must be cleaned and remain free of any contamination during the welding operation. Detergent cleaners and non-chlorinated cleaners, such as denatured isopropyl alcohol, may be used. The same requirements apply to the filler rod, it too must be cleaned and free of all contaminates. Welding gloves, especially the one holding the filler, must be contaminate free.

A good indication and measure of weld quality for titanium is the weld color. A bright silver weld indicates that the shielding is satisfactory and the heat affected zone and backup was properly purged until weld temperatures dropped. Straw-colored films indicate slight contamination, unlikely to affect mechanical properties; dark blue films or white powdery oxide on the weld would indicate a seriously deficient purge. A weld in that condition must be completely removed and rewelded.

ARC WELDING PROCEDURES, TECHNIQUES, AND WELDING SAFETY EQUIPMENT

Arc welding, also referred to as stick welding, has been performed successfully on almost all types of metals. This section addresses the procedures as they may apply to fusion welding of steel plate and provides the basic steps and procedures required to produce an acceptable arc weld. Additional instruction and information pertaining to arc welding of other metals can be obtained from training institutions and the various manufacturers of the welding equipment.

The first step in preparing to arc weld is to make certain that the necessary equipment is available and that the welding machine is properly connected and in good working order. Particular attention should be given to the ground connection, since a poor connection results in a fluctuating arc, that is difficult to control.

When using a shielded electrode, the bare end of the electrode should be clamped in its holder at a 90° angle to the flaws. (Some holders allow the electrode to be inserted at a 45° angle when needed for various welding positions.) Before starting to weld, the following typical list of items should be checked:

- Is the proper personal safety equipment being used, including a welding helmet, welding gloves, protective clothing, and footwear; if not, in an adequately ventilated area, appropriate breathing equipment?
- Has the ground connection been properly made to the work piece and is it making a good connection?
- Has the proper type and size electrode been selected for the job?
- Is the electrode properly secured in the holder?
- Does the polarity of the machine coincide with that of the electrode?
- Is the machine in good working order and is it adjusted to provide the necessary current for the job?

The welding arc is established by touching the base metal plate with the electrode and immediately withdrawing it a short distance. At the instant the electrode touches the plate, a rush of current flows through the point of contact. As the electrode is withdrawn, an electric arc is formed, melting a spot on the plate and at the end of the electrode.

Correctly striking an arc takes practice. The main difficulty in confronting a beginner in striking the arc is sticking the electrode to the work. If the electrode is not withdrawn promptly upon contact with the metal, the high amperage flows through the electrode causing it to stick or freeze to the plate and practically short circuits the welding machine.

A quick roll of the wrist, either right or left, usually breaks the electrode loose from the work piece. If that does not work, quickly unclamp the holder from the electrode, and turn off the machine. A small chisel and hammer frees the electrode from the metal so it can be regripped in the holder. The welding machine can then be turned back on.

There are two essentially similar methods of striking the arc. One is the tough or tapping method. When using this method, the electrode should be held in a vertical position and lowered until it is an inch or so above the point where the arc is to be struck. Then, the electrode is lightly tapped on the work piece and immediately lifted to form an arc approximately ¼ inch in length. (***Figure 15-29***)

The second (and usually easier to master) is a scratch or sweeping method. To strike the arc by the scratch method, the electrode is held just above the plate at an angle of 20°-25°. The arc should be struck by sweeping the electrode with a wrist motion and lightly scratching the plate. The electrode is then lifted immediately to form an arc. (***Figure 15-30***)

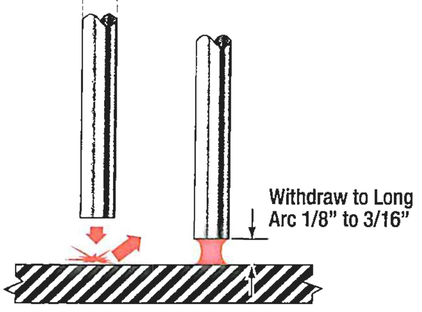


Figure 15-29. Touch method of starting an arc.

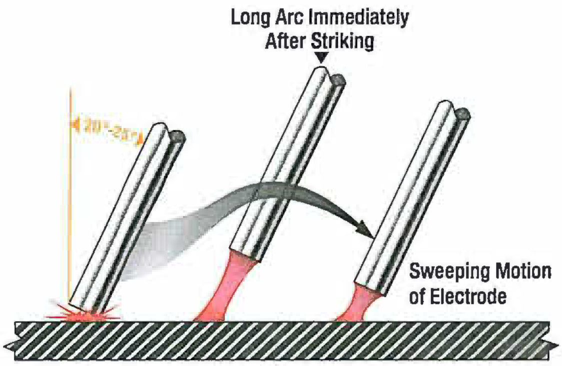


Figure 15-30. Scratch/sweeping method of starting the arc.

Either method takes some practice, but with time and experience, it becomes easy. The key is to raise the electrode quickly, but only about ¼ inch from the base or the arc is lost. If it is raised too slowly, the electrode sticks to the plate. To form a uniform bead, the electrode must be moved along the plate at a constant speed in addition to the downward feed of the electrode. If the rate of advance is too slow, a wide overlapping bead forms with no fusion at the edges.

If the rate is too fast, the bead is too narrow and has little or no fusion at the plate. The proper length of the arc cannot be judged by looking at it. Instead, depend on the sound that the short arc makes.
This is a sharp cracking sound, and it should be heard during the time the arc is being moved down to and along the surface of the plate.

A good weld bead on a flat plate should have the following characteristics:
- Little or no splatter on the surface of the plate.
- An arc crater in the bead of approximately 1⁄16 inch when the arc has been broken.
- The bead should be built up slightly, without metal overlap at the top surface.
- The bead should have a good penetration of approximately 1⁄16 inch into the base metal.

Figure 15-31 provides examples of operator's technique and welding machine settings.

When advancing the electrode, it should be held at an angle of about 20° to 25° in the direction of travel moving away from the finished bead.(***Figure 15-32***)

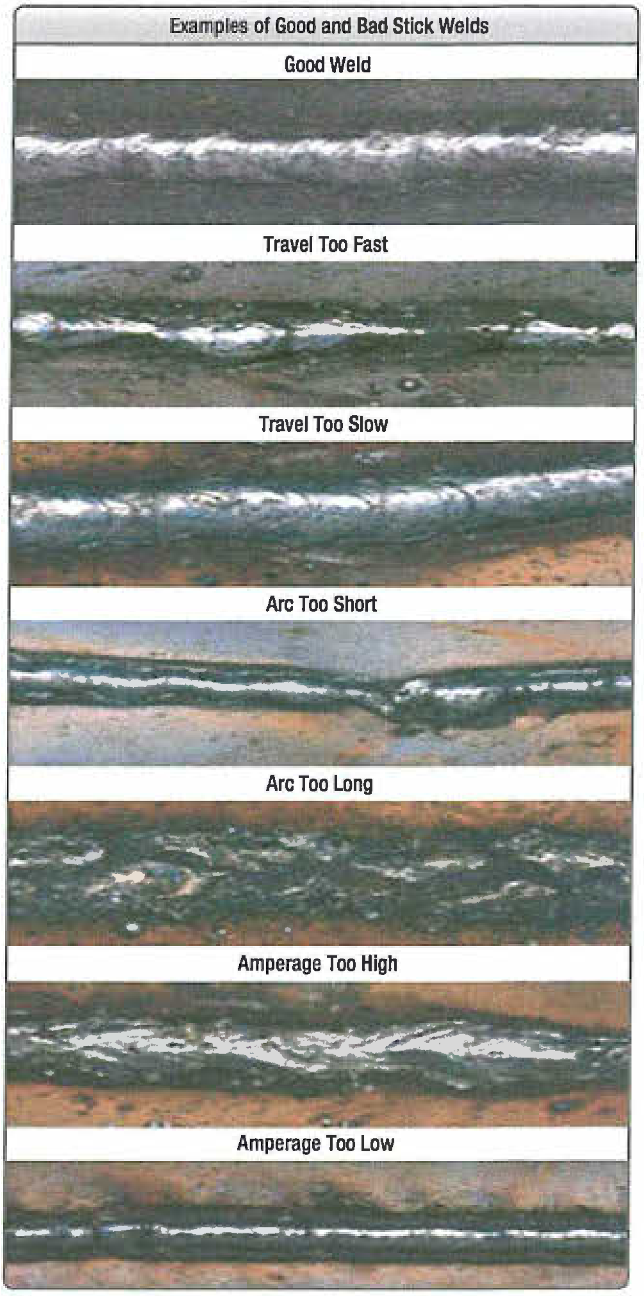


Figure 15-31. Examples of good and bad stick welds.

If you need to restart an arc of an interrupted bead, start just ahead of the crater of the previous weld bead. Then, the electrode should be returned to the back edge of the crater. From this point, the weld may be continued by welding right through the crater and down the line of weld as originally planned. (***Figure 15-33***)

Once a bead has been formed, every particle of slag must be removed from the area of the crater before restarting the arc. This is accomplished with a pick hammer and wire brush and prevents the slag from becoming trapped in the weld.

Figure 15-32. Angle of electrode.

MULTIPLE PASS WELDING

Groove and fillet welds in heavy metals often require the deposit of a number of beads to complete a weld.

It is important that the beads be deposited in a predetermined sequence to produce the soundest welds with the best proportions. The number of beads is determined by the thickness of the metal being welded. Plates from ⅛ inch to ¼ inch can be welded in one pass, but they should be tacked at intervals to keep them aligned. Any weld on a plate thicker than ¼-inch should have the edges beveled and multiple passes.

The sequence of the bead deposits is determined by the kind of joint and the position of the metal. All slag must be removed from each bead before another bead is deposited. Typical multiple-pass groove welding of butt joints is shown in ***Figure 15-34.***

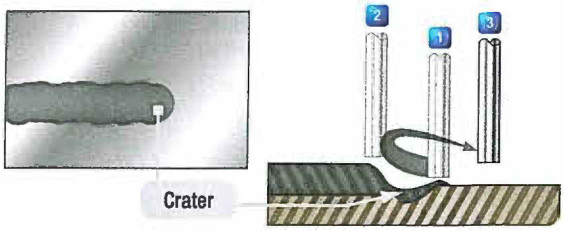


Figure 15-33. Re-starting the arc.

TECHNIQUES OF POSITION WELDING

Each time the position of a welded joint or the type of joint is changed, it may be necessary to change any one or a combination of the following:

- Current value
- Electrode
- Polarity
- Arc length
- Welding technique

Current values are determined by the electrode size, as well as the welding position. Electrode size is governed by the thickness of the metal and the joint preparation. The electrode type is determined by the welding position. Manufacturers specify the polarity to be used with each electrode. Arc length is controlled by a combination of the electrode size, welding position, and welding current.

Since it is impractical to cite every possible variation occasioned by different welding conditions, only the information necessary for the commonly used positions and welds is discussed here.

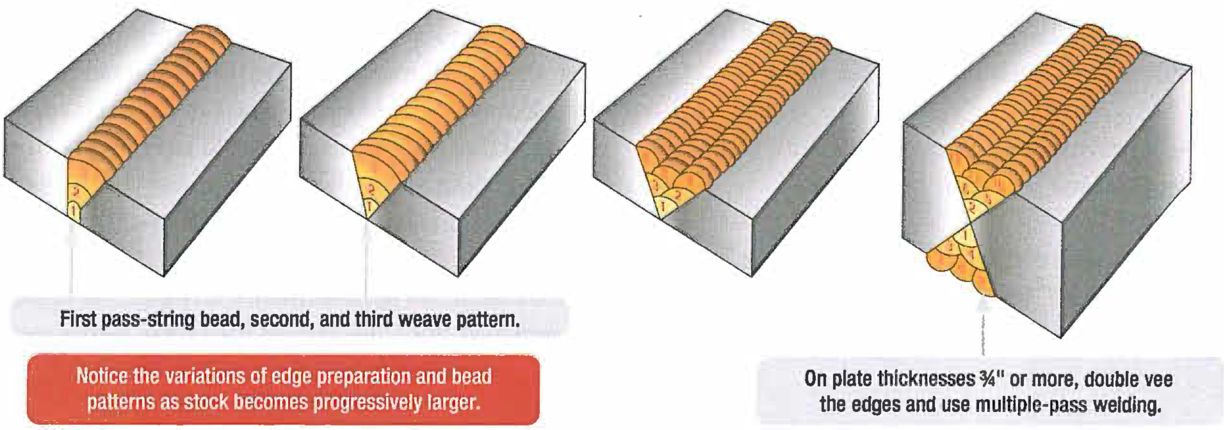


Figure 15-34. Multiple-pass groove welding of butt joints.

FLAT POSITION WELDING

There are four types of welds commonly used in flat position welding: bead, groove, fillet, and lap joint. Each type is discussed separately in the following paragraphs.

Bead Weld

The bead weld utilizes the same technique that is used when depositing a bead on a flat metal surface. (***Figure 15-35***) The only difference is that the deposited bead is at the butt joint of two steel plates, fusing them together. Square butt joints may be welded in one or multiple passes. If the thickness of the metal is such that complete fusion cannot be obtained by welding from one side, the joint must be welded from both sides. Most joints should first be tack-welded to ensure alignment and reduce warping.

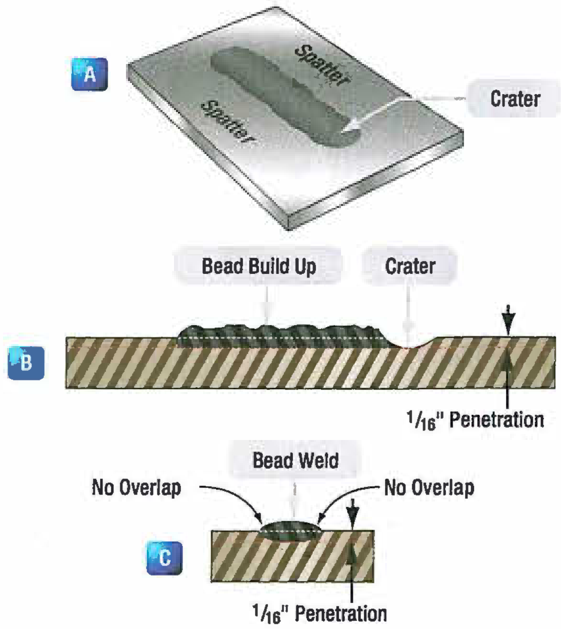


Figure 15-35. Proper bead weld.

Groove Weld

Groove welding may be performed on a butt joint or an outside corner joint. Groove welds are made on butt joints where the metal to be welded is 1/4-inch or more in thickness. The butt joint can be prepared using either a single or double groove depending on the thickness of the plate. The number of passes required to complete a weld is determined by the thickness of the metal being welded and the size of the electrode being used. Any groove weld made in more than one pass must have the slag, spatter, and oxide carefully removed from all previous weld deposits before welding over them. Some of the common types of groove welds performed on butt joints in the flat position are shown in ***Figure 15-36***.

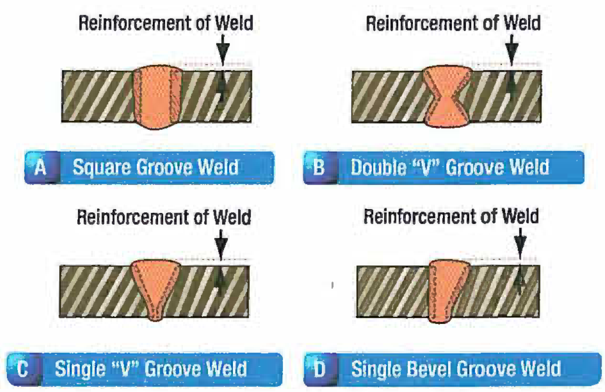


Figure 15-36. Groove welds on butt joints in the flat position.

Fillet Weld

Fillet welds are used to make tee and lap joints. The electrode should be held at an angle of 45° to the plate surface. The electrode should be tilted at an angle of about 15° in the direction of welding. Thin plates should be welded with little or no weaving motion of the electrode and the weld is made in one pass. Fillet welding of thicker plates may require two or more passes using a semicircular weaving motion of the electrode. (***Figure 15-37***)

Lap Joint Weld

The procedure for making fillet weld in a lap joint is similar to that used in the tee joint. The electrode is held at about a 30° angle to the vertical and tilted to an angle of about 15° in the direction of welding when joining plates of the same thickness. (***Figure 15-38***)

VERTICAL POSITION WELDING

Vertical positing welding includes any weld applied to a surface inclined more than 45° from the horizontal. Welding in the vertical position is more difficult than welding in the flat position because of the force of gravity. The molten metal has the tendency to run down. To control the flow of molten metal, the voltage and current adjustments of the welding machine must be correct. The current setting, or amperage, is less for welding in the vertical position than for welding in the flat position for similar size electrodes.

Additionally, the current used for welding upward should be set slightly higher than the current used for welding downward on the same work piece. When welding up, hold the electrode 90° to the vertical, and weld moving the bead upward. Focus on welding the sides of the joint and the middle takes care of itself.

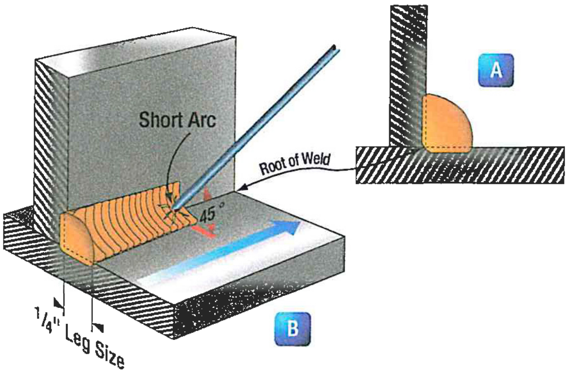


Figure 15-37. Tee joint fillet weld.

In welding downward, with the hand below the arc and the electrode tilted about 15° upward, the weld should move downward.

OVERHEAD POSITION WELDING

Overhead position welding is one of the most difficult in welding since a very short arc must be constantly maintained to control the molten metal. The force of gravity tends to cause the molten metal to drop down or sag from the plate, so it is important that protective clothing and head gear be worn at all times when performing overhead welding.

For bead welds in an overhead position, the electrode should be held at an angle of 90° to the base metal. In some cases where it is desirable to observe the arc and the crater of the weld, the electrode may be held at an angle of 15° in the direction of welding.

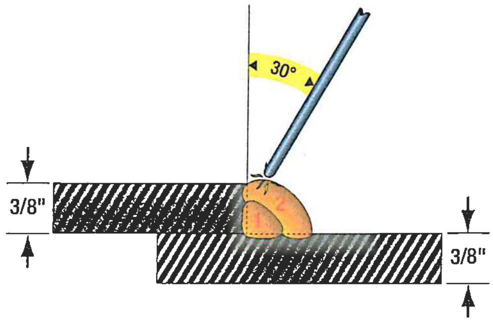


Figure 15-38. Typical lap joint fillet weld.

When making fillet welds on overhead tee or lap joints, a short arc should be held, and there should be no weaving of the electrode. The arc motion should be controlled to secure good penetration to the root of the weld and good fusion to the plates. If the molten metal becomes too fluid and tends to sag, the electrode should be whipped away quickly from the center ahead of the weld to lengthen the arc and allow the metal to solidify. The electrode should then be returned immediately to the crater of the weld and the welding continued.

Anyone learning or engaged in arc welding should always have a good view of the weld puddle. Otherwise there is no way to ensure that the welding is in the joint and keeping the arc on the leading edge of the puddle. For the best view, the welder should keep their head off to the side and out of the fumes so they can see the puddle.

EXPANSION AND CONTRACTION OF METALS

The expansion and contraction of metal is a factor taken into consideration during the design and manufacturing of all aircraft. It is equally important to recognize and allow for the dimensional changes and metal stress that may occur during any welding process. Heat causes metals to expand; cooling causes them to contract. Therefore, uneven heating causes uneven expansion, and uneven cooling causes uneven contraction. Under such conditions, stresses are set up within the metal. These forces must be relieved, and unless precautions are taken, warping or buckling of the metal takes place. Likewise, on cooling, if nothing is done to take up the stress set up by the contraction forces, further warping may result; or if the metal is too heavy to permit this change in shape, the stresses remain within the metal itself.

The coefficient of linear expansion of a metal is the amount in inches that a one inch piece of metal expands when its temperature is raised 1 °F. The amount that a piece of metal expands when heat is applied is found by multiplying the coefficient of linear expansion by the temperature rise and multiplying that product by the length of the metal in inches. Expansion and contraction have a tendency to buckle and warp thin sheet metal ⅛-inch or thinner. This is the result of having a large surface area that spreads heat rapidly and dissipates it soon after the source of heat is removed.

The most effective method of alleviating this situation is to remove the heat from the metal near the weld, preventing it from spreading across the whole surface area. This can be done by placing heavy pieces of metal, known as chill bars, on either side of the weld; to absorb the heat and prevent it from spreading.

Copper is most often used for chill bars because of its ability to absorb heat readily. Welding fixtures sometimes use this same principle to remove heat from the base metal. Expansion can also be controlled by tack welding at intervals along the joint.

The effect of welding a seam longer than 10 or 12 inches is to draw the seam together as the weld progresses. If the edges of the seam are placed in contact with each other throughout their length before welding starts, the far ends of the seam actually overlap before the weld is completed. This tendency can be overcome by setting the pieces to be welded with the seam spaced correctly at one end and increasing the space at the opposite end. (*Figure 15-39*)

The amount of space allowed depends on the type of material, the thickness of the material, the welding process being used, and the shape and size of the pieces to be welded. Instruction and/or welding experience dictates the space needed to produce a stress-free joint. The weld is started at the correctly spaced end and proceeds toward the end that has the increased gap. As the seam is welded, the space closes and should provide the correct gap at the point of welding. Sheet metal under 1⁄16-inch can be handled by flanging the edges, tack welding at intervals, and then by welding between the tacks.

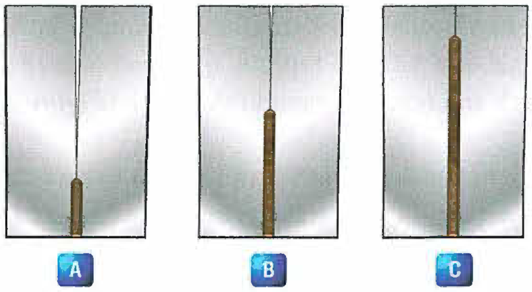


Figure 15-39. Allowance for a straight butt weld when joining steel sheets.

There are fewer tendencies for plate stock over 1⁄8 inch to warp and buckle when welded because the greater thickness limits the heat to a narrow area and dissipates it before it travels far on the plate.

Preheating the metal before welding is another method of controlling expansion and contraction. Preheating is especially important when welding tubular structures and castings. Great stress can be set up in tubular welds by contraction. When welding two members of a tee joint, one tube tends to draw up because of the uneven contraction. If the metal is preheated before the welding operation begins, contraction still takes place in the weld, but the accompanying contraction in the rest of the structure is at almost the same rate, and internal stress is reduced.

WELDED JOINTS USING OXY-ACETYLENE TORCH

Figure 15-40 shows various types of basic joints.

BUTT JOINTS

A butt joint is made by placing two pieces of material edge to edge, without overlap, and then welding. A plain butt joint is used for metals from 1⁄16 inch to 1⁄8 inch in thickness. A filler rod is used when making this joint to obtain a strong weld. The flanged butt joint can be used in welding thin sheets, 1⁄16-inch or less. The edges are prepared for welding by turning up a flange equal to the thickness of the metal. This type of joint is usually made without the use of a filler rod. If the metal is thicker than 1⁄8 inch, it may be necessary to bevel the edges so that the heat from the torch can completely penetrate the metal.

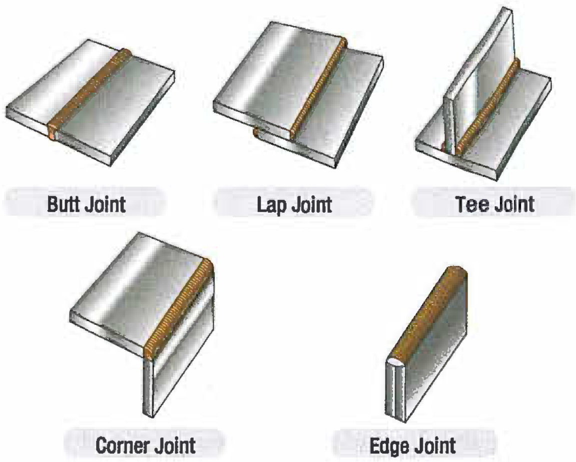


Figure 15-40. Basic joints.

These bevels may be either single or double-bevel type or single or double-V type. A filler rod is used to add strength and reinforcement to the weld. (***Figure 15-41***)

Repair of cracks by welding may be considered just another type of butt joint. The crack should be stop drilled at either end and then welded like a plain butt joint using filler rod. In most cases, the welding of the crack does not constitute a complete repair and some form of reinforcement is still required, as described in following sections.

TEE JOINTS

A tee joint is formed when the edge or end of one piece is welded to the surface of another. (***Figure 15-42***) These joints are quite common in aircraft construction, particularly in tubular structures. The plain tee joint is suitable for most thicknesses of metal used in aircraft, but heavier thicknesses require the vertical member to be either single or double beveled to permit the heat to penetrate deeply enough. The dark areas in ***Figure 15-42*** show the depth of heat penetration and fusion required. It is a good practice to leave a gap between the parts, about equal to the metal thickness to aid full penetration of the weld. This is common when welding from only one side with tubing clusters.

Tight fitment of the parts prior to welding does not provide for a proper weldment unless full penetration is secured, and this is much more difficult with a gapless fitment.

EDGE JOINTS

An edge joint is used when two pieces of sheet metal must be fastened together and load stresses are not important. Edge joints are usually made by bending the edges of one or both parts upward, placing the two ends parallel to each other, and welding along the outside of the seam formed by the two joined edges. The joint shown in ***Figure 15-43A***, requires no filler rod since the edges can be melted down to fill the seam.

The joint shown in ***Figure 15-43B***, being thicker material, must be beveled for heat penetration; filler rod is added for reinforcement.

CORNER JOINTS

A corner joint is made when two pieces of metal are brought together so that their edges form a corner of a box or enclosure. (***Figure 15-44***) The corner joint shown in ***Figure 15-44A*** requires no filler rod, since the edges fuse to make the weld. It is used where the load stress is not important. The type shown in ***Figure 15-44B*** is used on heavier metals, and filler rod is added for roundness and strength. If a higher stress is to be placed on the corner, the inside is reinforced with another weld bead. (***Figure 15-44C***)

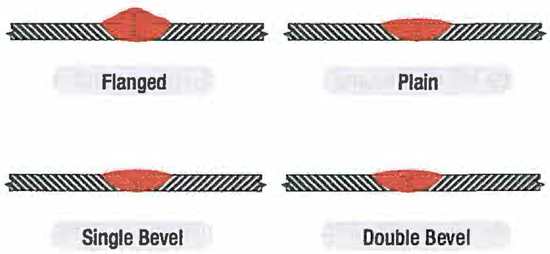


Figure 15-41. Types of butt joints.

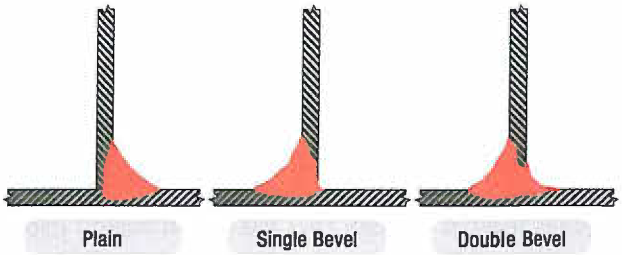


Figure 15-42. Types of tee joints showing filler penetration.

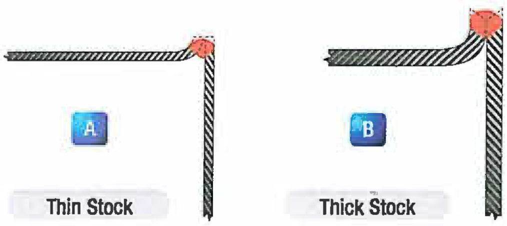


Figure 15-43. Edge joints.

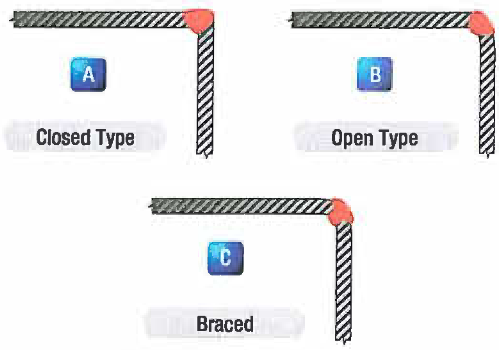


Figure 15-44. Corner joints.

LAP JOINTS

The lap joint is seldom used in aircraft structures when welding with oxy-acetylene, but is commonly used and joined by spot welding. The single lap joint has very little resistance to bending, and cannot withstand the shearing stress to which the weld may be subjected under tension or compression loads. The double lap joint offers more strength, but requires twice the amount of welding required on the simpler, more efficient butt weld. (*Figure 15-45*)

Figure 15-45. Single and double lap joints.

REPAIR OF STEEL TUBING AIRCRAFT STRUCTURE BY WELDING

DENTS AT A CLUSTER WELD

Dents at a cluster weld can be repaired by welding a formed steel patch plate over the dented area and surrounding tubes. Remove any existing finish on the damaged area and thoroughly clean prior to welding.

To prepare the patch plate, cut a section from a steel sheet of the same material and thickness as the heaviest tube damaged. Fashion the reinforcement plate so that the fingers extend over the tubes a minimum of 1½ times the respective tube diameter. The plate may be cut and formed prior to welding or cut and tack welded to the cluster, then heated and formed around the joint to produce a snug smooth contour. Apply sufficient heat to the plate while forming so there is a gap of no more than 1⁄16-inch from the contour of the joint to the plate. In this operation, avoid unnecessary heating and exercise care to prevent damage at the point of the angle formed by any two adjacent fingers of the plate. After the plate is formed and tack welded to the joint, weld all the plate edges to the cluster joint. (*Figure 15-46*)

DENTS BETWEEN CLUSTERS

A damaged tubular section can be repaired using welded split sleeve reinforcement. The damaged member should be carefully straightened and should be stop drilled at the ends of any cracks with a No. 40 drill bit. Select a length of steel tube of the same material and at least the same wall thickness having an inside diameter approximately equal to the outside diameter of the damaged tube.

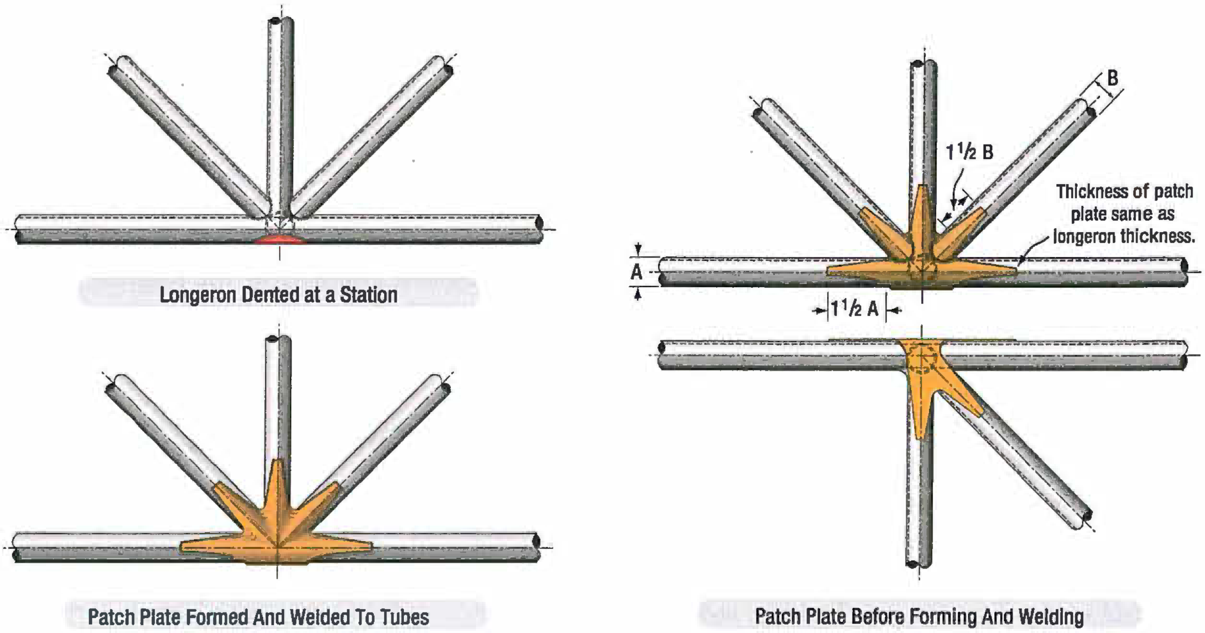


Figure 15-46. Repair of tubing dented at a cluster.

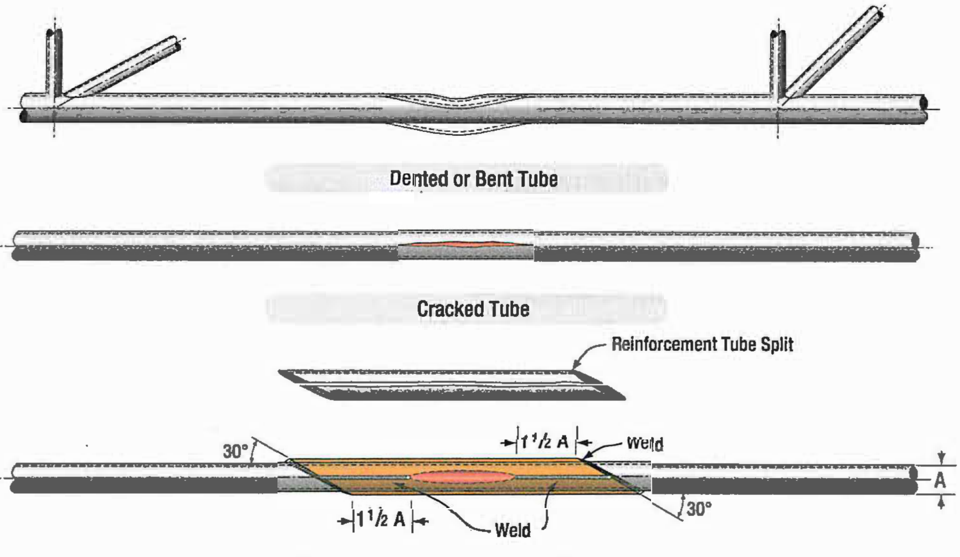


Figure 15-47. Repair using welded sleeve.

Diagonally cut the selected piece at a 30° angle on both ends so the minimum distance of the sleeve from the edge of the crack or dent is not less than 1½ times the diameter of the damaged tube. Then, cut through the entire length of the sleeve and separate the half sections as shown in ***Figure 15-47***. Clamp the two sleeve sections in the proper position on the damaged area of the tube. Weld the reinforcement sleeve along the length of the two sides, and weld both ends of the sleeve to the damaged tube.

TUBE SPLICING WITH INSIDE SLEEVE REINFORCEMENT

If a partial replacement of the tube is necessary, do an inner sleeve splice, especially where you want a smooth tube surface. Make a diagonal cut to remove the damaged section of the tube, and remove the burrs from the inner and outer cut edges with a file or similar means. Diagonally cut a replacement steel tube of the same material, diameter, and wall thickness to match the length of the removed section of the damaged tube. The replacement tube should allow a ⅛-inch gap for welding at each end to the stubs of the original tube.

Select a length of steel tubing of the same material and at least the same wall thickness with an outside diameter equal to the inside diameter of the damaged tube. From this inner sleeve tube material, cut two sections of tubing, each of such a length that the ends of the inner sleeve is a minimum distance of 1½ times the tube diameter from the nearest end of the diagonal cut. Tack the outer and inner replacement tubes using rosette welds. Weld the inner sleeve to the tube stubs through the ⅛-inch gap forming a weld bead over the gap and joining with the new replacement section. (***Figure 15-48***)

TUBE SPLICING WITH OUTER SPLIT SLEEVE REINFORCEMENT

If partial replacement of a damaged tube is necessary, make the outer sleeve splice using a replacement tube of the same diameter and material.
(***Figures 15-49 and 15-50***)

To perform the outer sleeve repair, remove the damaged section of the tube, utilizing a 90° cut at either end. Cut a replacement steel tube of the same material, diameter, and at least the same wall thickness to match the length of the removed portion of the damaged tube. The replacement tube must bear against the stubs of the original tube with a tolerance of ±1⁄64-inch. The material selected for the outer sleeve must be of the same material and at least the same wall thickness as the original tube. The clearance between the inside diameter of the sleeve and the outside diameter of the original tube may not exceed 1⁄16-inch.

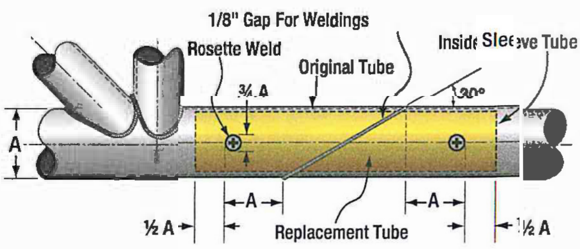


Figure 15-48. Splicing with inner sleeve method.

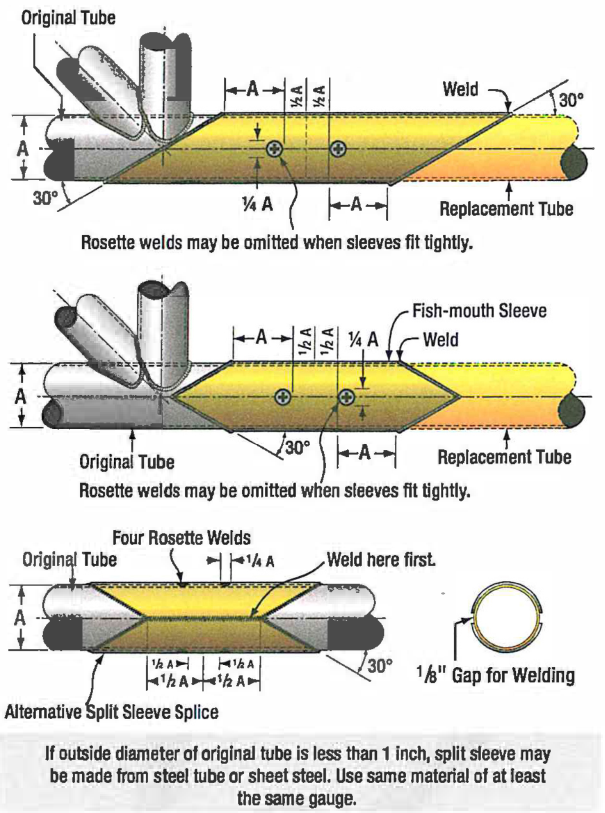


Figure 15-49. Splicing by the outer sleeve method.

From this outer sleeve tube material, either cut diagonally or fish mouth two sections of tubing, each of such a length that the nearest end of the outer sleeve is a minimum distance of 1½ tube diameters from the end of the cut on the original tube. Use the fish mouth sleeve wherever possible. Remove all burrs from the edges of the replacement tube, sleeves, and the original tube stubs.

Slip the two sleeves over the replacement tube, align the replacement tube with the original tube stubs, and slip the sleeves over the center of each joint. Adjust the sleeves to the area to provide maximum reinforcement.

Tack weld the two sleeves to the replacement tube in two places before welding ends. Apply a uniform weld around both ends of one of the reinforcement sleeves and allow the weld to cool. Then, weld around both ends of the remaining reinforcement tube. Allow one sleeve weld to cool before welding the remaining tube to prevent undue warping.

LANDING GEAR REPAIRS

Some components of a landing gear may be repaired by welding while others, when damaged, may require replacement. Representative types of repairable and non-repairable landing gear assemblies are shown in ***Figure 15-51.***

The landing gear types shown in A, B, and C of this figure are repairable axle assemblies. They are formed from steel tubing and may be repaired by approved methods. However, it must be determined if the assemblies were heat treated. Assemblies originally heat treated must be reheat treated after a welding repair.

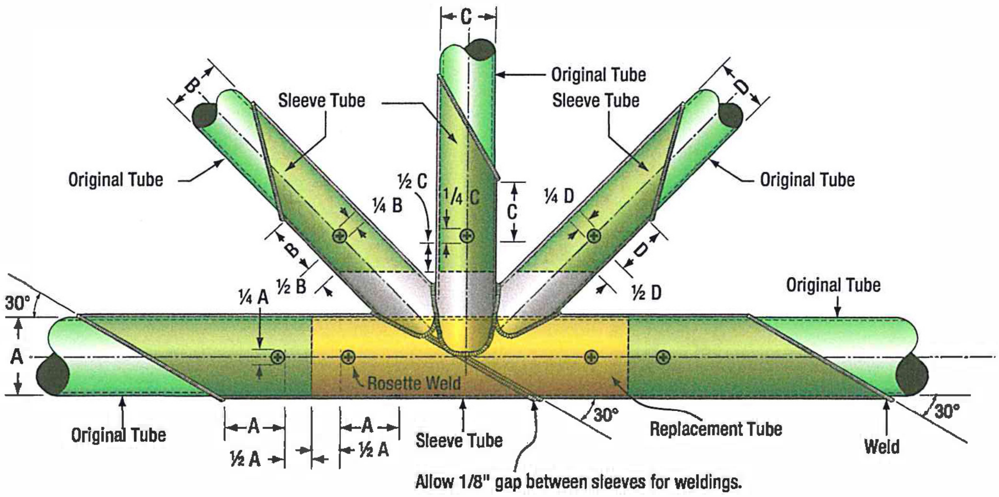


Figure 15-50. Tube replacement at a cluster by outer sleeve method.

The landing gear assembly type D is generally non-repairable for the following reasons:

1. The lower axle stub is usually made from a highly heat-treated nickel alloy steel and machined to close tolerances. It should be replaced when damaged.
2. During manufacture, the upper oleo section of the assembly is heat treated and machined to close tolerances to assure proper functioning of the shock absorber. These parts would be distorted by any welding repair and should be replaced if damaged to ensure the part was airworthy.

The spring-steel leaf, shown as type E, is a component of a standard main landing gear on many light aircraft. The spring-steel part is, in general, non-repairable, should not be welded on, and should be replaced when it is excessively sprung or otherwise damaged.

Streamline tubing, used for some light aircraft landing gear, may be repaired using a round insert tube of the same material and having a wall thickness of one gauge thicker than the original streamline tube and inserting and welding as shown in ***Figure 15-52***.

The streamline landing gear tube may also be repaired by inserting a tube of the same streamline original tubing and welding. This can be accomplished by cutting off the trailing edge of the insert and fitting it into the original tube. Once fitted, remove the insert, weld the trailing edge back together, and reinsert into the original tube. Use the figures and weld as indicated in ***Figure 15-53***.

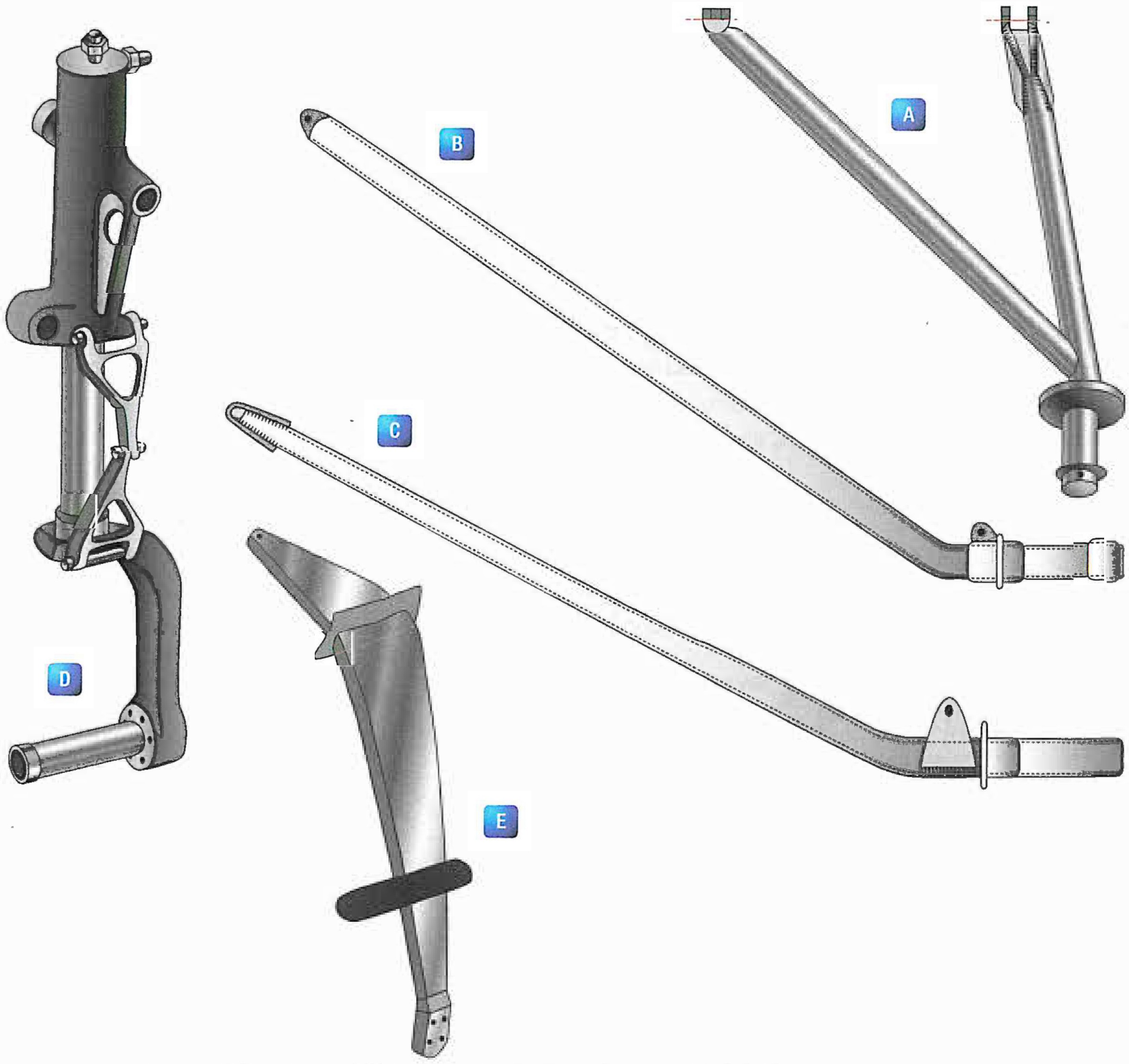
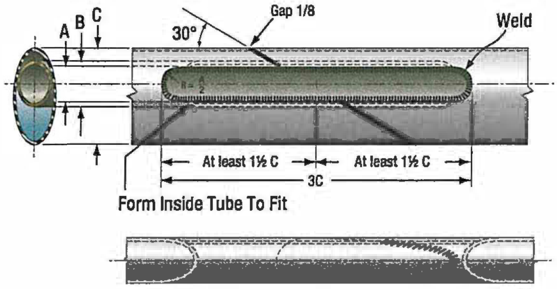


Figure 15-51. Representative types of repairable and non-repairable landing gear assemblies.

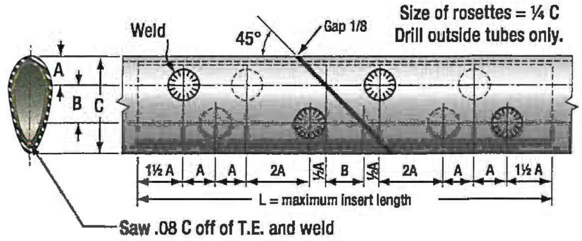


A = Slot width (original tube)
B = Outside diameter (insert tube)
C = Streamline tube length of major axis

S.L. size	A	B	C	6A
1"	0.380	0.560	1.340	0.496
1 1/4"	0.380	0.690	1.670	0.619
1 1/2"	0.500	0.875	2.005	0.743
1 3/4"	0.500	1.000	2.339	0.867
2"	0.500	1.125	2.670	0.991
2 1/4"	0.500	1.250	3.008	1.115
2 1/2"	0.500	1.380	3.342	1.239

Round insert tube (B) should be of same material and one gauge thicker than original streamline tube (C).

Figure 15-52. Streamline landing gear repair using round tube.



Insert tube is of same streamline tubing as original.
A = 2/3" B
B = Minor Axis Length of Original Streamline Tube
C = Major Axis Length of Original Streamline Tube

S.L. Size	A	B	C	6A
1"	0.382	0.572	1.340	5.160
1¼"	0.476	0.714	1.670	6.430
1½"	0.572	0.858	2.005	7.720
1¾"	0.667	1.000	2.339	9.000
2"	0.763	1.144	2.670	10.300
2¼"	0.858	1.286	3.008	11.580
2½"	0.954	1.430	3.342	12.880

Figure 15-53. Streamline tube splice using split insert.

ENGINE MOUNT REPAIRS

All welding on an engine mount should be performed by an experienced welder and be of the highest quality, since vibration tends to accentuate any minor defect.

The preferred method to repair an engine mount member is by using a larger diameter replacement tube telescoped over the stub of the original member using fish-mouth and rosette welds. 30° scarf welds are also acceptable in place of the fish-mouth welds.

One of the most important aspects to keep in mind when repairing an engine mount is that the alignment of the structure must be maintained. This can be accomplished by attaching to a fixture designed for that purpose, or bolting the mount to an engine and/or airframe before welding. All cracked welds should be ground out and only high-grade filler rod of the appropriate material should be used. If all members of the mount are out of alignment, the mount should be replaced with one supplied by the manufacturer or with one built to conform to the manufacturer's drawings and specifications.

Minor damage, such as a crack adjacent to an engine attachment lug, can be repaired by rewelding the ring and extending a gusset or a mounting lug past the damaged area. Engine mount rings that are extensively damaged must not be repaired unless the method of repair is specifically approved by FAA Engineering, a Designated Airworthiness Representative (DAR), or the repair is accomplished in accordance with FAA-approved instructions.

If the manufacturer stress relieved the engine mount after welding, the engine mount should again be stress relieved after weld repairs are made.

ROSETTE WELDING

Rosette welds are used on many of the type repairs that were previously discussed. They are holes, typically one-fourth the diameter of the original tube, drilled in the outer splice and welded around the circumference for attachment to the inner replacement tube or original tube structure.

INSPECTION OF WELDED JOINTS

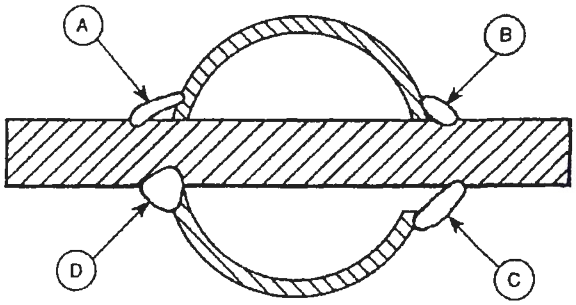
To ensure the airworthiness of any welded area, a visually inspection of the completed weld should be made. The weld should have a smooth seam and uniform thickness. There should be smooth blending of the weld contour into the base metal and a check for undercut should be made. The weld tapered smoothly into the base metal is a sign of a good weld.

When inspecting a weld, no oxide should have formed on the base metal more than ½ inch from the weld. There should be no signs of blowholes, porosity, or projecting globules. Many industry codes specify acceptable limits of porosity and other types of defects that are acceptable. The base metal should show no signs of pitting, burning, cracking, or distortion.

The depth of penetration should be sufficient to insure fusion of the base metal and the filler rod. The welding scale should be removed. The welding scale can be removed using a wire brush or by sandblasting. Also remove any roll over, cold lab, or unfused weld metal. Always inspect the underside of welded joints for defects.

Cracks in parts and materials can vary from tiny micro-fissures, that are visible only with magnification, to those easily identified by unaided eyes. Micro-fissures are the worst type of defect for two reasons; they are often hard to detect, and they produce the worst form of notch effect/stress concentration. Once a micro-fissure forms, it propagates with repeated applications of stress and leads to early failures. Every possible means should be used to detect the presence of cracks, and ensure their complete removal before welding operations proceed. (***Figure 15-54***)

Nondestructive testing (NDT) or evaluation of welds is advisable in critical applications. Nondestructive testing methods such as magnetic particle, liquid penetrant, radiography, ultrasonic, eddy current, and acoustic emission can be used; however, they require trained and qualified people to apply them. If there is any doubt about the integrity of a welded area, further NDT is required. Airframe manufacturer's may also have required testing procedures. A properly designed joint weld is stronger than the base metal which it joins. A good weld is uniform in width; the ripples are even and well feathered into the base metal, which shows no burn due to overheating. (***Figure 15-55***) The weld has good penetration and is free of gas pockets, porosity, or inclusions. The edges of the bead illustrated in ***Figure 15-54B*** are not in a straight line, yet the weld is good since penetration is excellent.



A - Incomplete Root Penetration
B - Insufficient Penetration on Thick Plate
C - Poor Tube Fit and Poor Penetration
D - Satisfactory Weld

Figure 15-54. Common defects to avoid when fitting and welding aircraft certification cluster.

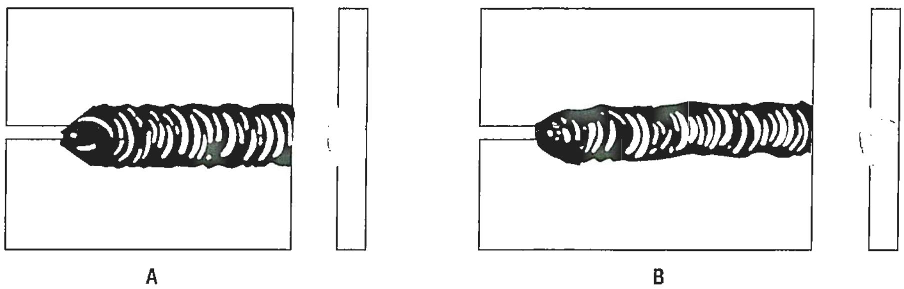


Figure 15-55. Examples of good welds.

Penetration is the depth of fusion in a weld. Thorough fusion is the most important characteristic contributing to a sound weld. Penetration is affected by the thickness of the material to be joined, the size of the filler rod, and how it is added. In a butt weld, the penetration should be 100 percent of the thickness of the base metal. On a fillet weld, the penetration requirements are 25 to 50 percent of the thickness of the base metal. The width and depth of bead for a butt weld and fillet weld are shown in ***Figure 15-55.***

To assist further in determining the quality of a welded joint, several examples of incorrect welds are discussed in the following paragraphs. The weld shown in ***Figure 15-56A*** was made too rapidly. The long and pointed appearance of the ripples was caused by an excessive amount of heat or an oxidizing flame. If the weld were cross-sectioned, it would probably disclose gas pockets, porosity, and slag inclusions.

Figure 15-56B illustrates a weld that has improper penetration and cold laps caused by insufficient heat.

It appears rough and irregular, and its edges are not feathered into the base metal. The puddle has a tendency to boil during the welding operation if an excessive amount of acetylene is used. This often leaves slight bumps along the center and craters at the finish of the weld.

Cross-checks are apparent if the body of the weld is sound. If the weld were cross-sectioned, pockets and porosity would be visible. Such a condition is shown in ***Figure 15-56C.***

A bad weld with irregular edges and considerable variation in the depth of penetration is shown in D of ***Figure 15-57.*** It often has the appearance of a cold weld.

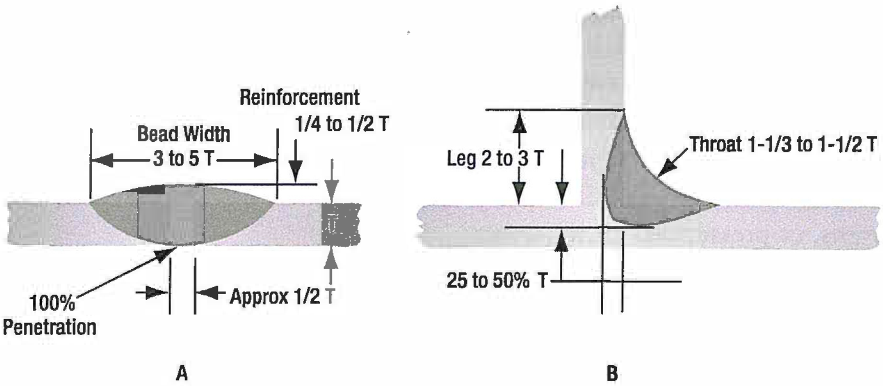


Figure 15-56. (A) Butt weld and (B) Fillet weld, showing width and depth of bead.

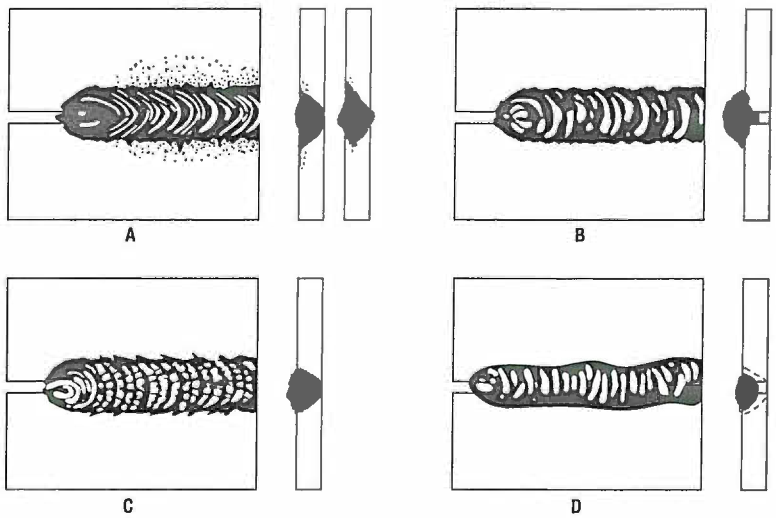


Figure 15-57. Examples of poor welds.

BONDING

Another method of joining two pieces of material is to bond them. Generally, the term bonding refers to the use of some sort of adhesive to chemically or mechanically join materials. The adhesive chosen is a factor of the properties of the materials to be joined and the application of the bonded part. Sealants also are considered to bond materials.

To achieve optimum bonding, performance, and life in service from adhesives and sealants, it is absolutely crucial to follow carefully planned processes and procedures. The utmost attention must be paid to the quality of work at every stage.

Bonding occurs on aircraft between many different materials and in both structural and non-structural applications. Absolute cleanliness at all stages is essential. Surface preparation of the component is also crucial. To ensure consistent results on structural components, a purpose-built 'clean room' may be required, in order to reduce contamination to a minimum. Pressure and heat may also be required. Sophisticated equipment is required to produce pressure over the components in areas where adhesives are applied. This will often entail vacuum bags, purpose-built ovens, or pressurized curing ovens (autoclaves) when dealing with composite materials.

Follow manufacturer's instructions whenever attempting a repair by bonding. To prepare, grease, oil or other contaminants are typically removed with a suitable solvent. Optimum surface roughness must also exist or be produced.

Increasingly, aircraft components are manufactured from non-metallic materials, especially composite materials. The creation and the repair of composite parts are centered around the bonding of materials. Build-up up and repair of composite aircraft parts is thoroughly discussed in *Module 06, Sub-Module 03*.

INSPECTION OF BONDED JOINTS

Simple non-structural bonded joints can be visually inspected for fit and security. Audible sonic testing is used to test composite material bonds for delimitation and/or disband. In composite and structural bonding, manufacturers may specify NDT methods of inspection such as ultrasound. Follow manufacturer's instruction when inspecting bonded joints.

Question: 15-1
Brazing metal adheres to the base metal by ________________ and inter-granular penetration; it does not fuse and amalgamate with them.

Question: 15-2
________________ is defined as a process that joins metal by melting or hammering the work pieces until they are united together.

Question: 15-3
________________ welding, either spot welding or seam welding, is typically used to join thin sheet metal components during the manufacturing process.

Question: 15-4
A ________________ attached to a gas cylinder is used to lower the cylinder pressure to the desired working pressure.

Question: 15-5
By selecting the proper ________________, tensile strength or ductility can be secured in an oxy-acetylene weld.

Question: 15-6
When oxy-acetylene welding, the three types of flame commonly used are the ________________, ________________, and ________________ flames.

Question: 15-7
The ________________ to be welded, the ________________ of the metal, the type of ________________, and the position of the weld dictates the procedure and technique to be used.

Question: 15-8
When welding chrome molybdenum steel over 3⁄16-inch thick, the surrounding area must be preheated to a temperature between 300 °F and 400 °F before beginning to weld to prevent ________________.

ANSWERS

Answer: 15-1
molecular attraction.

Answer: 15-2
Welding.

Answer: 15-3
Electric resistance

Answer: 15-4
pressure regulator.

Answer: 15-5
filler rod.

Answer: 15-6
neutral.
carburizing.
oxidizing.

Answer: 15-7
material.
thickness.
joint.

Answer: 15-8
cracking.

Question: 15-9
Welding uses helium or argon shielding gas and a tungsten electrode is called ________________.

Question: 15-10
When TIG welding aluminum, the machine is typically set to ________________ output waveform because it causes a cleaning action that breaks up surface oxides.

Question: 15-11
Heat causes metals to ________________; cooling causes them to ________________.

Question: 15-12
What may need to be changed each time the position of a welded joint or the type of joint is changed?

Question: 15-13
The ________________ is seldom used in aircraft structures when welding with oxyacetylene, but is commonly used and joined by spot welding.

Question: 15-14
One of the most important aspects to keep in mind when repairing an engine mount is that the ________________ of the structure must be maintained.

Question: 15-15
Generally, the term ________________ refers to the use of some sort of adhesive to chemically or mechanically join materials.

ANSWERS

Answer: 15-9
TIG or GMAW.

Answer: 15-10
an AC.

Answer: 15-11
Current value.
Electrode.
Polarity.
Arc length.
Welding technique.

Answer: 15-12
contract, expand.

Answer: 15-13
lap joint.

Answer: 15-14
alignment.

Answer: 15-15
bonding.

MAINTENANCE PRACTICES

AIRCRAFT WEIGHT AND BALANCE

SUB-MODULE 16

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 16 AIRCRAFT WEIGHT AND BALANCE Knowledge Requirements		
7.16 - Aircraft Weight and Balance		
(a) Center of Gravity/Balance limits calculation: use of relevant documents;	2	2
(b) Preparation of aircraft for weighing; Aircraft weighing.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

AIRCRAFT WEIGHT AND BALANCE

The weight of an aircraft and its balance are extremely important for operating an aircraft in a safe and efficient manner. When a manufacturer designs an aircraft and it is certified, the specifications identify the aircraft's maximum weight and the limits within which it must balance.

The maximum allowable weight is based on the surface area and shape of the wing, and how much lift it will generate at a safe and appropriate airspeed. If a small general aviation airplane, for example, required a takeoff speed of 200 miles per hour to generate enough lift to support its weight, that would not be safe. Taking off and landing at lower airspeeds is certainly safer than doing so at higher speeds.

Where an aircraft balances is also a significant factor in determining if the aircraft is safe to operate. An aircraft that does not have good balance can exhibit poor maneuverability and controllability, making it difficult or impossible to fly. This could result in an accident, causing damage to the aircraft and injury to the people on board. Safety is the primary reason for concern about an aircraft's weight and balance.

A secondary reason for concern about weight and balance, but also a very important one, is the efficiency of the aircraft. Improper loading reduces the efficiency of an aircraft from the standpoint of ceiling, maneuverability, rate of climb, speed, and fuel consumption. If an airplane is loaded in such a way that it is extremely nose heavy, higher than normal forces will need to be exerted at the tail to keep the airplane in level flight. The higher than normal forces at the tail will create additional drag, which will require additional engine power and therefore additional fuel flow in order to maintain airspeed.

The most efficient condition for an aircraft is to have the point where it balances fall very close to, or perhaps exactly at, the aircraft's center of lift. If this were the case, little or no flight control force would be needed to keep the aircraft flying straight and level. In terms of stability and safety, however, this perfectly balanced condition might not be desirable. All of the factors that affect aircraft safety and efficiency, in terms of its weight and balance, are discussed in detail in this chapter.

NEED AND REQUIREMENTS FOR AIRCRAFT WEIGHING

Every aircraft type certificated, before leaving the factory for delivery to its new owner, receives a weight and balance report as part of its required aircraft records. The weight and balance report identifies the empty weight of the aircraft and the location at which the aircraft balances, known as the center of gravity. If the manufacturer chooses to do so, it can weigh every aircraft it produces and issue the weight and balance report based on that weighing. As an alternative, the manufacturer is permitted to weigh an agreed upon percentage of a particular model of aircraft produced, perhaps 10 to 20 percent, and apply the average to all the aircraft.

After the aircraft leaves the factory and is delivered to its owner, the need or requirement for placing the aircraft on scales and reweighing it varies depending on the type of aircraft and how it is used. For a small general aviation airplane being used privately, such as a Cessna 172, there may be a requirement that it be periodically reweighed. There is, however, a requirement that the airplane always have a current and accurate weight and balance report. If the weight and balance report for an aircraft is lost, the aircraft must be weighed and a new report must be created. If the airplane has new equipment installed, such as a radio or a global positioning system, a new weight and balance report must be created.

If the installer of the equipment wants to place the airplane on scales and weigh it after the installation, that is a perfectly acceptable way of creating the new report. If the installer knows the exact weight and location of the new equipment, it is also possible to create a new report by doing a series of mathematical calculations.

Over a period of time, almost all aircraft have a tendency to gain weight. Examples of how this can happen include an airplane being repainted without the old paint being removed, and the accumulation of dirt, grease, and oil in parts of the aircraft that are not easily accessible for cleaning. When new equipment is installed, and its weight and location are mathematically accounted for, some miscellaneous weight might be overlooked, such as wire and hardware. For this reason, it is a good practice to periodically place an aircraft on scales and confirm its actual empty weight and empty weight center of gravity.

Some aircraft are required to be weighed and have their center of gravity calculated on a periodic basis, typically every 3 years. Examples of aircraft that may fall under this requirement are:

1. Air taxi and charter twin-engine airplanes.
2. Airplanes with a seating capacity of 20 or more passengers or a maximum payload of 6 000 pounds or more. This applies to most airplanes operated by the airlines, both main line and regional, and to many of the privately operated business jets.

WEIGHT AND BALANCE TERMINOLOGY

DATUM

The datum is an imaginary vertical plane from which all horizontal measurements are taken for balance purposes, with the aircraft in level flight attitude. If the datum was viewed on a drawing or photograph of an aircraft, it would appear as a vertical line which is perpendicular (90 degrees) to the aircraft's horizontal axis. For each aircraft make and model, the location of all items is identified in reference to the datum. For example, the fuel in a tank might be 60 inches (60") behind the datum, and a radio on the flight deck might be 90" forward of the datum.

There is no fixed rule for the location of the datum, except that it must be a location that will not change during the life of the aircraft. For example, it would not be a good idea to have the datum be the tip of the propeller spinner or the front edge of a seat, because changing to a new design of spinner or moving the seat would cause the datum to change. It might be located at or near the nose of the aircraft, a specific number of inches forward of the nose, at the engine firewall, at the center of the main rotor shaft of a helicopter, or any place that can be imagined.

The manufacturer has the choice of locating the datum where it is most convenient for measurement, equipment location, and weight and balance computation. ***Figure 16-1*** shows an aircraft with the leading edge of the wing being the datum.

For American manufactured aircraft, the location of the datum is identified in the Aircraft Specifications or Type Certificate Data Sheet. Aircraft certified prior to 1958 fell under the Civil Aeronautics Administration, and had their weight and balance information contained in a document known as Aircraft Specifications.

Aircraft certified since 1958 fall under the FAA and have their weight and balance information contained in a document known as a Type Certificate Data Sheet. The Aircraft Specifications typically included the aircraft equipment list. For aircraft with a Type Certificate Data Sheet, the equipment list is a separate document.

ARM

The arm is the horizontal distance that a part of the aircraft or a piece of equipment is located from the datum. The arm's distance is always given or measured in inches, and, except for a location which might be exactly on the datum, it is preceded by the algebraic sign for positive (+) or negative (–). The positive sign indicates an item is located aft of the datum and the negative sign indicates an item is located forward of the datum. If the manufacturer chooses a datum that is at the most forward location on an aircraft (or some distance forward of the aircraft), all the arms will be positive numbers. Location of the datum at any other point on the aircraft will result in some arms being positive numbers, or aft of the datum, and some arms being negative numbers, or forward of the datum.

Figure 16-1 shows an aircraft where the datum is the leading edge of the wing. For this aircraft, any item (fuel, seat, radio, and so forth) located forward of the wing leading edge will have a negative arm, and any item located aft of the wing leading edge will have a positive arm. If an item was located exactly at the wing leading edge, its arm would be zero, and mathematically it would not matter whether its arm was considered to be positive or negative.

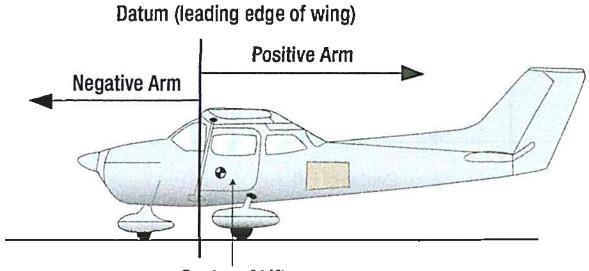


Figure 16-1. Datum location and its effect on positive and negative arms.

The arm of each item is usually included in parentheses immediately after the item's name or weight in the Aircraft Specifications, Type Certificate Data Sheet, or equipment list for the aircraft. In a Type Certificate Data Sheet, for example, the fuel quantity might be identified as 150 gallons (gal) (+138) and the nose baggage limit as 200 pounds (lbs) (-55). These numbers indicate that the fuel is located 138" aft of the datum and the nose baggage is located 55" forward of the datum. If the arm for a particular piece of equipment is not known, its exact location must be accurately measured. When the arm for a piece of equipment is being determined, the measurement is taken from the datum to the piece of equipment's own center of gravity.

MOMENT

A moment is the product of a weight multiplied by its arm. The moment for a piece of equipment is in fact a torque value, measured in units of inch-pounds (in-lbs). To obtain the moment of an item with respect to the datum, multiply the weight of the item by its horizontal distance from the datum. Likewise, the moment of an item with respect to the center of gravity (CG) of an aircraft can be computed by multiplying its weight by the horizontal distance from the CG.

A 5 lb radio located 80" from the datum would have a moment of 400 inch-pounds (in-lbs) (5 lbs × 8"). Whether the value of 400 in-lbs is preceded by a positive (+) or negative (–) sign depends on whether the moment is the result of a weight being removed or added and its location in relation to the datum. This situation is shown in ***Figure 16-2***, where the moment ends up being a positive number because the weight and arm are both positive.

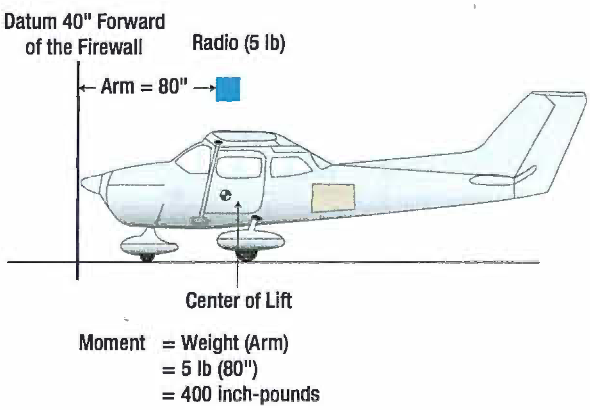


Figure 16-2. Moment of a radio located aft of the datum.

The algebraic sign of the moment, based on the datum location and whether weight is being installed or removed, would be as follows:

- Weight being added aft of the datum produces a positive moment (+ weight, + arm).
- Weight being added forward of the datum produces a negative moment (+ weight, – arm).
- Weight being removed aft of the datum produces a negative moment (– weight, + arm).
- Weight being removed forward of the datum produces a positive moment (– weight, – arm)

When dealing with positive and negative numbers, remember that the product of like signs produces a positive answer and the product of unlike signs produces a negative answer.

CENTER OF GRAVITY

The center of gravity (CG) of an aircraft is a point about which the nose heavy and tail heavy moments are exactly equal in magnitude. It is the balance point for the aircraft. An aircraft suspended from this point would have no tendency to rotate in either a nose-up or nose-down attitude. It is the point about which the weight of an airplane or any object is concentrated.

Figure 16-3 shows a first class lever with the pivot point (fulcrum) located at the center of gravity for the lever. Even though the weights on either side of the fulcrum are not equal, and the distances from each weight to the fulcrum are not equal, the product of the weights and arms (moments) are equal, and that is what produces a balanced condition.

MAXIMUM WEIGHT

The maximum weight is the maximum authorized weight of the aircraft and its contents, and is indicated in the Aircraft Specifications or Type Certificate Data Sheet. For many aircraft, there are variations to the maximum allowable weight, depending on the purpose

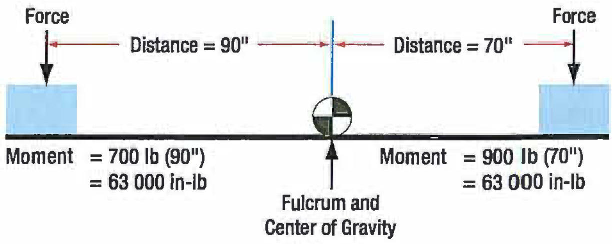


Figure 16-3. Center of gravity and a first class lever.

and conditions under which the aircraft is to be flown. For example, a certain aircraft may be allowed a maximum gross weight of 2 750 lbs when flown in the normal category, but when flown in the utility category, which allows for limited aerobatics, the same aircraft's maximum allowable gross weight might only be 2 175 lbs. There are other variations when dealing with the concept of maximum weight, as follows:

- Maximum Ramp Weight—the heaviest weight to which an aircraft can be loaded while it is sitting on the ground. This is sometimes referred to as the maximum taxi weight.
- Maximum Takeoff Weight—the heaviest weight an aircraft can have when it starts the takeoff roll. The difference between this weight and the maximum ramp weight would equal the weight of the fuel that would be consumed prior to takeoff.
- Maximum Landing Weight—the heaviest weight an aircraft can have when it lands. For large wide body commercial airplanes, it can be 100 000 lbs less than maximum takeoff weight, or even more.
- Maximum Zero Fuel Weight—the heaviest weight an aircraft can be loaded to without having any usable fuel in the fuel tanks. Any weight loaded above this value must be in the form of fuel.

EMPTY WEIGHT

The empty weight of an aircraft includes all operating equipment that has a fixed location and is actually installed in the aircraft. It includes the weight of the airframe, powerplant, required equipment, optional or special equipment, fixed ballast, hydraulic fluid, and residual fuel and oil. Residual fuel and oil are the fluids that will not normally drain out because they are trapped in the fuel lines, oil lines, and tanks. They must be included in the aircraft's empty weight. For most aircraft certified after 1978, the full capacity of the engine oil system is also included in the empty weight. Information regarding residual fluids in aircraft systems that must be included in the empty weight, and whether or not full oil is included, will be indicated in the Aircraft Specifications or Type Certificate Data Sheet.

Other terms that are sometimes used when describing empty weight include basic empty weight, licensed empty weight, and standard empty weight. The term "basic empty weight" typically applies when the full capacity of the engine oil system is included in the value. The term "licensed empty weight" typically applies when only the weight of residual oil is included in the value, so it generally involves only aircraft certified prior to 1978. Standard empty weight would be a value supplied by the aircraft manufacturer, and it would not include any optional equipment that might be installed in a particular aircraft. For most people working in the aviation maintenance field, the basic empty weight of the aircraft is the most important one.

EMPTY WEIGHT CENTER OF GRAVITY

The empty weight center of gravity for an aircraft is the point at which it balances when it is in an empty weight condition. The concepts of empty weight and center of gravity were discussed earlier in this chapter, and now they are being combined into a single concept.

One of the most important reasons for weighing an aircraft is to determine its empty weight center of gravity. All other weight and balance calculations, including loading the aircraft for flight, performing an equipment change calculation, and performing an adverse condition check, begin with knowing the empty weight and empty weight center of gravity. This crucial information is part of what is contained in the aircraft weight and balance report.

USEFUL LOAD

To determine the useful load of an aircraft, subtract the empty weight from the maximum allowable gross weight. For aircraft certificated in both normal and utility categories, there may be two useful loads listed in the aircraft weight and balance records. An aircraft with an empty weight of 900 lbs will have a useful load of 850 lbs, if the normal category maximum weight is listed as 1 750 lbs. When the aircraft is operated in the utility category, the maximum gross weight may be reduced to 1 500 lbs, with a corresponding decrease in the useful load to 600 lbs. Some aircraft have the same useful load regardless of the category in which they are certificated.

The useful load consists of fuel, any other fluids that are not part of empty weight, passengers, baggage, pilot, copilot, and crew members. Whether or not the weight of engine oil is considered to be a part of useful load depends on when the aircraft was certified, and can be determined by looking at the Aircraft Specifications or Type Certificate Data Sheet. The payload of an aircraft is similar to the useful load, except it does not include fuel.

A reduction in the weight of an item, where possible, may be necessary to remain within the maximum weight allowed for the category in which an aircraft weights is called a weight check.

MINIMUM FUEL

There are times when an aircraft will have a weight and balance calculation done, known as an extreme condition check. This is a pencil and paper check in which the aircraft is loaded in as nose heavy or tail heavy a condition as possible to see if the center of gravity will be out of limits in that situation. In a forward adverse check, for example, all useful load in front of the forward CG limit is loaded, and all useful load behind this limit is left empty. An exception to leaving it empty is the fuel tank. If the fuel tank is located behind the forward CG limit, it cannot be left empty because the aircraft cannot fly without fuel. In this case, an amount of fuel is accounted for, which is known as minimum fuel. Minimum fuel is typically that amount needed for 30 minutes of flight at cruise power.

For a piston engine powered aircraft, minimum fuel is calculated based on the METO (maximum except take-off) horsepower of the engine. For each METO horsepower of the engine, one-half pound of fuel is used. This amount of fuel is based on the assumption that the piston engine in cruise flight will burn 1 lb of fuel per hour for each horsepower, or ½ lb for 30 minutes. The piston engines currently used in small general aviation aircraft are actually more efficient than that, but the standard for minimum fuel has remained the same.

Minimum fuel is calculated as follows:

Minimum Fuel (pounds) = Engine METO Horsepower ÷ 2

For example, if a forward adverse condition check was being done on a piston engine powered twin, with each engine having a METO horsepower of 500, the minimum fuel would be 250 lbs (500 METO Hp ÷ 2).

For turbine engine powered aircraft, minimum fuel is not based on engine horsepower. If an adverse condition check is being performed on a turbine engine powered aircraft, the aircraft manufacturer would need to supply information on minimum fuel.

TARE WEIGHT

When aircraft are placed on scales and weighed, it is sometimes necessary to use support equipment to aid in the weighing process. For example, to weigh a tail dragger airplane, it is necessary to raise the tail in order to get the airplane level. To level the airplane, a jack might be placed on the scale and used to raise the tail. Unfortunately, the scale is now absorbing the weight of the jack in addition to the weight of the airplane. This extra weight is known as tare weight, and must be subtracted from the scale reading. Other examples of tare weight are wheel chocks placed on the scales and ground locks left in place on retractable landing gear.

PROCEDURES FOR WEIGHING AN AIRCRAFT

GENERAL CONCEPTS

The most important reason for weighing an aircraft is to find out its empty weight (basic empty weight), and to find out where it balances in the empty weight condition. When an aircraft is to be flown, the pilot in command must know what the loaded weight of the aircraft is, and where its loaded center of gravity is. In order for the loaded weight and center of gravity to be calculated, the pilot or dispatcher handling the flight must first know the empty weight and empty weight center of gravity.

Earlier in this chapter it was identified that the center of gravity for an object is the point about which the nose heavy and tail heavy moments are equal. One method that could be used to find this point would involve lifting an object off the ground twice, first suspending it from a point near the front, and on the second lift suspending it from a point near the back. With each lift, a perpendicular line (90 degrees) would be drawn from the suspension point to the ground. The two perpendicular lines would intersect somewhere in the object, and the point of intersection would be the center of gravity.

This concept is shown in ***Figure 16-4***, where an irregular shaped object is suspended from two different points. The perpendicular line from the first suspension point is shown in red, and the new suspension point line is shown in blue. Where the red and blue lines intersect is the center of gravity.

If an airplane were suspended from two points, one at the nose and one at the tail, the perpendicular drop lines would intersect at the center of gravity the same way they do for the object in ***Figure 16-4***. Suspending an airplane from the ceiling by two hooks, however, is clearly not realistic. Even if it could be done, determining where in the airplane the lines intersect would not be possible.

A more realistic way to find the center of gravity for an object, especially an airplane, is to place it on a minimum of two scales and to calculate the moment value for each scale reading. In ***Figure 16-5***, there is a plank that is 200" long, with the left end being the datum (zero arm), and 6 weights placed at various locations along the length of the plank. The purpose of ***Figure 16-5*** is to show how the center of gravity can be calculated when the arms and weights for an object are known.

To calculate the center of gravity for the object in ***Figure 16-5***, the moments for all the weights need to be calculated and then summed, and the weights need to be summed. In the four column table in ***Figure 16-6***, the item, weight, and arm are listed in the first three columns, with the information coming from ***Figure 16-5***.

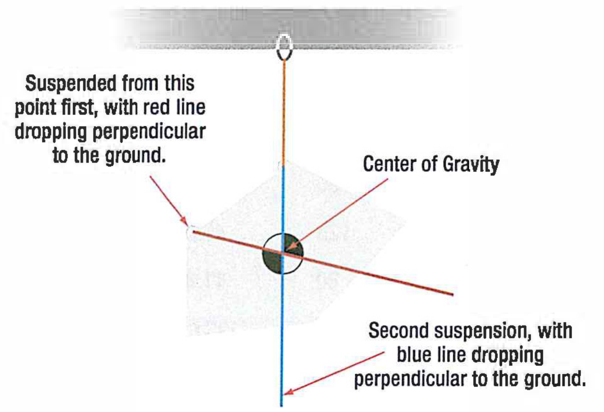


Figure 16-4. Center of gravity determined by two suspension points.

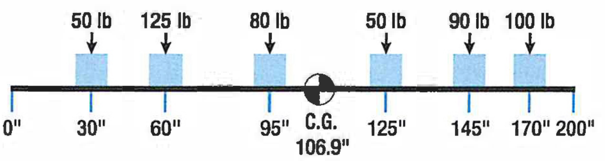


Figure 16-5. Center of gravity for weights on a plank, datum at one end.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	+30	1 500
125 pound weight	125	+60	7 500
80 pound weight	80	+95	7 600
50 pound weight	50	+125	6 250
90 pound weight	90	+145	13 050
100 pound weight	100	+170	17 000
Total	495	+106.9	52 900

Figure 16-6. Center of gravity calculation for weights on a plank with datum at one end.

The moment value in the fourth column is the product of the weight and arm. The weight and moment columns are summed, with the center of gravity being equal to the total moment divided by the total weight. The arm column is not summed. The number appearing at the bottom of that column is the center of gravity. The calculation would be as shown in ***Figure 16-6***.

For the calculation shown in ***Figure 16-6***, the total moment is 52 900 in-lbs, and the total weight is 495 lb. The center of gravity is calculated as follows:

Center of Gravity = Total Moment ÷ Total Weight
= 52 900 in-lbs ÷ 495 lb
= 106.9" (106.87 rounded off to tenths)

An interesting characteristic exists for the problem presented in ***Figure 16-5***, and the table showing the center of gravity calculation. If the datum (zero arm) for the object was in the middle of the 200" long plank, with 100" of negative arm to the left and 100" of positive arm to the right, the solution would show the center of gravity to be in the same location. The arm for the center of gravity would not be the same number, but its physical location would be the same. ***Figure 16-7*** and ***Figure 16-8*** show the new calculation.

Center of Gravity = Total Moment ÷ Total Weight
= 3 400 in-lb ÷ 495 lb
= 6.9" (6.87 rounded off to tenths)

In ***Figure 16-7***, the center of gravity is 6.9" to the right of the plank's center. Even though the arm is not the same number, in ***Figure 16-5*** the center of gravity is also 6.9" to the right of center (CG location of 106.9 with the center being 100). Because both problems are the same in these two figures, except for the datum location, the center of gravity must be the same.

The definition for center of gravity states that it is the point about which all the moments are equal. We can prove that the center of gravity for the object in ***Figure 16-7*** is correct by showing that the total moments on either side of this point are equal. Using 6.87 as the CG location for slightly greater accuracy, instead of the rounded off 6.9 number, the moments to the left of the CG would be as shown in ***Figure 16-9***.

The moments to the right of the CG, as shown in ***Figure 16-7***, would be as shown in ***Figure 16-10***. Disregarding the slightly different decimal value, the moment in both of the previous calculations is 10 651 in-lb. Showing that the moments are equal is a good way of proving that the center of gravity has been properly calculated.

WEIGHT AND BALANCE DATA

In order to weigh an aircraft and calculate its empty weight and empty weight center of gravity, a technician must have access to weight and balance information about the aircraft. Possible sources of weight and balance data are as follows:

- Aircraft Specifications—applies primarily to aircraft certified under the Civil Aeronautics Administration, when the specifications also included a list of equipment with weights and arms.
- Aircraft Operating Limitations—supplied by the aircraft manufacturer.
- Aircraft Flight Manual—supplied by the aircraft manufacturer.
- Aircraft Weight and Balance Report—supplied by the aircraft manufacturer when the aircraft is new, and by the technician when an aircraft is reweighed in the field.
- Aircraft Type Certificate Data Sheet—applies primarily to aircraft certified under the FAA and the Federal Aviation Regulations, where the equipment list with weights and arms is a separate document.

The document in ***Figure 16-11*** is a Type Certificate Data Sheet (TCDS) for a Piper twin-engine airplane known as the Seneca (PA-34-200). The main headings for the information typically contained in a TCDS are included, but much of the information contained under these headings has been removed if it did not directly pertain

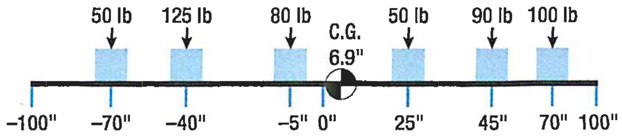


Figure 16-7. Center of gravity for weights on a plank, datum in the middle.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	–70	–3 500
125 pound weight	125	–40	–5 000
80 pound weight	80	–5	–400
50 pound weight	50	+25	1 250
90 pound weight	90	+45	4 050
100 pound weight	100	+70	7 000
Total	495	+6.9	3 400

Figure 16-8. Center of gravity calculation for weights on a plank with datum in the middle.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	76.87	3 843.50
125 pound weight	125	46.87	5 858.75
80 pound weight	80	11.87	949.60
Total	255	135.61	10 651.85

Figure 16-9. Moments to the left of the center of gravity.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
50 pound weight	50	18.13	906.50
90 pound weight	90	38.13	3 431.70
100 pound weight	100	63.13	6 313.00
Total	240	119.39	10 651.25

Figure 16-10. Moments to the right of the center of gravity.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

TYPE CERTIFICATE DATA SHEET NO. A7SO – REVISION 14

PIPER
PA-34-200
PA-34-200T
PA-34-220T

June 1, 2001

This data sheet, which is a part of type certificate No. A7SO, prescribes conditions and limitations under which the product for which the type certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder:
The New Piper Aircraft, Inc.
2926 Piper Drive
Vero Beach, Florida 32960

I. Model PA-34-200 (Seneca), 7 PCLM (Normal Category), Approved 7 May 1971.

Engines
S/N 34-E4, 34-7250001 through 34-7250214:
1 Lycoming LIO-360-C1E6 with fuel injector,
Lycoming P/N LW-10409 or LW-12586 (right side); and
1 Lycoming IO-360-C1E6 with fuel injector,
Lycoming P/N LW-10409 or LW 12586 (left side).
S/N 34-7250215 through 34-7450220:
1 Lycoming LIO-360-C1E6 with fuel injector,
Lycoming P/N LW-12586 (right side); and
1 Lycoming IO-360-C1E6 with fuel injector,
Lycoming P/N LW-12586 (left side).

Fuel
100/130 minimum grade aviation gasoline

Engine Limits
For all operations, 2,700 RPM (200 hp)

Propeller and Propeller Limits
Left Engine
1 Hartzell, Hub Model HC-C2YK-2 ( ) E, Blade Model C7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EU, Blade Model C7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EF, Blade Model FC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) EFU, Blade Model FC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2CG (F), Blade Model (F) C7666A
(This model includes the Hartzell damper); or
1 Hartzell, Hub Model HC-C2YK-2CGU (F), Blade Model (F) C7666A
(This model includes the Hartzell damper).
Note: HC-( )2YK-( ) may he substituted for HC-( )2YR-( ) per Hartzell Service Advisory 61.

Right Engine
1 Hartzell, Hub Model HC-C2YK-2 ( ) LE, Blade Model JC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEU, Blade Model JC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEF, Blade Model FJC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2 ( ) LEFU, Blade Model FJC7666A-0;
1 Hartzell, Hub Model HC-C2YK-2CLG (F), Blade Model (F) JC7666A
(This model includes the Hartzell damper); or

Figure 16-11. Type Certificate Data Sheet.

1 Hartzell, Hub Model HC-C2YK-2CLGU (F), Blade Model (F) JC7666A
(This model includes the Hartzell damper.)
Note: HC-( )2YK-( ) may be substituted for HC-( )2YR-( ) per Hartzell Service Advisory 61.
Pitch setting: High 79° to 81°, Low 13.5° at 30" station.
Diameter: Not over 76", not under 74". No further reduction permitted.

Spinner: Piper P/N 96388 Spinner Assembly and P/N 96836 Cap Assembly, or P/N 78359-0 Spinner Assembly and P/N 96836-2 Cap Assembly (See NOTE 4)

Governor Assembly:
1 Hartzell hydraulic governor, Model F-6-18AL (Right);
1 Hartzell hydraulic governor, Model F-6-18A (Left).
Avoid continuous operation between 2,200 and 2,400 RPM unless aircraft is equipped with Hartzell propellers which incorporate a Hartzell damper on both left and right engine as noted above.

Airspeed Limits

VNE (Never exceed)	217 mph	(188 knots)
VNO (Maximum structural cruise)	190 mph	(165 knots)
VA (Maneuvering, 4,200 lb)	146 mph	(127 knots)
VA (Maneuvering, 4,000 lb)	146 mph	(127 knots)
VA (Maneuvering, 2,743 lb)	133 mph	(115 knots)
VFE (Flaps extended)	125 mph	(109 knots)
VLO (Landing gear operating)		
Extension	150 mph	(130 knots)
Retract	125 mph	(109 knots)
VLE (Landing gear extended)	150 mph	(130 knots)
VMC (Minimum control speed)	80 mph	(69 knots)

CG Range (Gear Extended)
S/N 34-E4, 34-7250001 through 34-7250214 (See NOTE 3):
(+86.4) to (+94.6) at 4,000 lb
(+82.0) to (+94.6) at 3,400 lb
(+80.7) to (+94.6) at 2,780 lb
S/N 34-7250215 through 34-7450220:
(+87.9) to (+94.6) at 4,200 lb
(+82.0) to (+94.6) at 3,400 lb
(+80.7) to (+94.6) at 2,780 lb
Straight line variation between points given.
Moment change due to gear retracting landing gear (-32 in-lb)

Empty Weight CG Range
None

Maximum Weight
S/N 34-E4, 34-7250001 through 34-7250214:
4,000 lb – Takeoff
4,000 lb – Landing
See NOTE 3.

Maximum Weight
S/N 34-7250215 through 34-7450220:
4,200 lb – Takeoff
4,000 lb – Landing

No. of Seats
7 (2 at +85.5, 3 at +118.1, 2 at +155.7)

Maximum Baggage
200 lb (100 lb at +22.5, 100 lb at +178.7)

Figure 16-11. Type Certificate Data Sheet. (continued)

to weight and balance. Information on only one model of Seneca is shown, because to show all the different models would make the document excessively long. The portion of the TCDS that has the most direct application to weight and balance is highlighted in yellow.

Some of the important weight and balance information found in a Type Certificate Data Sheet is as follows:

1. Center of gravity range
2. Maximum weight
3. Leveling means
4. Number of seats and location
5. Baggage capacity
6. Fuel capacity
7. Datum location
8. Engine horsepower
9. Oil capacity
10. Amount of fuel in empty weight
11. Amount of oil in empty weight

WEIGHT AND BALANCE EQUIPMENT

SCALES

Two types of scales are typically used to weigh aircraft: those that operate mechanically with balance weights or springs, and those that operate electronically with what are called load cells. The balance weight type of mechanical scale, known as a beam scale, is similar to that found in a doctor's office, in which a bar rises up when weight is put on the scale. A sliding weight is then moved along the bar until the bar is centered between a top and bottom stop.

The sliding weight provides the capability to measure up to 50 lbs, and the cup holds fixed weights that come in 50 lb equivalent units. As an example of this scale in use, let's say the nosewheel of a small airplane is placed on the scale with an applied weight of 580 lb. To find out what the applied weight is, a technician would place 550 lbs of equivalent weight in the cup, and then slide the weight on the beam out to the 30 lb point. The 580 lbs

Fuel Capacity	98 gallons (2 wing tanks) at (+93.6) (93 gallons usable) See NOTE 1 for data on system fuel.			
Oil Capacity	8 qt per engine (6 qt per engine usable) See NOTE 1 for data on system oil.			
Control Surface Movements	Ailerons	(±2°)	Up 30°	Down 15°
	Stabilator		Up 12.5° (+0,-1°)	Down 7.5° (±1°)
Rudder	(±1°)	Left 35°		Right 35°
	Stabilator Trim Tab (Stabilator neutral)	(±1°)	Down 10.5°	Up 6.5°
	Wing Flaps	(±2°)	Up 0°	Down 40°
	Rudder Trim Tab (Rudder neutral)	(±1°)	Left 17°	Right 22°
	Nosewheel	S/N 34-E4, 34-7250001 through 34-7350353:		
	Travel	(±1°)	Left 21°	Right 21°
	Nosewheel	S/N 34-7450001 through 34-7450220:		
	Travel	(±1°)	Left 27°	Right 27°
Manufacturer's Serial Numbers	3449001 and up.			

DATA PERTINENT TO ALL MODELS

Datum	78.4" forward of wing leading edge from the inboard edge of the inboard fuel tank.
Leveling Means	Two screws left side fuselage below window.
Certification Basis	Type Certificate No. A7SO issued May 7, 1971, obtained by the manufacturer under the delegation option authorization. Date of Type Certificate application July 23, 1968. Model PA-34-200 (Seneca I): 14 CFR part 23 as amended by Amendment 23-6 effective August 1, 1967; 14 CFR part 23.959 as amended by Amendment 23-7 effective September 14, 1969; and 14 CFR part 23.1557(c)(1) as amended by Amendment 23-18 effective May 2, 1977. Compliance with 14 CFR part 23.1419 as amended by Amendment 23-14 effective December 20, 1973, has been established with optional ice protection provisions.
Production Basis	Production Certificate No. 206. Production Limitation Record issued and the manufacturer is authorized to issue an airworthiness certificate under the delegation option provisions of 14 CFR part 21.
Equipment	The basic required equipment as prescribed in the applicable airworthiness regulations (see Certification Basis) must be installed in the aircraft for certification. In addition, the following items of equipment are required:

Figure 16-11. Type Certificate Data Sheet. (continued)

MODEL	AFM/POH	REPORT #	APPROVED	SERIAL EFFECTIVITY
PA-34-200(Seneca)	AFM	VB-353	7/2/71	34-E4, 34-7250001 through 34-7250214
	AFM	VB-423	5/20/72	34-7250001 through 34-7250189 when Piper Kit 760-607 is installed; 34-7250190 through 34-7250214 when Piper Kit 760-611 is installed; and 34-7250215 through 34-7350353
	AFM	VB-563	5/14/73	34-7450001 through 34-7450220
	AFM Supp.	VB-588	7/20/73	34-7250001 through 34-7450039 when propeller with dampers are installed
	AFM Supp.	VB-601	11/9/73	34-7250001 through 34-745017 when ice protection system is installed

NOTES

NOTE 1 Current Weight and Balance Report, including list of equipment included in certificated empty weight, and loading instructions when necessary, must be provided for each aircraft at the time of original certification. The certificated empty weight and corresponding center of gravity locations must include undrainable system oil (not included in oil capacity) and unusable fuel as noted below:

Fuel: 30.0 lb at (+103.0) for PA-34 series, except Model PA-34-220T (Seneca V), S/N 3449001 and up
Fuel: 36.0 lb at (+103.0) for Model PA-34-220T (Seneca V), S/N 3449001 and up
Oil: 6.2 lb at (+ 39.6) for Model PA-34-200
Oil: 12.0 lb at (+ 43.7) for Models PA-34-200T and PA-34-220T

NOTE 2 All placards required in the approved Airplane Flight Manual or Pilot's Operating Handbook and approved Airplane Flight Manual or Pilot's Operating Handbook supplements must be installed in the appropriate location.

NOTE 3 The Model PA-34-200; S/N 34-E4, 34-7250001 through 34-7250189, may be operated at a maximum takeoff weight of 4,200 lb when Piper Kit 760-607 is installed. S/N 34-7250190 through 34-7250214 may be operated at a maximum takeoff weight of 4,200 lb when Piper Kit 760-611 is installed.

NOTE 4 The Model PA-34-200; S/N 34-E4, 34-7250001 through 34-7250189, may be operated without spinner domes or without spinner domes and rear bulkheads when Piper Kit 760-607 has been installed. ----------

NOTE 5 The Model PA-34-200 may be operated in known icing conditions when equipped with spinner assembly and the following kits: ----------

NOTE 6 Model PA-34-200T; S/N 34-7570001 through 34-8170092, may be operated in known icing conditions when equipped with deicing equipment installed per Piper Drawing No. 37700 and spinner assembly.

Figure 16-11. Type Certificate Data Sheet. (continued)

applied by the nosewheel would now be balanced by the 580 lbs of equivalent weight, and the end of the beam would be centered between the top and bottom stop.

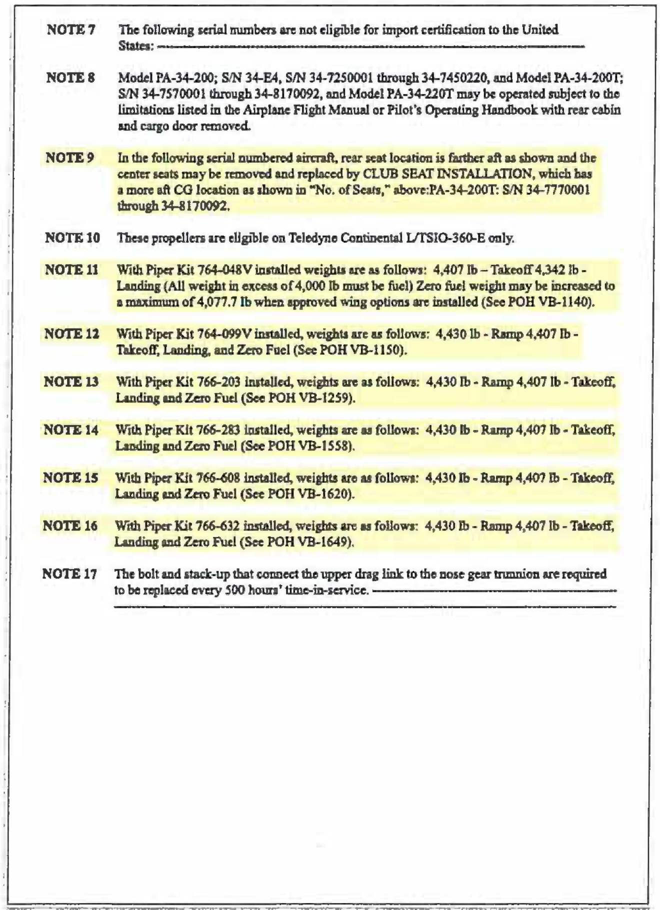
A mechanical scale based on springs is like the typical bathroom scale. When weight is applied to the scale, a spring compresses, which causes a wheel that displays the weight to rotate. It would be difficult to use this type of scale to weigh anything other than a very small aircraft, because these scales typically measure only up to 300 lb. The accuracy of this type of scale is also an issue.

Electronic scales that utilize load cells come in two varieties: the platform type and the type that mounts to the top of a jack. The platform type of electronic scale sits on the ground, with the tire of the airplane sitting on top of the platform. Built into the platform is an electronic load cell, which senses the weight being applied to it and generates a corresponding electrical signal.

Inside the load cell there is an electronic grid that experiences a proportional change in electrical resistance as the weight being applied to it increases. An electrical cable runs from the platform scale to a display unit, which interprets the resistance change of the load cell and equates it to a specific number of pounds. A digital readout on the display typically shows the weight. In ***Figure 16-12***, a Piper Archer is being weighed using platform scales that incorporate electronic load cells. In this case, the platform scales are secured to the hangar floor and stay permanently in place.

In ***Figure 16-13***, a Mooney M20 airplane is being weighed with portable electronic platform scales. Notice in the picture of the Mooney that its nose tire is deflated (close-up shown in the lower right corner of the photo). This was done to get the airplane in a level flight attitude. This type of scale is easy to transport and can be powered by household current or by a battery contained in the display unit. The display unit for these scales is shown in ***Figure 16-14***.

The display unit for the portable scales is very simple to operate. (***Figure 16-14***) In the lower left corner is



NOTE 7	The following serial numbers are not eligible for import certification to the United States: --
NOTE 8	Model PA-34-200; S/N 34-E4, S/N 34-7250001 through 34-7450220, and Model PA-34-200T; S/N 34-7570001 through 34-8170092, and Model PA-34-220T may be operated subject to the limitations listed in the Airplane Flight Manual or Pilot's Operating Handbook with rear cabin and cargo door removed.
NOTE 9	In the following serial numbered aircraft, rear seat location is farther aft as shown and the center seats may be removed and replaced by CLUB SEAT INSTALLATION, which has a more aft CG location as shown in "No. of Seats," above:PA-34-200T: S/N 34-7770001 through 34-8170092.
NOTE 10	These propellers are eligible on Teledyne Continental L/TSIO-360-E only.
NOTE 11	With Piper Kit 764-048V installed weights are as follows: 4,407 lb – Takeoff 4,342 lb - Landing (All weight in excess of 4,000 lb must be fuel) Zero fuel weight may be increased to a maximum of 4,077.7 lb when approved wing options are installed (See POH VB-1140).
NOTE 12	With Piper Kit 764-099V installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing, and Zero Fuel (See POH VB-1150).
NOTE 13	With Piper Kit 766-203 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1259).
NOTE 14	With Piper Kit 766-283 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1558).
NOTE 15	With Piper Kit 766-608 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1620).
NOTE 16	With Piper Kit 766-632 installed, weights are as follows: 4,430 lb - Ramp 4,407 lb - Takeoff, Landing and Zero Fuel (See POH VB-1649).
NOTE 17	The bolt and stack-up that connect the upper drag link to the nose gear trunnion are required to be replaced every 500 hours' time-in-service. --

Figure 16-11. Type Certificate Data Sheet. (continued)

the power switch, and in the lower right is the switch for selecting pounds or kilograms. The red, green, and yellow knobs are potentiometers for zeroing the three scales, and next to them are the ON/OFF switches for

Figure 16-12. Weighing a Piper Archer using electronic platform scales.

the scales. Before the weight of the airplane is placed on the scales, each scale switch is turned on and the potentiometer knob turned until the digital display reads zero. In ***Figure 16-14***, the nose scale is turned on and the readout of 546 lbs is for the Mooney airplane in ***Figure 16-13***. If all three scale switches are turned on at the same time, the total weight of the airplane will be displayed.

The second type of electronic scale utilizes a load cell that attaches to the top of a jack. The top of the load cell has a concave shape that matches up with the jack pad on the aircraft, with the load cell absorbing all the weight of the aircraft at each jacking point. Each load cell has an electrical cable attached to it, which connects to the display unit that shows the weight being absorbed by each load cell. An important advantage of weighing an aircraft this way is that it allows the technician to

Figure 16-13. Mooney M20 being weighed with portable electronic platform scales.

level the aircraft. An aircraft needs to be in a flight level attitude when it is weighed. If an aircraft is sitting on floor scales, the only way to level the aircraft might be to deflate tires and landing gear struts. When an aircraft is weighed using load cells on jacks, leveling the aircraft is easy by simply adjusting the height with the jacks. ***Figure 16-15*** shows a regional jet on jacks with the load cells in place.

SPIRIT LEVEL

Before an aircraft can be weighed and reliable readings obtained, it must be in a level flight attitude. One method that can be used to check for a level condition is to use a spirit level, sometimes thought of as a carpenter's level, by placing it on or against a specified place on the aircraft. Spirit levels consist of a vial full of liquid, except for a small air bubble. When the air bubble is centered between the two black lines, a level condition is indicated. In ***Figure 16-16***, a spirit level is being used on a Mooney M20 to check for a flight level attitude. By looking in the Type Certificate Data Sheet, it is determined that the leveling means is two screws on the left side of the airplane fuselage, in line with the trailing edge of the wing.

PLUMB BOB

A plumb bob is a heavy metal object, cylinder or cone shape, with a sharp point at one end and a string attached to the other end. If the string is attached to a given point on an aircraft, and the plumb bob is allowed to hang down so the tip just touches the ground, the point where the tip touches will be perpendicular to where the string is attached. An example of the use of a plumb bob would be measuring the distance from an aircraft's datum to the center of the main landing gear axle. If the leading edge of the wing was the datum, a plumb bob could be dropped from the leading edge and a chalk mark made on the hangar floor. The plumb bob could also be dropped from the center of the axle on the main landing gear, and a chalk mark made on the floor. With a tape measure, the distance between the two chalk marks could be determined, and the arm for the main landing gear would be known. ***Figure 16-17*** shows a plumb bob being dropped from the leading edge of an aircraft wing.

Figure 16-14. Display unit showing nosewheel weight for Mooney M20.

HYDROMETER

Figure 16-15. Airplane on jacks with load cells in use.

Figure 16-16. Spirit level being used on a Mooney M20.

When an aircraft is weighed with full fuel in the tanks, the weight of the fuel must be accounted for by mathematically subtracting it from the scale readings. To subtract it, its weight, arm, and moment must be known. Although the standard weight for aviation gasoline is 6.0 lbs/gal and jet fuel is 6.7 lbs/gal, these values are not exact for all conditions. On a hot day versus a cold day, these values can vary dramatically. On a hot summer day in the state of Florida, aviation gasoline checked with a hydrometer typically weighs between 5.85 and 5.9 lbs/gal. If 100 gallons of fuel were involved in a calculation, using the actual weight versus the standard weight would make a difference of 10 to 15 lbs.

When an aircraft is weighed with fuel in the tanks, the weight of fuel per gallon should be checked with a hydrometer. A hydrometer consists of a weighted glass tube which is sealed, with a graduated set of markings on the side of the tube. The graduated markings and their corresponding number values represent units of fuel in it, the glass tube floats at a level dependent on the density of the fuel. Where the fuel intersects the markings on the side of the tube indicates the pounds per gallon.

PREPARING AN AIRCRAFT FOR WEIGHING

Weighing an aircraft is a very important and exacting phase of aircraft maintenance, and must be carried out with accuracy and good workmanship. Thoughtful preparation saves time and prevents mistakes.

To begin, assemble all the necessary equipment, such as:

1. Scales, hoisting equipment, jacks, and leveling equipment.
2. Blocks, chocks, or sandbags for holding the airplane on the scales.
3. Straightedge, spirit level, plumb bobs, chalk line, and a measuring tape.
4. Applicable Aircraft Specifications and weight and balance computation forms.

If possible, aircraft should be weighed in a closed building where there are no air currents to cause incorrect scale readings. An outside weighing is permissible if wind and moisture are negligible.

Figure 16-17. Plumb bob dropped from a wing leading edge.

FUEL SYSTEM

When weighing an aircraft to determine its empty weight, only the weight of residual (unusable) fuel should be included. To ensure that only residual fuel is accounted for, the aircraft should be weighed in one of the following three conditions.

1. Weigh the aircraft with absolutely no fuel in the aircraft tanks or fuel lines. If an aircraft is weighed add the proper amount of residual fuel to the aircraft, and account for its arm and moment. The proper amount of fuel can be determined by looking at the Aircraft Specifications or Type Certificate Data Sheet.
2. Weigh the aircraft with only residual fuel in the tanks and lines.
3. Weigh the aircraft with the fuel tanks completely full. If an aircraft is weighed in this condition, the technician can mathematically subtract the weight of usable fuel, and account for its arm and moment. A hydrometer can be used to determine the weight of each gallon of fuel, and the Aircraft Specifications or Type Certificate Data Sheet can be used to identify the fuel capacity. If an aircraft is to be weighed with load cells attached to jacks, the technician should check to make sure it is permissible to jack the aircraft with the fuel tanks full. It is possible that this may not be allowed because of stresses that would be placed on the aircraft.

Never weigh an aircraft with the fuel tanks partially full, because it will be impossible to determine exactly how much fuel to account for.

OIL SYSTEM

For aircraft certified since 1978, full engine oil is typically included in an aircraft's empty weight. This can be confirmed by looking at the Type Certificate Data Sheet. If full oil is to be included, the oil level needs to be checked and the oil system serviced if it is less than full.

If the Aircraft Specifications or Type Certificate Data Sheet specifies that only residual oil is part of empty weight, this can be accommodated by one of the following two methods.

1. Drain the engine oil system to the point that only residual oil remains.
2. Check the engine oil quantity, and mathematically subtract the weight of the oil that would leave only the residual amount. The standard weight for lubricating oil is 7.5 lbs/gal (1.875 pounds per quart (lbs/qt)), so if 7 quarts of oil is needed to be removed, the technician would subtract 13.125 lbs at the appropriate arm.

MISCELLANEOUS FLUIDS

Unless otherwise noted in the Aircraft Specifications or manufacturer's instructions, hydraulic reservoirs and systems should be filled, drinking and washing water reservoirs and lavatory tanks should be drained, and constant speed drive oil tanks should be filled.

FLIGHT CONTROLS

The position of such items as spoilers, slats, flaps, and helicopter rotor systems is an important factor when weighing an aircraft. Always refer to the manufacturer's instructions for the proper position of these items.

OTHER CONSIDERATIONS

Inspect the aircraft to see that all items included in the certificated empty weight are installed in the proper location. Remove items that are not regularly carried in flight. Also look in the baggage compartments to make sure they are empty. Replace all inspection plates, oil and fuel tank caps, junction box covers, cowling, doors, emergency exits, and other parts that have been removed. All doors, windows, and sliding canopies should be in their normal flight position. Remove excessive dirt, oil, grease, and moisture from the aircraft.

Some aircraft are not weighed with the wheels on the scales, but are weighed with the scales placed either at the jacking points or at special weighing points. Regardless of what provisions are made for placing the aircraft on the scales or jacks, be careful to prevent it from falling or rolling off, thereby damaging the aircraft and equipment. When weighing an aircraft with the wheels placed on the scales, release the brakes to reduce the possibility of incorrect readings caused by side loads on the scales.

All aircraft have leveling points or lugs, and care must be taken to level the aircraft, especially along the longitudinal axis. With light, fixed-wing airplanes, the lateral level is not as critical as it is with heavier airplanes. However, a reasonable effort should be made to level the light airplanes along the lateral axis. Helicopters must be level longitudinally and laterally when they are weighed. Accuracy in leveling all aircraft longitudinally cannot be overemphasized.

WEIGHING POINTS

When an aircraft is being weighed, the arms must be known for the points where the weight of the aircraft is being transferred to the scales. If a tricycle gear small airplane has its three wheels sitting on floor scales, the weight transfer to each scale happens through the center of the axle for each wheel. If an airplane is weighed while it is on jacks, the weight transfer happens through the center of the jack pad. For a helicopter with skids for landing gear, determining the arm for the weighing points can be difficult if the skids are sitting directly on floor scales. The problem is that the skid is in contact with the entire top portion of the scale, and it is impossible to know exactly where the center of weight transfer is occurring. In such a case, place a piece of pipe between the skid and the scale, and the center of the pipe will now be the known point of weight transfer.

The arm for each of the weighing points is the distance from the center of the weight transfer point to the aircraft's datum. If the arms are not known, based on previous weighing of the aircraft or some other source of data, they must be measured when the aircraft is weighed. This involves dropping a plumb bob from the center of each weighing point and from the aircraft datum, and putting a chalk mark on the hangar floor representing each point. The perpendicular distance between the datum and each of the weighing points can then be measured. In ***Figure 16-18***, the distance from the nosewheel centerline to the datum is being measured on a Cessna 310 airplane. Notice the chalk lines on the

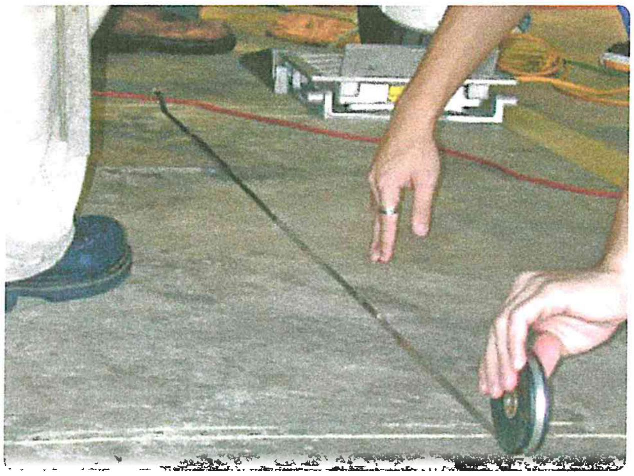


Figure 16-18. Measuring the nosewheel arm on a Cessna 310.

hangar floor, which came as a result of dropping a plumb bob from the nosewheel axle centerline and from the datum. The nosewheel sitting on an electronic scale can be seen in the background.

CENTER OF GRAVITY RANGE

The center of gravity range for an aircraft is the limits within which the aircraft must balance. It is identified as a forward most limit (arm) and an aft most limit (arm).

In the Type Certificate Data Sheet for the Piper Seneca airplane, shown earlier in this chapter, the range is given as follows:

CG Range: (Gear Extended)
S/N 34-E4, 34-7250001 through
34- 7250214 (See NOTE 3):
(+86.4") to (+94.6") at 4 000 lb
(+82.0") to (+94.6") at 3 400 lb
(+80.7") to (+94.6") at 2 780 lb
Straight line variation between points given.
Moment change due to gear retracting landing
gear (–32 in-lb).

Because the Piper Seneca is a retractable gear airplane, the specifications identify that the range applies when the landing gear is extended, and that the airplane's total moment will be decreased by 32 when the gear retracts. To know how much the center of gravity will change when the gear is retracted, the moment of 32 in-lbs would need to be divided by the loaded weight of the airplane. For example, if the airplane weighed 3 500 lbs, the center of gravity would move forward 0.009" (32 ÷ 3 500).

Based on the numbers given, up to a loaded weight of 2 780 lbs, the forward CG limit is +80.7" and the aft CG limit is +94.6". As the loaded weight of the airplane increases to 3 400 lbs and eventually to the maximum of 4 000 lbs, the forward CG limit moves aft. In other words, as the loaded weight of the airplane increases, the CG range gets smaller. The range gets smaller as a result of the forward limit moving back, while the aft limit stays in the same place.

The data sheet identifies that there is a straight line variation between the points given. The points being referred to are the forward and aft center of gravity limits. From a weight of 2 780 lbs to a weight of 3 400 lbs, the forward limit moves from +80.7" to +82.0", and if plotted on a graph, that change would form a straight line. From 3 400 lbs to 4 000 lbs, the forward limit moves from +82 to +86.4", again forming a straight line. Plotted on a graph, the CG limits would look like what is shown in ***Figure 16-19***. When graphically plotted, the CG limits form what is known as the CG envelope.

In ***Figure 16-19***, the red line represents the forward limit up to a weight of 2 780 lbs. The blue and green lines represent the straight line variation that occurs for the forward limit as the weight increases up to a maximum of 4 000 lbs. The yellow line represents the maximum weight for the airplane, and the purple line represents the aft limit.

EMPTY WEIGHT CENTER OF GRAVITY RANGE

For some aircraft, a center of gravity range is given for the aircraft in the empty weight condition. This practice is not very common with airplanes, but is often done for helicopters. This range would only be listed for an airplane if it was very small and had limited positions for people and fuel. If the empty weight CG of an aircraft falls within the empty weight CG limits, it is known that the loaded CG of the aircraft will be within limits if standard loading is used. This information will be listed in the Aircraft Specifications or Type Certificate Data Sheet, and if it does not apply, it will be identified as "none."

OPERATING CENTER OF GRAVITY RANGE

All aircraft will have center of gravity limits identified for the operational condition, with the aircraft loaded and ready for flight. If an aircraft can operate in more

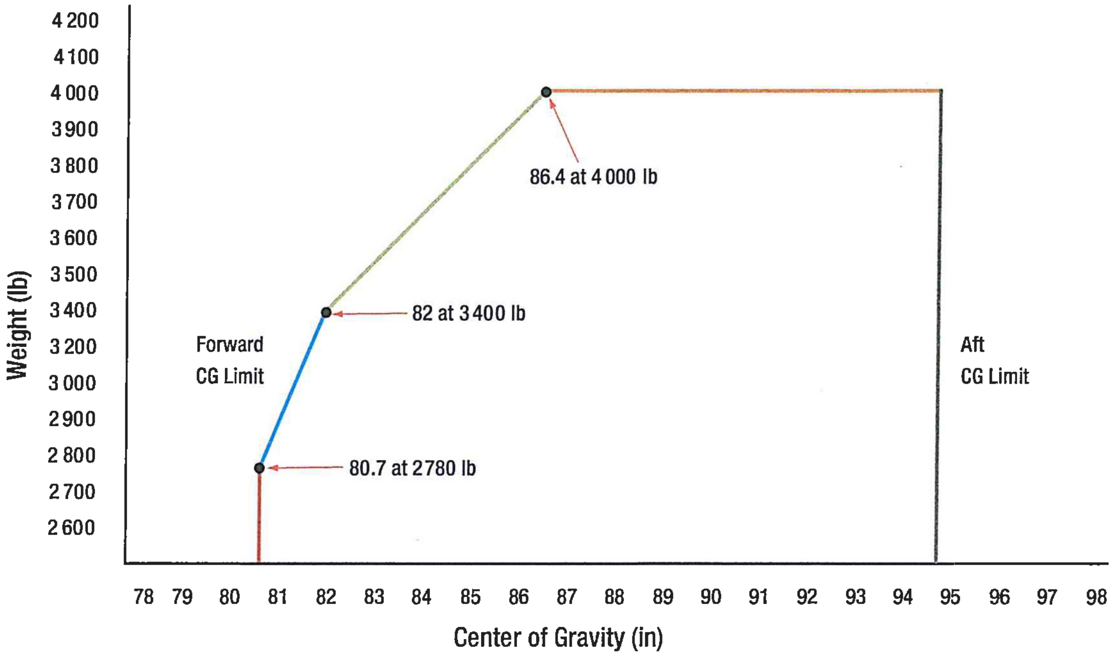


Figure 16-19. Center of gravity envelope for the Piper Seneca.

than one category, such as normal and utility, more than one set of limits might be listed. As shown earlier for the Piper Seneca airplane, the limits can change as the weight of the aircraft increases. In order to legally fly, the center of gravity for the aircraft must fall within the CG limits.

STANDARD WEIGHTS USED FOR AIRCRAFT WEIGHT AND BALANCE

Unless the specific weight for an item is known, the standard weights used in aircraft weight and balance are as follows:

- Aviation gasoline 6 lbs/gal
- Turbine fuel 6.7 lbs/gal
- Lubricating oil 7.5 lbs/gal
- Water 8.35 lbs/gal
- Crew and passengers 170 lbs per person

EXAMPLE WEIGHING OF AN AIRPLANE

In ***Figure 16-20***, a tricycle gear airplane is being weighed by using three floor scales. The specifications on the airplane and the weighing specific data are as follows:

- Aircraft Datum: Leading edge of the wing
- Leveling Means: Two screws, left side of fuselage below window
- Wheelbase: 100"
- Fuel Capacity: 30 gals aviation gasoline at +95"
- Unusable Fuel: 6 lbs at +98"
- Oil Capacity: 8 qts at –38"
- Note 1: Empty weight includes unusable fuel and full oil
- Left Main Scale Reading: 650 lbs
- Right Main Scale Reading: 640 lbs
- Nose Scale Reading: 225 lbs
- Tare Weight: 5 lb chocks on left main, 5 lb chocks on right main, 2.5 lb chock on nose
- During Weighing: Fuel tanks full and oil full; Hydrometer check on fuel shows 5.9 lbs/gal

By analyzing the data identified for the airplane being weighed in ***Figure 16-20***, the following needed information is determined.

- Because the airplane was weighed with the fuel tanks full, the full weight of the fuel must be subtracted and the unusable fuel added back in. The weight of the fuel being subtracted is based on the pounds per gallon determined by the hydrometer check (5.9 lbs/gal).
- Because wheel chocks are used to keep the airplane from rolling off the scales, their weight must be subtracted from the scale readings as tare weight.
- Because the main wheel centerline is 70" behind the datum, its arm is a +70".
- The arm for the nosewheel is the difference between the wheelbase (100") and the distance from the datum to the main wheel centerline (70"). Therefore, the arm for the nosewheel is –30".

To calculate the airplane's empty weight and empty weight center of gravity, a six column chart is used. ***Figure 16-21*** shows the calculation for the airplane in ***Figure 16-20***.

Based on the calculation shown in the chart, the center of gravity is at +50.1", which means it is 50.1" aft of the datum. This places the center of gravity forward of the main landing gear, which must be the case for a tricycle gear airplane. This number is the result of dividing the total moment of 66 698 in-lbs by the total weight of 1 331.5 lbs.

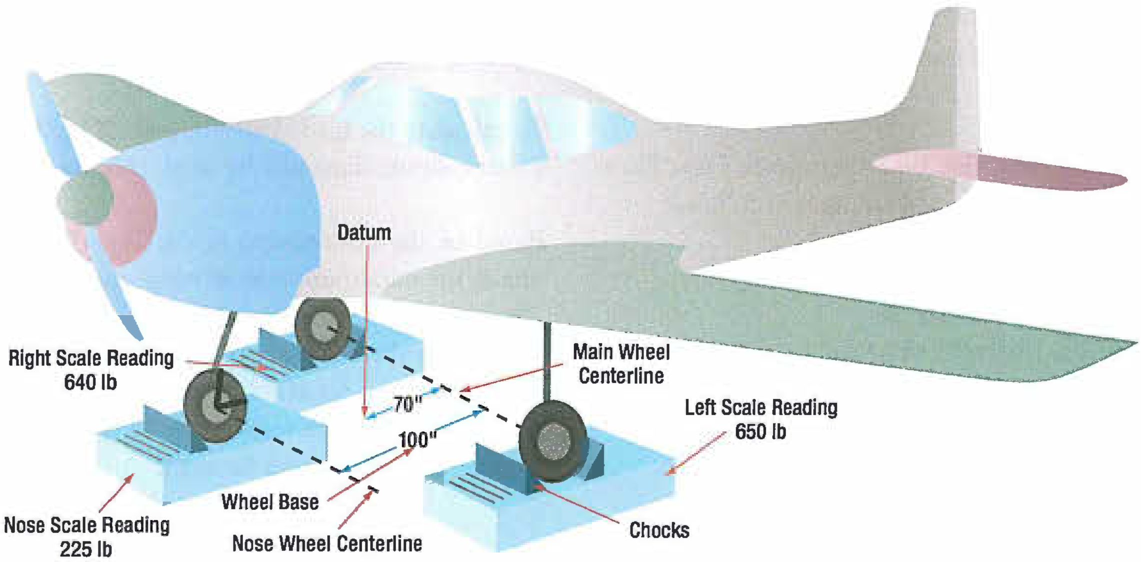


Figure 16-20. Example airplane being weighed.

Item	Weight (lb)	Tare (lb)	Net Wt. (lb)	Arm (inches)	Moment (in-lb)
Nose	225	–2.5	222.5	–30	–6 675
Left Main	650	–5	645	+70	45 150
Right Main	640	–5	635	+70	44 450
Subtotal	1 515	–12.5	1 502.5		82 925
Fuel Total			–177	+95	–16 815
Fuel Unuse			+6	+98	588
Oil			Full		
Total			1 331.5	+50.1	66 698

Figure 16-21. Example airplane being weighed.

LOADING AN AIRPLANE FOR FLIGHT

The ultimate test of whether or not there is a problem with an airplane's weight and balance is when it is loaded and ready to fly. The only real importance of an airplane's empty weight and empty weight center of gravity is how it affects the loaded weight and balance of the airplane, since an airplane doesn't fly when it is empty. The pilot in command is responsible for the weight and balance of the loaded airplane, and he or she makes the final decision on whether or not the airplane is safe to fly.

EXAMPLE LOADING OF AN AIRPLANE

As an example of an airplane being loaded for flight, the Piper Seneca twin will be used. The Type Certificate Data Sheet for this airplane was shown earlier in this chapter, and its center of gravity range and CG envelope were also shown.

The information from the Type Certificate Data Sheet that pertains to this example loading is as follows:

CG Range (Gear Extended) S/N 34-7250215 through 34-7450220:
(+87.9") to (+94.6") at 4 200 lb
(+82.0") to (+94.6") at 3 400 lb
(+80.7") to (+94.6") at 2 780 lb
Straight line variation between points given.
-32 in-lb moment change due to gear retracting landing gear

Empty Weight CG Range None

Maximum Weight S/N 34-7250215 through 34-7450220:
4 200 lb—Takeoff
4 000 lb—Landing

No. of Seats 7 (2 at +85.5", 3 at +118.1", 2 at +155.7")

Maximum Baggage 200 lb (100 lb at +22.5, 100 lb at +178.7)

Fuel Capacity 98 gal (2 wing tanks) at (+93.6") (93 gal usable). See NOTE 1 for data on system fuel.

For the example loading of the airplane, the following information applies:

- Airplane Serial Number: 34-7250816
- Airplane Empty Weight: 2 650 lb
- Airplane Empty Weight CG: +86.8"

For today's flight, the following useful load items will be included:

- 1 pilot at 180 lbs at an arm of +85.5"
- 1 passenger at 160 lbs at an arm of +118.1"
- 1 passenger at 210 lbs at an arm of +118.1"
- 1 passenger at 190 lbs at an arm of +118.1"
- 1 passenger at 205 lbs at an arm of +155.7"
- 50 lbs of baggage at +22.5"
- 100 lbs of baggage at +178.7"
- 80 gals of fuel at +93.6"

To calculate the loaded weight and CG of this airplane, a four column chart will be used. (***Figure 16-22***)

Based on the information in the Type Certificate Data Sheet, the maximum takeoff weight of this airplane is 4 200 lbs, and the aft-most CG limit is +94.6". The loaded airplane in the chart above is 25 lbs too heavy, and the CG is 1.82" too far aft. To make the airplane safe to fly, the load needs to be reduced by 25 lbs and some of the load needs to be shifted forward.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 650	+86.80	230 020.0
Pilot	180	+85.50	15 390.0
Passenger	160	+118.10	18 896.0
Passenger	210	+118.10	24 801.0
Passenger	190	+118.10	22 439.0
Passenger	205	155.70	31 918.5
Baggage	50	+22.50	1 125.0
Baggage	100	+178.70	17 870.0
Fuel	480	+93.60	44 928.0
Total	4 255	+96.42	407 387.5

Figure 16-22. Center of gravity calculation for Piper Seneca.

For example, the baggage can be reduced by 25 lbs, and a full 100 lbs of it can be placed in the more forward compartment. One passenger can be moved to the forward seat next to the pilot, and the aft-most passenger can then be moved forward. If these changes are made, the four column calculation will be as shown in ***Figure 16-23***.

With the changes made, the loaded weight is now at the maximum allowable of 4 200 lbs, and the CG has moved forward 4.41". The airplane is now safe to fly.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 650	+86.8	230 020.0
Pilot	180	+85.5	15 390.0
Passenger	210	+85.5	17 955.0
Passenger	160	+118.1	24 801.0
Passenger	190	+118.1	22 439.0
Passenger	205	+118.1	24 210.5
Baggage	100	+22.5	2 250.0
Baggage	25	+178.7	4 467.5
Fuel	480	93.6	44 928.0
Total	4 200	+92.0	386 461.0

Figure 16-23. Center of gravity calculation for Piper Seneca with weights shifted.

WEIGHT AND BALANCE EXTREME CONDITIONS

A weight and balance extreme condition check, sometimes called an adverse condition check, involves loading the aircraft in as nose heavy or tail heavy a condition as possible, and seeing if the center of gravity falls outside the allowable limits. This check is done with pencil and paper. In other words, the aircraft is not actually loaded in an adverse way and an attempt made to fly it.

On what is called a forward extreme condition check, all useful load items in front of the forward CG limit are loaded, and all useful load items behind the forward CG limit are left empty. So if there are two seats and a baggage compartment located in front of the forward CG limit, two people weighing 170 lbs each will be put in the seats, and the maximum allowable baggage will be put in the baggage compartment. Any seat or baggage compartment located behind the forward CG limit will be left empty. If the fuel is located behind the forward CG limit, minimum fuel will be shown in the tank. Minimum fuel is calculated by dividing the engine's METO horsepower by 2.

On an aft extreme condition check, all useful load items behind the aft CG limit are loaded, and all useful load items in front of the aft CG limit are left empty. Even though the pilot's seat will be located in front of the aft CG limit, the pilot's seat cannot be left empty. If the fuel tank is located forward of the aft CG limit, minimum fuel will be shown.

EXAMPLE FORWARD AND AFT EXTREME CONDITION CHECKS

Using the stick airplane in ***Figure 16-24*** as an example, adverse forward and aft checks will be calculated.

Some of the data for the airplane is shown in the figure, such as seat, baggage, and fuel information. The center of gravity limits are shown, with arrows pointing in the direction where maximum and minimum weights will be loaded. On the forward check, any useful load item located in front of 89" will be loaded, and anything behind that location will be left empty. On the aft check, maximum weight will be added behind 99" and minimum weight in front of that location. For either of the checks, if fuel is not located in a maximum weight location, minimum fuel must be accounted for. Notice that the front seats show a location of 82" to 88", meaning they are adjustable fore and aft. In a forward check, the pilot's seat will be shown at 82", and in the aft check it will be at 88".

Additional specifications for the airplane shown in ***Figure 16-25*** are as follows:

- Airplane Empty Weight: 1 850 lb
- Empty Weight CG: +92.45"
- CG Limits: +89" to +99"
- Maximum Weight: 3 200 lb
- Fuel Capacity: 45 gal at +95" (44 usable)
  40 gal at +102" (39 usable)

In evaluating the two extreme condition checks, the following key points should be recognized:

- The total arm is the airplane center of gravity, and is found by dividing the total moment by the total weight.
- For the forward check, the only thing loaded behind the forward limit was minimum fuel.
- For the forward check, the pilot and passenger seats were shown at the forward position of 82".
- For the forward check, the CG was within limits, so the airplane could be flown this way.
- For the aft check, the only thing loaded in front of the aft limit was the pilot, at an arm of 88".
- For the aft check, the fuel tank at 102" was filled, which more than accounted for the required minimum fuel.
- For the aft check, the CG was out of limits by 0.6", so the airplane should not be flown this way.

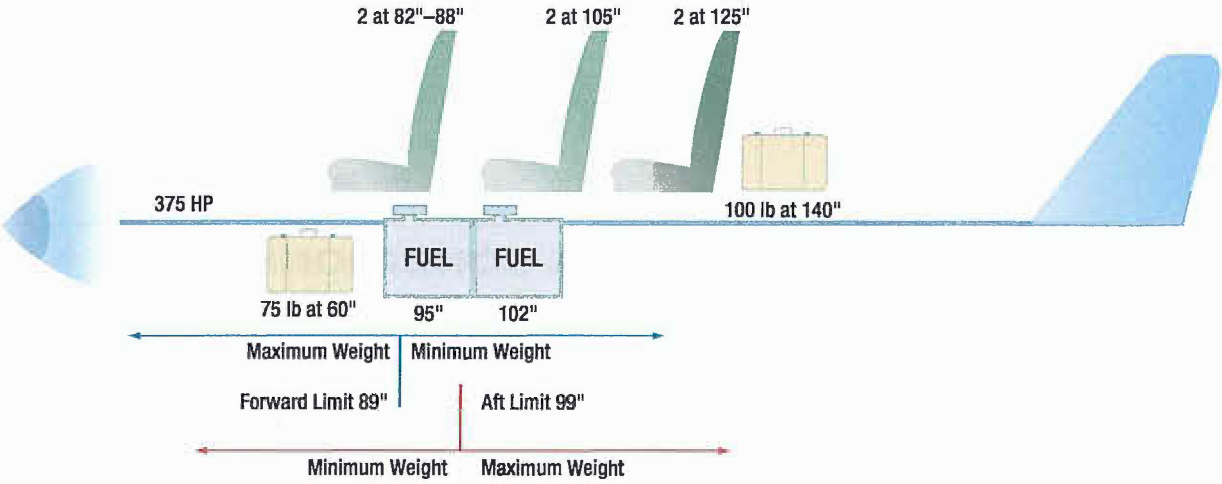


Figure 16-24. Example airplane for extreme condition checks.

Extreme Condition Forward Check			
Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	1 850.0	+92.45	171 032.5
Pilot	170.0	+82.00	13 940.0
Passenger	170.0	+82.00	13 940.0
Baggage	75.0	+60.00	4 500.0
Fuel	187.5	+95.00	17 812.5
Total	2 452.5	+90.20	221 225.0

Extreme Condition Aft Check			
Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	1 850	+92.45	171 032.5
Pilot	170	+88.00	14 960.0
2 Passengers	340	+105.00	35 700.0
2 Passengers	340	+125.00	42 500.0
Baggage	100	+140.00	14 000.0
Fuel	234	+102.00	23 868.0
Total	3 034	+99.60	302 060.5

Figure 16-25. Center of gravity extreme condition checks.

EQUIPMENT CHANGE AND AIRCRAFT ALTERATION

When the equipment in an aircraft is changed, such as the installation of a new radar system or ground proximity warning system, or the removal of a radio or seat, the weight and balance of an aircraft will change. An alteration performed on an aircraft, such as a cargo door being installed or a reinforcing plate being attached to the spar of a wing, will also change the weight and balance of an aircraft. Any time the equipment is changed or an alteration is performed, the new empty weight and empty weight center of gravity must be determined.

This can be accomplished by placing the aircraft on scales and weighing it, or by mathematically calculating the new weight and balance. The mathematical calculation is acceptable if the exact weight and arm of all the changes are known.

EXAMPLE CALCULATION AFTER AN EQUIPMENT CHANGE

A small twin-engine airplane has some new equipment installed, and some of its existing equipment removed.

The details of the equipment changes are as follows:

- Airplane Empty Weight: 2 350 lb
- Airplane Empty Weight CG: +24.7"
- Airplane Datum: Leading edge of the wing
- Radio Installed: 5.8 lb at an arm of –28"
- Global Positioning System Installed: 7.3 lb at an arm of –26"
- Emergency Locater Transmitter Installed: 2.8 lb at an arm of +105"
- Strobe Light Removed: 1.4 lb at an arm of +75"
- Automatic Direction Finder (ADF) Removed: 3 lb at an arm of –28"
- Seat Removed: 34 lb at an arm of +60"

To calculate the new empty weight and empty weight center of gravity, a four column chart is used. The calculation would be as shown in ***Figure 16-26.***

In evaluating the weight and balance calculation shown in ***Figure 16-26***, the following key points should be recognized.

- The weight of the equipment needs to be identified with a plus or minus to signify whether it is being installed or removed.
- The sign of the moment (plus or minus) is determined by the signs of the weight and arm.
- The strobe and the ADF are both being removed (negative weight), but only the strobe has a negative moment. This is because the arm for the ADF is also negative, and two negatives multiplied together produce a positive result.
- The total arm is the airplane's center of gravity, and is found by dividing the total moment by the total weight.
- The result of the equipment change is that the airplane's weight was reduced by 22.5 lbs and the center of gravity has moved forward 0.67".

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	2 350.0	+24.70	58 045.0
Radio Install	+5.8	–28.00	–162.4
GPS Install	+7.3	–26.00	–189.8
ELT Install	+2.8	+105.00	294.0
Strobe Remove	–1.4	+75.00	–105.0
ADF Remove	–3.0	–28.00	84.0
Seat Remove	–34.0	+60.00	–2 040.0
Total	2 327.5	24.03	55 925.8

Figure 16-26. Center of gravity calculation after equipment change.

THE USE OF BALLAST

Ballast is used in an aircraft to attain the desired CG balance, when the center of gravity is not within limits or is not at the location desired by the operator. It is usually located as far aft or as far forward as possible to bring the CG within limits, while using a minimum amount of weight. Ballast that is installed to compensate for the removal or installation of equipment items and that is to remain in the aircraft for long periods is called permanent ballast.

It is generally lead bars or plates bolted to the aircraft structure. It may be painted red and placarded:

- PERMANENT BALLAST—DO NOT REMOVE. The installation of permanent ballast results in an increase in the aircraft empty weight, and it reduces the useful load.

Temporary ballast, or removable ballast, is used to meet certain loading conditions that may vary from time to time. It generally takes the form of lead shot bags, sand bags, or other weight items that are not permanently installed. Temporary ballast should be placarded:

- BALLAST, XX LB. REMOVAL REQUIRES WEIGHT AND BALANCE CHECK.
  The baggage compartment is usually the most convenient location for temporary ballast.

Whenever permanent or temporary ballast is installed, it must be placed in an approved location and secured in an appropriate manner. If permanent ballast is being bolted to the structure of the aircraft, the location must be one that was previously approved and designed for the installation, or it must be approved by the FAA as a major alteration before the aircraft is returned to service. When temporary ballast is placed in a baggage compartment, it must be secured in a way that prevents it from becoming a projectile if the aircraft encounters turbulence or an unusual flight attitude. To calculate how much ballast is needed to bring the center of gravity within limits, the following formula is used.

$$\text{Ballast Needed} = \frac{\text{Loaded weight of aircraft (distance CG is out of limits)}}{\text{Arm from ballast location to affected limit}}$$

Figure 16-24 and ***Figure 16-27*** show an aft extreme condition check being performed on an airplane. In this previously shown example, the airplane's center of gravity was out of limits by 0.6". If there were a need or a desire to fly the airplane loaded this way, one way to make it possible would be the installation of temporary ballast in the front of the airplane. The logical choice for placement of this ballast is the forward baggage compartment.

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Empty Weight	1 850	+92.45	171 032.5
Pilot	170	+88.00	14 960.0
2 Passengers	340	+105.00	35 700.0
2 Passengers	340	+125.00	42 500.0
Baggage	100	+140.00	14 000.0
Fuel	234	+102.00	23 868.0
Total	3 034	+99.60	302 060.5

Figure 16-27. Extreme condition check.

The center of gravity for this airplane is 0.6" too far aft. If the forward baggage compartment is used as a temporary ballast location, the ballast calculation will be as follows:

$$\text{Ballast Needed} = \frac{\text{Loaded weight of aircraft (distance CG is out of limits)}}{\text{Arm from ballast location to affected limit}}$$

$$= \frac{3\,034 \text{ lb } (0.6")}{39"}$$

$$= 46.68 \text{ lbs}$$

When ballast is calculated, the answer should always be rounded up to the next higher whole pound, or in this case, 47 lbs of ballast would be used. To ensure the ballast calculation is correct, the weight of the ballast should be plugged back into the four column calculation and a new center of gravity calculated.

The aft limit for the airplane was 99", and the new CG is at 98.96", which puts it within acceptable limits. The new CG did not fall exactly at 99" because the amount of needed ballast was rounded up to the next higher whole pound. If the ballast could have been placed farther forward, such as being bolted to the engine firewall, less ballast would have been needed. That is why ballast is always placed as far away from the affected limit as possible. (***Figure 16-28.***)

In evaluating the ballast calculation shown above, the following key points should be recognized.

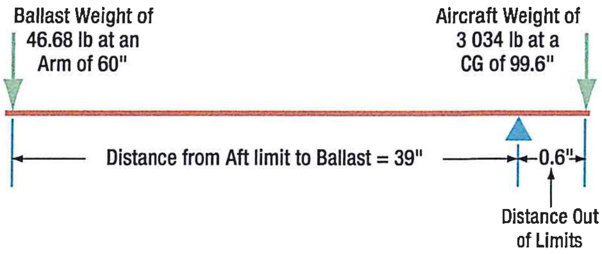
- The loaded weight of the aircraft, as identified in the formula, is what the airplane weighed when the CG was out of limits.

- The distance the CG is out of limits is the difference between the CG location and the CG limit, in this case 99.6" minus 99".
- The affected limit identified in the formula is the CG limit which has been exceeded. If the CG is too far aft, it is the aft limit that has been exceeded.
- The aft limit for this example airplane is 99", and the ballast is being placed in the baggage compartment at an arm of 60". The difference between the two is 39", the quantity divided by in the formula.

Viewed as a first class lever problem, ***Figure 16-29*** shows what this ballast calculation would look like. A ballast weight of 46.68 lbs on the left side of the lever multiplied by the arm of 39" (99 minus 60) would equal the aircraft weight of 3 034 lb multiplied by the distance the CG is out of limits, which is 0.6" (99.6 minus 99).

Item	Weight (lb)	Arm (inches)	Moment (in-lb)
Loaded Weight	3 034	+99.60	302 060.5
Ballast	47	+60.00	2 820.0
Total	3 081	+98.96	304 880.5

Figure 16-28. Ballast calculation.



In order to balance at the aft limit of 99" the moment to the left of the fulcrum must equal the moment to the right of the fulcrum. The moment to the right is the weight of the airplane multiplied by 0.6". The moment to the left is the ballast weight multiplied by 39".

Figure 16-29. Ballast calculation as a first class lever.

LOADING GRAPHS AND CG ENVELOPES

The weight and balance computation system, commonly called the loading graph and CG envelope system, is an excellent and rapid method for determining the CG location for various loading arrangements. This method can be applied to any make and model of aircraft, but is more often seen with small general aviation aircraft.

Aircraft manufacturers using this method of weight and balance computation prepare graphs similar to those shown in ***Figures 16-30 and 16-31*** for each make and model aircraft at the time of original certification. The graphs become a permanent part of the aircraft records, and are typically found in the Airplane Flight Manual or Pilot's Operating Handbook (AFM/POH). These graphs, used in conjunction with the empty weight and empty weight CG data found in the weight and balance report, allow the pilot to plot the CG for the loaded aircraft.

The loading graph illustrated in ***Figure 16-30*** is used to determine the index number (moment value) of any item or weight that may be involved in loading the aircraft. To use this graph, find the point on the vertical scale that represents the known weight. Project a horizontal line to the point where it intersects the proper diagonal weight line (i.e., pilot, copilot, baggage). Where the horizontal line intersects the diagonal, project a vertical line downward to determine the loaded moment (index number) for the weight being added.

After the moment for each item of weight has been determined, all weights are added and all moments are added. The total weight and moment is then plotted on the CG envelope. (***Figure 16-31***) The total weight is plotted on the vertical scale of the graph, with a horizontal line projected out from that point. The total moment is plotted on the horizontal scale of the graph, with a vertical line projected up from that point. Where the horizontal and vertical plot lines intersect on the graph is the center of gravity for the loaded aircraft. If the point where the plot lines intersect falls inside the CG envelope, the aircraft CG is within limits.

In ***Figure 16-31***, there are actually two CG envelopes, one for the aircraft in the Normal Category and one for the aircraft in the Utility Category.

Figure 16-30. Aircraft loading graph.

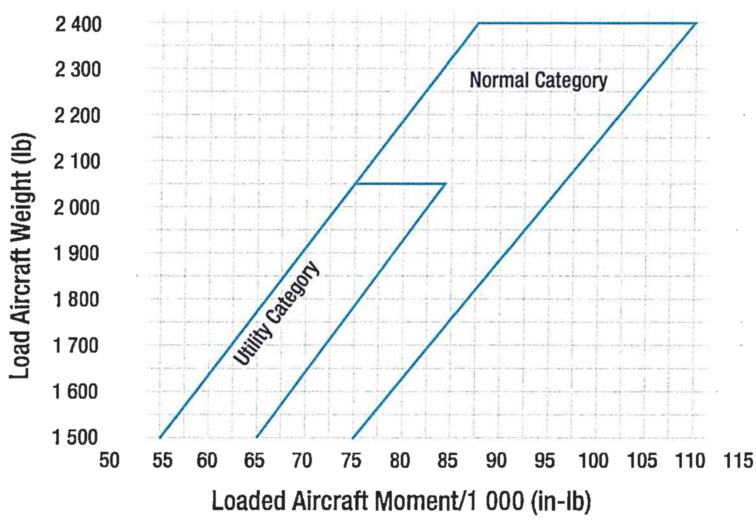


Figure 16-31. CG envelope.

The loading graph and CG envelope shown in ***Figures 16-30 and 16-31*** are for an airplane with the following specifications and weight and balance data.

- Number of Seats: 4
- Fuel Capacity (Usable): 38 gal of Av Gas
- Oil Capacity: 8 qt (included in empty weight)
- Baggage: 120 lb
- Empty Weight: 1 400 lb
- Empty Weight CG: 38.5"
- Empty Weight Moment: 53 900 in-lb

An example of loading the airplane for flight and calculating the total loaded weight and the total loaded moment is shown in ***Figures 16-32 and 16-33***. The use of the loading graph to determine the moment for each

Item	Weight (lb)	Moment (in-lb)
Aircraft Empty Wt.	1 400	53 900
Pilot	180	6 000
Front Passengers	140	4 500
Rear Passengers	210	15 000
Baggage	100	9 200
Fuel	228	10 800
Total	2 258	99 400

Figure 16-32. Aircraft load chart.

of the useful load items is shown in ***Figure 16-33***. The color used for each useful load item in ***Figure 16-32*** matches the color used for the plot on the loading graph.

The total loaded weight of the airplane is 2 258 pounds and the total loaded moment is 99 400 in-lbs. These two numbers can now be plotted on the CG envelope to see if the airplane is within CG limits.

Figure 16-34 shows the CG envelope, with the loaded weight and moment of the airplane plotted. The CG location shown falls within the normal category envelope, so the airplane is within CG limits for this category. It is interesting to note that the lines that form the CG envelope are actually graphic plots of the forward and aft CG limits. In ***Figure 16-34***, the red line is a graphic plot of the forward limit, and the blue and green lines are graphic plots of the aft limit for the two different categories.

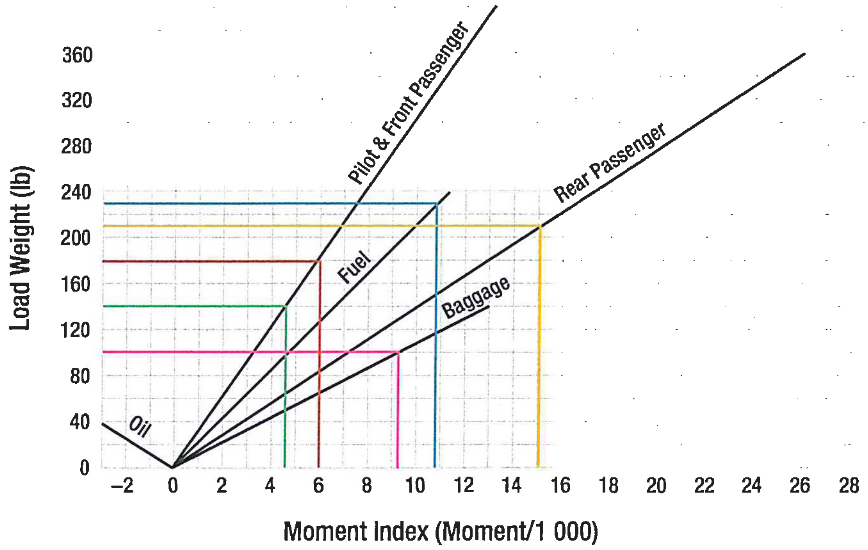


Figure 16-33. CG envelope.

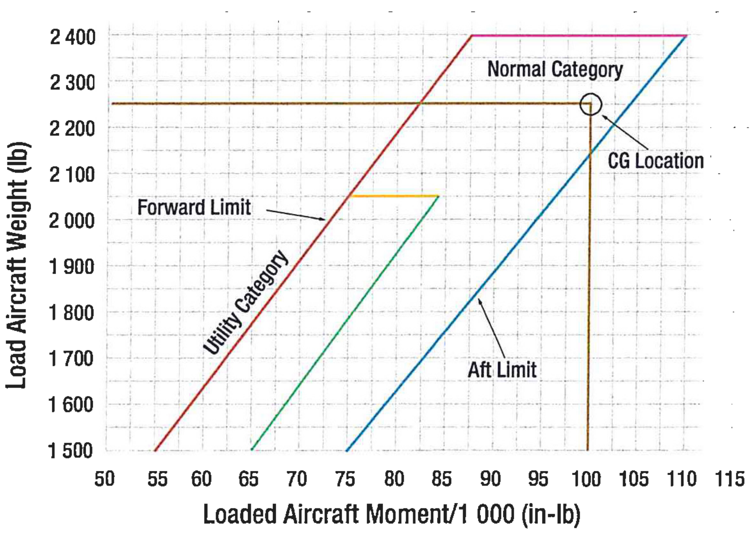


Figure 16-34. CG envelope example plot.

WEIGHT AND BALANCE FOR LARGE AIRPLANES

Weight and balance for large airplanes is almost identical to what it is for small airplanes, on a much larger scale. If a technician can weigh a small airplane and calculate its empty weight and empty weight center of gravity, that same technician should be able to do it for a large airplane. The jacks and scales will be larger, and it may take more personnel to handle the equipment, but the concepts and processes are the same.

BUILT-IN ELECTRONIC WEIGHING

One difference that may be found with large airplanes is the incorporation of electronic load cells in the aircraft's landing gear. With this type of system, the airplane is capable of weighing itself as it sits on the tarmac. The load cells are built into the axles of the landing gear, or the landing gear strut, and they work in the same manner as load cells used with jacks.

This system is currently in use on the Boeing 747-400, Boeing 777, Boeing 787, McDonnell Douglas MD-11, and the wide body Airbus airplanes like the A-330, A-340, and A-380. The Boeing 777 utilizes two independent systems that provide information to the airplane's flight management computer. If the two systems agree on the weight and center of gravity of the airplane, the data being provided are considered accurate and the airplane can be dispatched based on that information.

The flight crew has access to the information on the flight deck by accessing the flight management computer and bringing up the weight and balance page.

MEAN AERODYNAMIC CHORD

On small airplanes and on all helicopters, the center of gravity location is identified as being a specific number of inches from the datum. The center of gravity range is identified the same way. On larger airplanes, from private business jets to large jumbo jets, the center of gravity and its range are typically identified in relation to the width of the wing.

The width of the wing on an airplane is known as the chord. If the leading edge and trailing edge of a wing are parallel to each other, the chord of the wing is the same along the wing's length. Business jets and commercial transport airplanes have wings that are tapered and that are swept back, so the width of their wings is different along their entire length. The width is greatest where the wing meets the fuselage and progressively decreases toward the tip. In relation to the aerodynamics of the wing, the average length of the chord on these tapered swept-back wings is known as the mean aerodynamic chord (MAC).

On these larger airplanes, the CG is identified as being at a location that is a specific percent of the mean aerodynamic chord (% MAC). For example, imagine that the MAC on a particular airplane is 100", and the CG falls 20" behind the leading edge of the MAC. That means it falls one-fifth of the way back, or at 20% of the MAC.

Figure 16-35 shows a large twin-engine commercial transport airplane. The datum is forward of the nose of the airplane, and all the arms shown in the figure are being measured from that point. The center of gravity for the airplane is shown as an arm measured in inches. In the lower left corner of the figure, a cross section of the wing is shown, with the same center of gravity information being presented.

To convert the center of gravity location from inches to a percent of MAC, for the airplane shown in ***Figure 16-35***, the steps are as follows:

1. Identify the center of gravity location, in inches from the datum.
2. Identify the leading edge of the MAC (LEMAC), in inches from the datum.
3. Subtract LEMAC from the CG location.
4. Divide the difference by the length of the MAC.
5. Convert the result in decimals to a percentage by multiplying by 100.

As a formula, the solution to solve for the percent of MAC would be:

$$\text{Percent of MAC} = \frac{\text{CG-LEMAC}}{\text{MAC}} \times 100$$

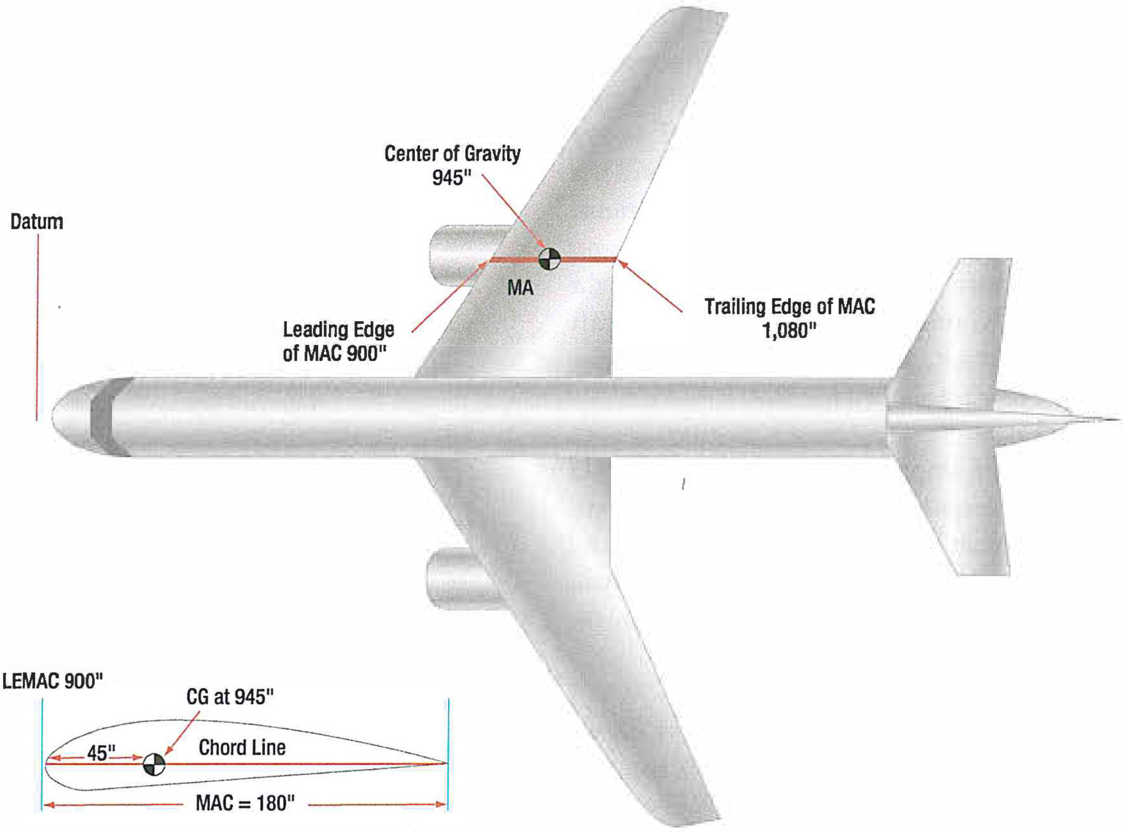


Figure 16-35. Center of gravity location on a large commercial transport.

The result using the numbers shown in ***Figure 16-35*** would be:

$$\text{Percent of MAC} = \frac{\text{CG-LEMAC}}{\text{MAC}} \times 100$$

$$= \frac{945 - 900}{180} \times 100$$

$$= 25\%$$

If the center of gravity is known in percent of MAC, and there is a need to know the CG location in inches from the datum, the conversion would be done as follows:

1. Convert the percent of MAC to a decimal by dividing by 100.
2. Multiply the decimal by the length of the MAC.
3. Add this number to LEMAC.

As a formula, the solution to convert a percent of MAC to an inch value would be:

$$\text{CG in inches} = \text{MAC \%} \div 100 \times \text{MAC} + \text{LEMAC}$$

For the airplane in ***Figure 16-35***, if the CG was at 32.5% of the MAC, the solution would be:

$$\begin{aligned} \text{CG in inches} &= \text{MAC \%} \div 100 \times \text{MAC} + \text{LEMAC} \\ &= 32.5 \div 100 \times 180 + 900 \\ &= 958.5 \end{aligned}$$

WEIGHT AND BALANCE RECORDS

When a technician gets involved with the weight and balance of an aircraft, it almost always involves a calculation of the aircraft's empty weight and empty weight center of gravity. Only on rare occasions will the technician be involved in calculating extreme conditions, how much ballast is needed, or the loaded weight and balance of the aircraft. Calculating the empty weight and empty weight CG might involve putting the aircraft on scales and weighing it, or a pencil and paper exercise after installing a new piece of equipment.

Current and accurate empty weight and empty weight center of gravity are required to be known for an aircraft. This information must be included in the weight and balance report, which is a part of the aircraft permanent records. The weight and balance report must be in the aircraft when it is being flown.

There is no required format for this report, but ***Figure 16-36*** is a good example of recording the data obtained from weighing an aircraft. As it is currently laid out, the form would accommodate either a tricycle gear or tail dragger airplane. Depending on the gear type, either the nose or the tail row would be used. If an airplane is being weighed using jacks and load cells, or if a helicopter is being weighed, the item names must be changed to reflect the weight locations.

If an equipment change is being done on an aircraft, and the new weight and balance is calculated mathematically instead of weighing the aircraft, the same type of form shown in ***Figure 16-36*** can be used. The only change would be the use of a four column solution, instead of six columns, and there would be no tare weight or involvement with fuel and oil.

Aircraft Weight and Balance Report

Results of Aircraft Weighing

Make ____________ Model ____________

Serial # ____________ N# ____________

Datum Location ____________

Leveling Means ____________

Scale Arms: Nose ______ Tail ______ Left Main ______ Right Main ______

Scale Weights: Nose ______ Tail ______ Left Main ______ Right Main ______

Tare Weights: Nose ______ Tail ______ Left Main ______ Right Main ______

Weight and Balance Calculation

Item	Scale (lb)	Tare Wt. (lb)	Net Wt. (lb)	Arm (inches)	Moment (in-lb)
Nose					
Tail					
Left Main					
Right Main					
Subtotal					
Fuel					
Oil					
Misc.					
Total					

Aircraft Current Empty Weight: ____________

Aircraft Current Empty Weight CG: ____________

Aircraft Maximum Weight: ____________

Aircraft Useful Load: ____________

Computed By: ____________ (print name)

____________ (signature)

Certificate #: ____________ (A&P, Repair Station, etc.)

Date: ____________

Figure 16-36. Aircraft weight and balance report.

Question: 16-1
The most efficient condition for an aircraft is to have the point where it balances very close to, or perhaps exactly at, the aircraft's ________________.

Question: 16-2
The ________________ of an aircraft is a point about which the nose heavy and tail heavy moments are exactly equal in magnitude.

Question: 16-3
A more realistic way to find the center of gravity for an object, especially an airplane, is to place it on a minimum of two scales and to calculate the ________________ value for each scale reading.

Question: 16-4
Electronic scales utilize ________ cells.

Question: 16-5
Before an aircraft can be weighed and reliable readings obtained, it must be in a ________________ attitude.

Question: 16-6
When weighing an aircraft, whether engine oil should be full or residual is specified in the ________________ or ________________.

Question: 16-7
Because wheel chocks are used to keep the airplane from rolling off the scales, their weight must be subtracted from the scale readings as ________________.

Question: 16-8
On a forward extreme condition check, all useful load items in front of the forward CG limit are loaded, and all useful load items behind the forward CG limit are ________________.

ANSWERS

Answer: 16-1
center of lift.

Answer: 16-2
center of gravity (CG).

Answer: 16-3
moment.

Answer: 16-4
load.

Answer: 16-5
level flight.

Answer: 16-6
Aircraft Specifications.
Type Certificate Data Sheet.

Answer: 16-7
tare weight.

Answer: 16-8
left empty.

SUB-MODULE 17

PART-66 SYLLABUS CERTIFICATION CATEGORY →	LEVELS B1	 B2
Sub-Module 17 AIRCRAFT HANDLING AND STORAGE Knowledge Requirements		
7.17 - Aircraft Handling and Storage Aircraft taxiing/towing and associated safety precautions; Aircraft jacking, chocking, securing and associated safety precautions; Aircraft storage methods; Refuelling/defuelling procedures; De-icing/anti-icing procedures; Electrical, hydraulic and pneumatic ground supplies. Effects of environmental conditions on aircraft handling and operation.	2	2

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:

(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

TIEDOWN PROCEDURES

PREPARATION OF AIRCRAFT

Aircraft should be tied down after each flight to prevent damage from sudden storms. The direction in which aircraft are to be parked and tied down is determined by prevailing or forecast wind direction.

Aircraft should be headed as nearly as possible into the wind, depending on the locations of the parking area's fixed tiedown points. Spacing of tie-downs should allow for ample wingtip clearance. (***Figure 17-1***) After the aircraft is properly located, lock the nose wheel or the tailwheel in the fore-and-aft position.

TIEDOWN PROCEDURES FOR LAND PLANES

SECURING LIGHT AIRCRAFT

Light aircraft are most often secured with ropes tied only at the aircraft tiedown rings provided for securing purposes. Rope should never be tied to a lift strut, since this practice can bend a strut if the rope slips to a point where there is no slack. Manila rope shrinks when wet; about 1 inch (1") of slack should be provided for movement. Too much slack allows the aircraft to jerk against the ropes. Tight tiedown ropes put inverted flight stresses on the aircraft, many of which are not designed to take such loads.

A tiedown rope holds no better than the knot. Anti-slip knots such as the bowline are quickly tied and are easy to untie. (***Figure 17-2***) Aircraft not equipped with tiedown fittings should be secured in accordance with the manufacturer's instructions. Ropes should be tied to outer ends of struts on high-wing monoplanes, and suitable rings should be provided where structural conditions permit, if the manufacturer has not already provided them.

SECURING HEAVY AIRCRAFT

The normal tiedown procedure for heavy aircraft can be accomplished with rope or cable tiedown. The number of such tiedowns should be governed by anticipated weather conditions.

Most heavy aircraft are equipped with surface control locks, which should be engaged or installed when the aircraft is secured. Since the method of locking controls will vary on different type aircraft, check the manufacturer's instructions for proper installation or engaging procedures. If high winds are anticipated, control surface battens can also be installed to prevent damage. ***Figure 17-3*** illustrates four common tiedown points on heavy aircraft.

The normal tiedown procedure for heavy aircraft should generally include the following:

1. Head airplane into prevailing wind whenever possible.
2. Install control locks, all covers and guards.
3. Chock all wheels fore and aft. (***Figure 17-4***)
4. Attach tiedown reels to airplane tiedown loops and to tiedown anchors or tiedown stakes. Use tiedown stakes for temporary tiedown only. If tiedown reels are not available, ¼" wire cable or 1½" manila line may be used.

TIEDOWN PROCEDURES FOR SEAPLANES

Seaplanes can be moored to a buoy, weather permitting, or tied to a dock. Weather causes wave action, and waves cause the seaplane to bob and roll. This bobbing and rolling while tied to a dock can cause damage.

When warning of an impending storm is received and it is not possible to fly the aircraft out of the storm area, some compartments of the seaplane can be flooded, partially sinking the aircraft. In addition, the aircraft

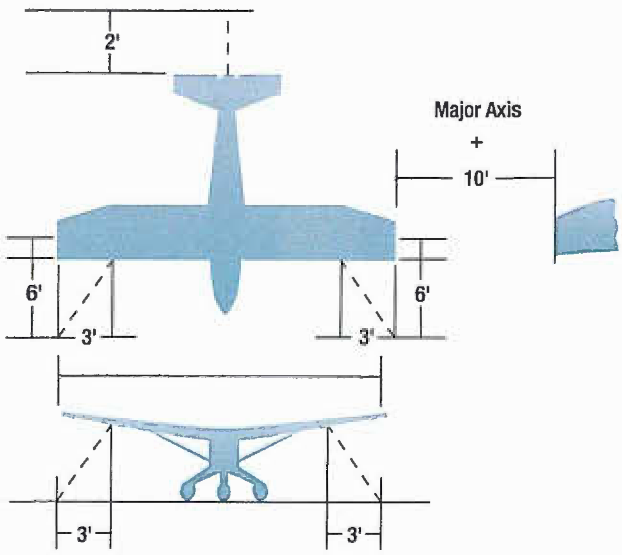


Figure 17-1. Diagram of tiedown dimensions.

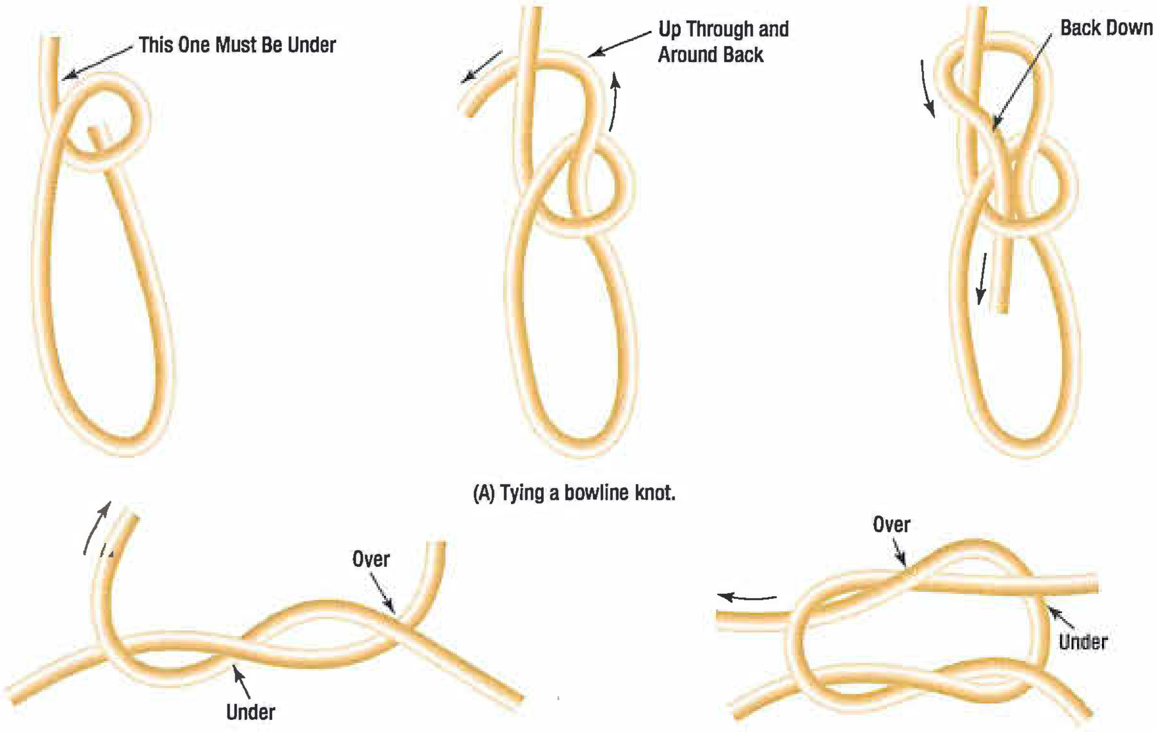


Figure 17-2. Knots commonly used for aircraft tiedown.

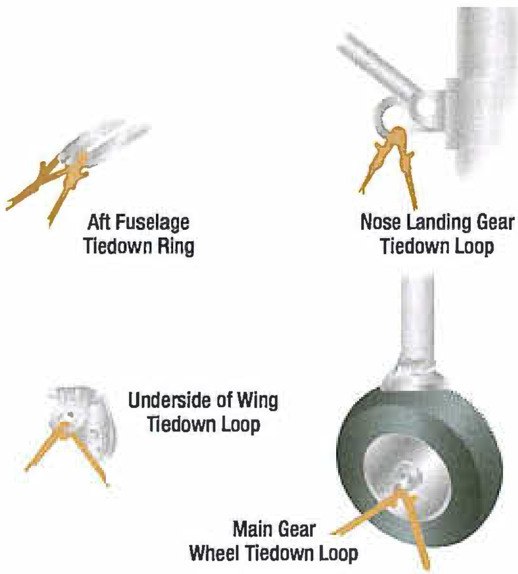


Figure 17-3. Common tiedown points.


Figure 17-4. Wheels chocked fore and aft.

should be tied down securely to anchors. Seaplanes tied down on land have been saved from high-wind damage by filling the floats with water in addition to tying the aircraft down in the usual manner.

During heavy weather, if possible, remove the seaplane from the water and tie down in the same manner as a land plane. If this is not possible, the seaplane could be anchored in a sheltered area away from wind and waves.

TIEDOWN PROCEDURES FOR SKI-PLANES

Ski planes are tied down, if the securing means are available, in the same manner as land planes.

Ski-equipped airplanes can be secured on ice or in snow by using a device called a dead-man. A dead-man is any item at hand (such as a piece of pipe, log, and so forth) that a rope is attached to and buried in a snow or ice trench. Using caution to keep the free end of the rope dry and unfrozen, snow is packed in the trench. If available, pour water into the trench; when it is frozen, tie down the aircraft with the free end of the rope.

Operators of ski-equipped aircraft sometimes pack soft snow around the skis, pour water on the snow, and permit the skis to freeze to the ice. This, in addition to the usual tiedown procedures, aids in preventing damage from windstorms. Caution must be used when moving an aircraft that has been secured in this manner to ensure that a ski is not still frozen to the ground. Otherwise, damage to the aircraft or skis can occur.

TIEDOWN PROCEDURES FOR HELICOPTERS

Helicopters, like other aircraft are secured to prevent structural damage, which can occur from high-velocity surface winds. Helicopters should be secured in hangars, when possible. If not, they should be tied down securely. Helicopters that are tied down can usually sustain winds up to approximately 65 mph. If at all possible, helicopters should be evacuated to a safe area if tornadoes or hurricanes are anticipated.

For added protection, helicopters should be moved to a clear area so that they will not be damaged by flying objects or falling limbs from surrounding trees. If high winds are anticipated with the helicopter parked in the open, the main rotor blades should be tied down. Detailed instructions for securing and mooring each type of helicopter can be found in the applicable maintenance manual. (*Figure 17-5*)

Figure 17-5. Example of mooring of a helicopter.

Methods of securing helicopters vary with weather conditions, the length of time the aircraft is expected to remain on the ground, and location and characteristics of the aircraft. Wheel chocks, control locks, rope tiedowns, mooring covers, tip socks, tiedown assemblies, parking brakes, and rotor brakes are used to secure helicopters.

Typical mooring procedures are as follows:

1. Face the helicopter in the direction from which the highest forecast wind or gusts are anticipated.
2. Spot the helicopter slightly more than one rotor span distance from other aircraft.
3. Place wheel chocks ahead of and behind all wheels (where applicable). On helicopters equipped with skids, retract the ground handling wheels, lower the helicopter to rest on the skids, and install wheel position lock-pins or remove the ground handling wheels. Ground handling wheels should be secured inside the aircraft or inside the hangar or storage buildings. Do not leave them unsecured on the flight line.
4. Align the blades and install tiedown assemblies as prescribed by the helicopter manufacturer. (*Figure 17-6*) Tie straps snugly without strain, and during wet weather, provide some slack to avoid the possibility of the straps shrinking, causing undue stresses on the aircraft and/or its rotor system(s).
5. Fasten the tiedown ropes or cables to the forward and aft landing gear cross tubes and secure to ground stakes or tiedown rings.

PROCEDURES FOR SECURING WEIGHT-SHIFT CONTROL AIRCRAFT

There are many types of weight-shift control aircraft engine-powered and non-powered. These types of aircraft are very suitable to wind damage. The wings can be secured in a similar manner as a conventional aircraft in light winds. But in high winds, the mast can be disconnected from the wing and the wing placed close to the ground and secured. This type of aircraft can also be partially disassembled or moved into a hangar for protection.

PROCEDURES FOR SECURING POWERED PARACHUTES

Powered parachutes should have the parachute packed in a bag to prevent the chute from filling with air from the wind and dragging the seat and engine. The engine and seat can also be secured if needed.

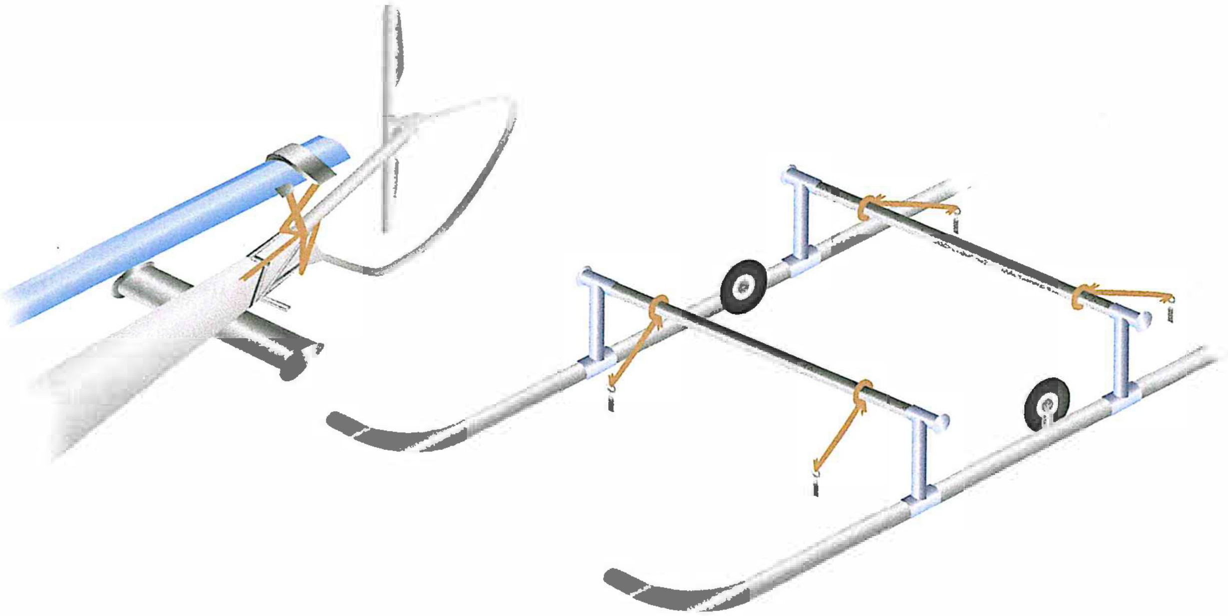


Figure 17-6. Securing helicopter blades and fuselage.

AIRCRAFT JACKING

The aircraft technician is required to jack the aircraft for certain maintenance and repair operations. Always used the manufacturer's specified jacking equipment and instructions. Errors made while jacking an aircraft can be dangerous and costly. An aircraft must be in the proper configuration for jacking. Specific doors may be required to be closed and certain stressed panels may need to be installed to provide the fuselage vessel with sufficient strength to be raised on jacks without causing structural damage. The same is true when hoisting the aircraft. Check the manufacturer's instructions for jacking and hoisting and prepare the aircraft as specified.

Most aircraft are designed with jack points located so that 3 or 4 jacks are required for jacking. Some light aircraft may contain a tie-down ring at the rear of the fuselage. By anchoring the empennage to a weight or the hangar floor, this tiedown ring is used with only 2 jacks to lift the aircraft cleanly and completely off the ground. Wing jacks are normally placed under the wing spars at the jack point specified by the manufacturer.

Most aircraft have specified jack points on the airframe. Jack pads are engineered to insert into the jack points and make contact with the jacks. A jack pad is engineered by the manufacturer to protect the airframe from the jack. Under no circumstance should the aircraft be jacked without the specified jack pad. As stated, the jack points on most aircraft are located under the main wing spar with a third jack near the nose of the aircraft. A fourth jack, if used, usually supports the empennage.

When jacking an aircraft it is important to raise and maintain the aircraft in a level position. Some transport category aircraft have a grid over which a plumb bob is hung to guide the pace of jacking at each jack. Jacks should always remain flat on the ground with no side loads. If a jack begins to tip, lower the aircraft and reposition the jack. An aircraft elevated on jacks should be guarded against movement which could shift the load. Most aircraft jacks have a threaded, locking safety collar that is rotated as the aircraft is raised so that, should the hydraulic cylinder on the jack fail, the aircraft will remain supported. Other jacks have drilled lift shafts which accept lock pins as the aircraft is raised so the jack will not collapse in case of hydraulic failure.

It may not be necessary to lift the entire aircraft to perform maintenance on one of the landing gear. Often, a single tire, wheel or brake will require servicing. Manufactures often locate jack points on each landing gear strut which can be used to raise just a single gear off the ground. The wheels remaining on the ground must be chocked securely during this operation. It is still important to use manufacturer recommended equipment and precisely follow all jacking instructions.

However, raising just a single gear with one jack to change a tire, for example is much less time consuming that jacking the entire aircraft.

When a raised aircraft is ready to be lowered back to the ground, ensure any objects that are under the aircraft are removed so that the aircraft does not lower onto them. The gear should be in the down and locked position as well. Gear retraction, extension and free-fall tests are performed on jacks. The position of the gear deployment lever should be double checked before lowering the jacks. When use of aircraft jacks is complete, they should be covered and moved to a designated storage area in the hangar.

Hoisting of aircraft is less common than jacking. It is vital to follow manufacturer's instruction for hoisting to prevent airframe damage.

EFFECT OF ENVIRONMENTAL CONDITIONS ON AIRCRAFT HANDLING AND OPERATION

Environmental conditions must be considered at all times when moving, maintaining, or operating aircraft. Technicians are required to make allowances for extreme environmental conditions to maintain safe practices.

Any aircraft engine or powered support equipment must be approved for the operation intended. Extremely hot or extremely cold weather could produce conditions outside of the certified operating range. In this case, do not operate the equipment. More often, the operating conditions presented are within certified limits but require adaptation.

Aircraft performance losses due to extremely hot weather are well documented. Warm air is less dense that cold air which causes engine power and aerodynamic performance to degrade. Keeping aircraft and any volatile materials out of extreme heat is recommended if possible. In desert climates, protection from airborne particles (sand and dust) is also a top priority. Seals, fabrics and electrical equipment deteriorate faster in hot, humid conditions. Follow all manufacturer recommended starting and operating procedures to avoid vapor lock and over-temperature situations when operating aircraft in hot environments.

Cold temperatures and operation in cold climates present a complete set of operating difficulties. While cold can be considered better for the materials from which aircraft are made, extremely cold temperature can reduce seal flexibility and make brittle electrical wiring and other parts that are normally robust. Avoid unnecessary contact with wires and cables in extremely cold conditions. Also remember that thermal shock is always to be avoided due to the stresses it puts on aircraft materials and parts. The rapid cooling of a warm aircraft or rapid heating of a cold aircraft is potentially more damaging than the actual temperature to which the aircraft is exposed.

In cold operating environments, contained gas pressures decrease. Tire and strut pressures may need to be adjusted to move or fly the aircraft. Accumulator and fire extinguisher agent pre-charge pressures will also be lower. Fluid viscosities increase with a decrease in temperature. This can interfere with proper lubrication. It can also slow the functioning of the hydraulic system. Engine nacelle pre-heaters can be used to warm the oil and engine accessories before starting. Note that it is primarily the oil that should be preheated. Failure to heat a dry sump oil tank or the wet sump of a reciprocating engine does little to protect vital engine parts against oil starvation due to high viscosity upon start-up. Hot air is the most common form of preheating. On aircraft with an APU, there may be an optional preheat function for the main engines using pneumatic bleed air from the APU. Ground-based permanent and portable heaters are also available. Follow manufacturer's instructions when preheating an engine nacelle.

Fuel is also affected by the cold. Be certain that all fuel vents are clear from snow and ice. Without proper fuel venting, fuel flow will be hindered. Fuel drains must also be clear. It is just as important to sump excess water out of the fuel before operation in the cold as it is in any other operating environment. If there is a disruption of fuel flow during a cold weather start, check the fuel filters for frozen water that could be disrupting fuel flow. Consistent frigid weather climate operation may require the use of JP 4 if approved in turbine engines. It has better cold weather starting characteristics than regular jet fuel.

Snow, ice, and frost on a propeller or airframe are common hindrances to safe operation in cold weather. They must be completely removed before flight occurs and before start-up in the case of propeller icing. A warm battery delivers its rated power but a cold battery may not deliver enough power to start an engine. Often, removal of the battery and storing it in a warm location until it can be reinstalled for the next operation is a workable solution. With a preheated engine oil supply and a strong, warm battery, the procedure for starting an engine in cold weather is pretty much the same as under normal conditions. Once started however, propeller control changes and hydraulic functions should be delayed until the oil has had time to warm.

Full engine power should also be delayed until oil temperature has warmed to levels near typical operating temperatures. Finally, it is not unusual for tires or chocks to be frozen to the ground in cold weather. Preheated air from a portable cart can loosen this connection without damaging the tires or struts.

GROUND DEICING AND ANTI-ICING OF AIRCRAFT

The presence of ice on an aircraft may be the result of direct precipitation, formation of frost on integral fuel tanks after prolonged flight at high altitude, or accumulations on the landing gear following taxiing through snow or slush. The aircraft must be free of all frozen contaminants adhering to the wings, control surfaces, propellers, engine inlets, or other critical surfaces before takeoff.

Any deposits of ice, snow, or frost on the external surfaces of an aircraft may drastically affect its performance. This may be due to reduced aerodynamic lift and increased aerodynamic drag resulting from the disturbed airflow over the airfoil surfaces, or it may be due to the weight of the deposit over the whole aircraft. The operation of an aircraft may also be seriously affected by the freezing of moisture in controls, hinges, valves, microswitches, or by the ingestion of ice into the engine. When aircraft are hangared to melt snow or frost, any melted snow or ice may freeze again if the aircraft is subsequently moved into subzero temperatures. Any measures taken to remove frozen deposits while the aircraft is on the ground must also prevent the possible refreezing of the liquid.

FROST REMOVAL

Frost deposits can be removed by placing the aircraft in a warm hangar or by using a frost remover or deicing fluid. These fluids normally contain ethylene glycol and isopropyl alcohol and can be applied either by spray or by hand. It should be applied within 2 hours of flight. Deicing fluids may adversely affect windows or the exterior finish of the aircraft, only the type of fluid recommended by the aircraft manufacturer should be used. Transport category aircraft are often deiced on the ramp or a dedicated deicing location on the airport. Deicing trucks are used to spray the deicing and/or anti-icing fluid on aircraft surfaces. (***Figure 17-7***)

DEICING AND ANTI-ICING OF TRANSPORT TYPE AIRCRAFT

DEICING FLUID

The deicing fluid must be accepted according to its type for holdover times, aerodynamic performance, and material compatibility. The coloring of these fluids is also standardized. In general, glycol is colorless, Type-I fluids are orange, Type-II fluids are white/pale yellow, and Type-IV fluids are green. The color for Type-III fluid has not yet been determined.

When aircraft surfaces are contaminated by frozen moisture, they must be deiced prior to dispatch. When freezing precipitation exists, and there is a risk of contamination of the surface at the time of dispatch,

Figure 17-7. An American Airlines aircraft being deiced at Syracuse Hancock International Airport.

Type IV Holdover Time Guidelines

Guidelines for holdover times anticipated for SAE type IV fluid mixtures as function of weather conditions and OAT.
CAUTION: This table is for use in departure planning only, and it should be used in conjunction with pretakeoff check procedures.

OAT °C	OAT °F	SAE type IV fluid concentration (vol. %/vol.%)	Frost*	Freezing Fog	Snow◊	Freezing drizzle***	Light free rain	Rain on cold soaked wing	Other*
above 0	above 32	100/0	18:00	1:05–2:15	0:35–1:05	0:40–1:10	0:25–0:40	0:10–0:50	CAUTION: no holdover time guidelines exist
		72/25	6:00	1:05–1:45	0:30–1:05	0:35–0:50	0:15–0:30	0:05–0:35	
		50/50	4:00	0:15–0:35	0:05–0:20	0:10–0:20	0:05–0:10	CAUTION: clear ice may require touch for confirmation	
0 through −3	32 through 27	100/0	12:00	1:05–2:15	0:30–0:55	0:40–1:10	0:15–0:40		
		75/25	5:00	1:05–2:15	0:25–0:50	0:35–0:50	0:15–0:30		
		50/50	3:00	1:15–0:35	0:05–0:15	0:10–0:20	0:05–0:15		
below −3 through −14	below 27 through 7	100/0	12:00	0:20–0:50	0:20–0:40	**0:20–0:45	**0:10–0:25		
		75/25	5:00	0:25–0:50	0:15–0:25	**0:15–0:30	**0:10–0:20		
below −14 through −25	below 7 through −13	100/0	12:00	0:15–0:40	0:15–0:30				
below −25	below −13	100/0	SAE type IV fluid may be used below −25 °C(−13 °F) if the freezing point of the fluid is at least 7 °C(13 °F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE type I when SAE type IV fluid cannot be used.						

°C = Degrees Celsius
°F = Degrees Fahrenheit
OAT= Outside Air Temperature
VOL = Volume

The responsiblity for the application of these data remains with the user.
* During conditions that apply to aircraft protection for ACTIVE FROST
** No holdover time guidelines exist for this condition below −10 °C (14 °F)
*** Use light freezing rain holdover times if positive identification of freezing drizzle is not possible
‡ Snow pellets, ice pellets, heavy snow, moderate and heavy freezing rain, hail.
◊ Snow includes snow grains

CAUTIONS:
- The time of protection will be shortened in heavy weather conditions: heavy precipitation rates or high moisture contents.
- High wind velocity or jet blast may reduce holdover time below the lowest time stated in the range.
- Holdover time may be reduced when aircraft skin temperature is lower than OAT.

Figure 17-8. Deice holdover time guidelines.

aircraft surfaces must be anti-iced. If both deicing and anti-icing are required, the procedure may be performed in one or two steps. The selection of a one or two step process depends upon weather conditions, available equipment, available fluids, and the holdover time to be achieved.

HOLDOVER TIME (HOT)

Holdover Time (HOT) is the estimated time that deicing/anti-icing fluid prevents the formation of frost or ice and the accumulation of snow on the critical surfaces of an aircraft. HOT begins when the final application of deicing/anti-icing fluid commences and expires when the deicing/anti-icing fluid loses its effectiveness. ***Figure 17-8*** shows a holdover timetable for Type IV fluid. It is displayed for educational purposes only.

CRITICAL SURFACES

Basically, all surfaces that have an aerodynamic, control, sensing, movement, or measuring function must be clean. These surfaces cannot necessarily be cleaned and protected in the same conventional deicing/anti-icing manner as the wings. Some areas require only a cleaning operation, while others need protection against freezing. The procedure of deicing may also vary according to aircraft limitations. The use of hot air may be required when deicing (e.g., landing gear or propellers).

Figure 17-9 shows critical areas on an aircraft that should not be sprayed directly. Some critical elements and procedures that are common for most aircraft are:

- Deicing/anti-icing fluids must not be sprayed directly on wiring harnesses and electrical components (e.g., receptacles, junction boxes), onto brakes, wheels, exhausts, or thrust reversers.
- Deicing/anti-icing fluid shall not be directed into the orifices of pitot heads, static ports, or directly onto airstream direction detectors probes/angle of attack airflow sensors.
- All reasonable precautions shall be taken to minimize fluid entry into engines, other intakes/outlets, and control surface cavities.

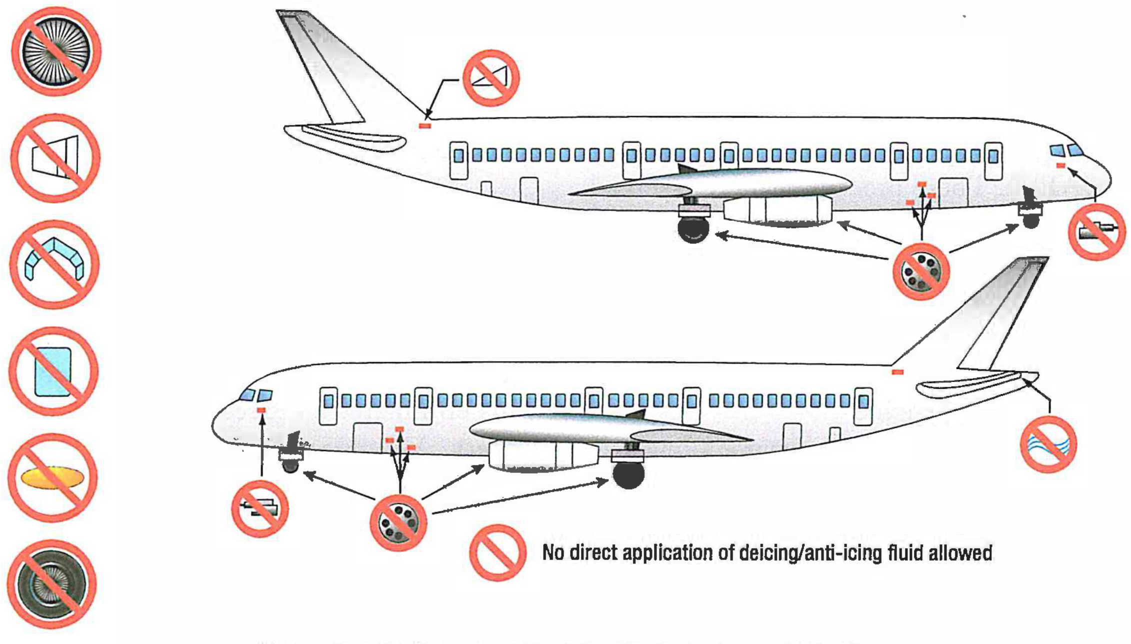


Figure 17-9. No direct application of deicing/anti-icing fluid allowed.

- Fluids shall not be directed onto flight deck or cabin windows as this can cause crazing of acrylics or penetration of the window seals.
- Any forward area from which fluid can blow back onto windscreens during taxi or subsequent takeoff shall be free of residues prior to departure.
- If Type II, III, or IV fluids are used, all traces of the fluid on flight deck windows should be removed prior to departure, particular attention being paid to windows fitted with wipers.
- Landing gear and wheel bays shall be kept free from buildup of slush, ice, or accumulations of blown snow.
- When removing ice, snow, slush, or frost from aircraft surfaces, care shall be taken to prevent it entering and accumulating in auxiliary intakes or control surface hinge areas (e.g., manually remove snow from wings and stabilizer surfaces forward toward the leading edge and remove from ailerons and elevators back towards the trailing edge).

ICE AND SNOW REMOVAL

Probably the most difficult deposit to deal with is deep, wet snow when ambient temperatures are slightly above the freezing point. This type of deposit should be removed with a soft brush or squeegee. Use care to avoid damage to antennas, vents, stall warning devices, vortex generators, etc., that may be concealed by the snow. Light, dry snow in subzero temperatures should be blown off whenever possible; the use of hot air is not recommended, since this would melt the snow, which would then freeze and require further treatment. Moderate or heavy ice and residual snow deposits should be removed with a deicing fluid. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of deicing operations, inspect the aircraft to ensure that its condition is satisfactory for flight. All external surfaces should be examined for signs of residual snow or ice, particularly in the vicinity of control gaps and hinges. Check the drain and pressure sensing ports for obstructions. When it becomes necessary to physically remove a layer of snow, all protrusions and vents should be examined for signs of damage. Control surfaces should be moved to ascertain that they have full and free movement.

The landing gear mechanism, doors and bay, and wheel brakes should be inspected for snow or ice deposits and the operation of uplocks and microswitches checked. Snow or ice can enter turbine engine intakes and freeze in the compressor. If the compressor cannot be turned by hand for this reason, hot air should be blown through the engine until the rotating parts are free.

ENGINE STARTING AND OPERATION

The following instructions cover the starting procedures for reciprocating, turboprop, turbofan, and auxiliary power units (APU). These procedures are presented only as a general guide for familiarization with typical procedures and methods. Detailed instructions for starting a specific type of engine can be found in the manufacturer's instruction book.

Before starting an aircraft engine:

1. Position the aircraft to head into the prevailing wind to ensure adequate airflow over the engine for cooling purposes.
2. Make sure that no property damage or personal injury will occur from the propeller blast or jet exhaust.
3. If external electrical power is used for starting, ensure that it can be removed safely and it is sufficient for the total starting sequence.
4. During any and all starting procedures, a "fireguard" equipped with a suitable fire extinguisher shall be stationed in an appropriate place. A fireguard is someone familiar with aircraft starting procedures. The fire extinguisher should be a CO_2 extinguisher of at least 5-pound capacity. The appropriate place is adjacent to the outboard side of the engine, in view of the pilot, and also where he or she can observe the engine/aircraft for indication of starting problems.
5. If the aircraft is turbine engine powered, the area in front of the jet inlet must be kept clear of personnel, property, and/or debris (FOD).
6. These "before starting" procedures apply to all aircraft powerplants.
7. Follow manufacturer's checklists for start procedures and shutdown procedures.

RECIPROCATING ENGINES

The following procedures are typical of those used to start reciprocating engines. There are, however, wide variations in the procedures for the many reciprocating engines. No attempt should be made to use the methods presented here for actually starting an engine. Instead, always refer to the procedures contained in the applicable manufacturer's instructions.

Reciprocating engines are capable of starting in fairly low temperatures without the use of engine heating or oil dilution, depending on the grade of oil used.

The various covers (wing, tail, cockpit, wheel, and so forth) protecting the aircraft must be removed before attempting to turn the engine. External sources of electrical power should be used when starting engines equipped with electric starters, if possible or needed. This eliminates an excessive burden on the aircraft battery. All unnecessary electrical equipment should be left off until the generators are furnishing electrical power to the aircraft power bus.

Before starting a radial engine that has been shut down for more than 30 minutes, check that the ignition switch is off; turn the propeller three or four complete revolutions by hand to detect a hydraulic lock, if one is present. Any liquid present in a cylinder is indicated by the abnormal effort required to rotate the propeller, or by the propeller stopping abruptly during rotation. Never use force to turn the propeller when a hydraulic lock is detected. Sufficient force can be exerted on the crankshaft to bend or break a connecting rod if a lock is present.

To eliminate a lock, remove either the front or rear spark plug from the lower cylinders and pull the propeller through. Never attempt to clear the hydraulic lock by pulling the propeller through in the direction opposite to normal rotation. This tends to inject the liquid from the cylinder into the intake pipe. The liquid will be drawn back into the cylinder with the possibility of complete or partial lock occurring on the subsequent start.

To start the engine, proceed as follows:

1. Turn the auxiliary fuel pump on, if equipped.
2. Place the mixture control to the position recommended for the engine and carburetor combination being started. As a general rule, the mixture control should be in the "idle cut-off" position for fuel injection and in the "full rich" position for float-type carburetors. Many light aircraft are equipped with a mixture control pull rod which has no detent intermediate positions. When such controls are pushed in flush with the instrument panel, the mixture is set in the "full rich" position. Conversely, when the control rod

is pulled all the way out, the carburetor is in the "idle cut-off" or "full lean" position. The operator can select unmarked intermediate positions between these two extremes to achieve any desired mixture setting.

3. Open the throttle to a position that will provide 1 000 to 1 200 rpm (approximately ⅛ to ½-inch from the "closed" position).
4. Leave the pre-heat or alternate air (carburetor air) control in the "cold" position to prevent damage and fire in case of backfire. These auxiliary heating devices should be used after the engine warms up. They improve fuel vaporization, prevent fouling of the spark plugs, ice formation, and eliminate icing in the induction system.
5. Move the primer switch to "on" intermittently (press to prime by pushing in on the ignition switch during the starting cycle), or prime with one to three strokes of priming pump, depending on how the aircraft is equipped. The colder the weather, the more priming will be needed.
6. Energize the starter after the propeller has made at least two complete revolutions, and turn the ignition switch on. On engines equipped with an induction vibrator ("shower of sparks", magneto that incorporates a retard breaker assembly), turn the switch to the "both" position and energize the starter by turning the switch to the "start" position. After the engine starts, release the starter switch to the "both" position. When starting an engine that uses an impulse coupling magneto, turn the ignition switch to the "left" position. Place the start switch to the "start" position. When the engine starts, release the start switch. Do not crank the engine continuously with the starter for more than 1 minute. Allow a 3-5 minute period for cooling the starter between attempts. Otherwise, the starter may burn out from overheating.
7. After the engine is operating smoothly, move the mixture control to the "full rich" position if started in the "idle cutoff" position. Carbureted engines will already be in the rich mixture position. Check for oil pressure.

Instruments for monitoring the engine during operation include a tachometer for RPM, manifold pressure gauge, oil pressure gauge, oil temperature gauge, cylinder head temperature gauge, exhaust gas temperature gauge and fuel flow gauge.

HAND CRANKING ENGINE

Warning: If your battery is dead, do not hand prop the aircraft. Have the battery serviced or use external power. Hand propping is very dangerous. If the aircraft has no self-starter, the engine must be started by turning the propeller by hand (hand propping the propeller). The person who is turning the propeller calls: "Fuel on, switch off, throttle closed, brakes on."The person operating the engine will check these items and repeat the phrase. The switch and throttle must not be touched again until the person swinging the prop calls "contact." The operator will repeat "contact" and then turn on the switch. Never turn on the switch and then call "contact."

A few simple precautions will help to avoid accidents when hand propping the engine. While touching a propeller, always assume that the ignition is on. The switches which control the magnetos operate on the principle of short-circuiting the current to turn the ignition off. If the switch is faulty, it can be in the "off" position and still permit current to flow in the magneto primary circuit. This condition could allow the engine to start when the switch is off.

Be sure the ground is firm. Slippery grass, mud, grease, or loose gravel can lead to a fall into or under the propeller. Never allow any portion of your body to get in the way of the propeller. This applies even though the engine is not being cranked.

Stand close enough to the propeller to be able to step away as it is pulled down. Stepping away after cranking is a safeguard in case the brakes fail. Do not stand in a position that requires leaning forward to reach the prop. This throws the body off balance and could cause you to fall inwards when the engine starts. In swinging the prop, always move the blade downward by pushing with the palms of the hands.

Do not grip the blade with the fingers curled over the edge, since "kickback" may break them or draw your body in the blade path. Excessive throttle opening after the engine has fired is the principal cause of backfiring during starting. Gradual opening of the throttle, while the engine is cold, will reduce the potential for backfiring. Slow, smooth movement of the throttle will assure correct engine operation.

Avoid overpriming the engine before it is turned over by the starter. This can result in fires, scored or scuffed cylinders and pistons, and, in some cases, engine failures due to hydraulic lock. If the engine is inadvertently flooded or overprimed, turn the ignition switch off and move the throttle to the "full open" position. To rid the engine of the excess fuel, turn it over by hand or by the starter. If excessive force is needed to turn over the engine, stop immediately. Do not force rotation of the engine. If in doubt, remove the lower cylinder spark plugs.

Immediately after the engine starts, check the oil pressure indicator. If oil pressure does not show within 30 seconds, stop the engine and determine the trouble.

If oil pressure is indicated, adjust the throttle to the aircraft manufacturer's specified RPM for engine warm up. Warm-up rpm will usually be in the 1 000 to 1 300 rpm range.

Most aircraft reciprocating engines are air cooled and depend on the forward speed of the aircraft to maintain proper cooling. Therefore, particular care is necessary when operating these engines on the ground.

During all ground running, operate the engine with the propeller in full low pitch and headed into the wind with the cowling installed to provide the best degree of engine cooling. Closely monitor the engine instruments at all times. Do not close the cowl flaps for engine warm-up; they should be in the open position while operating on the ground. When warming up the engine, ensure that personnel, ground equipment that may be damaged, or other aircraft are not in the propeller wash.

EXTINGUISHING ENGINE FIRES

In all cases, a fireguard should stand by with a CO_2 fire extinguisher while the aircraft engine is being started. This is a necessary precaution against fire during the starting procedure. The fireguard should be familiar with the induction system of the engine so that in case of fire he or she can direct the CO_2 into the air intake of the engine to extinguish it. A fire could also occur in the exhaust system of the engine from liquid fuel being ignited in the cylinder and expelled during the normal rotation of the engine.

If an engine fire develops during the starting procedure, continue cranking to start the engine and blow out the fire. If the engine does not start and the fire continues to burn, discontinue the start attempt. The fireguard should extinguish the fire using the available equipment. The fireguard must observe all safety practices at all times while standing by during the starting procedure.

TURBOPROP ENGINES

The starting of any turbine engine consists of three steps that must be carried out in the correct sequence. The starter turns the main compressor to provide airflow though the engine. At the correct speed (which provides enough airflow) the igniters are turned on and provide a hot spark to light the fuel which is engaged next. As the engine accelerates, it will reach a self sustaining speed and the starter is disengaged.

The various covers protecting the aircraft must be removed. Carefully inspect the engine exhaust areas for the presence of fuel or oil. Make a close visual inspection of all accessible parts of the engines and engine controls, followed by an inspection of all nacelle areas to determine that all inspection and access plates are secured. Check sumps for water. Inspect air inlet areas for general condition and foreign material. Check the compressor for free rotation, when the installation permits, by reaching in and turning the blades by hand.

The following procedures are typical of those used to start turboprop engines. There are, however, wide variations in the procedures applicable to the many turboprop engines, and no attempt should be made to use these procedures in the actual starting of a turboprop engine. These procedures are presented only as a general guide for familiarization with typical procedures and methods. For starting of all turboprop engines, refer to the detailed procedures contained in the applicable manufacturer's instructions or their approved equivalent.

Turboprop engines are usually fixed turbine or free turbine. The propeller is connected to the engine directly in a fixed turbine, which results in the propeller being turned as the engine starts. This provides extra drag which must be overcome during starting. If the propeller is not at the "start" position, difficulty may be encountered in making a start due to high loads. Because of this, the propeller is in flat pitch at shut down and subsequently in flat pitch during start. The free turbine engine has no mechanical connection between the gas generator and the power turbine which is connected to the propeller. In this type of engine, the propeller remains in the feather position during starting and starts to turn only as the gas generator accelerates.

Instrumentation for turbine engines varies according to the type of turbine engine. Turboprop engines use the normal instruments—oil pressure, oil temperature, interturbine temperature (ITT) and fuel flow. They also use instruments to measure gas generator speed, propeller speed, and torque produced by the propeller. (***Figure 17-10***) A typical turboprop uses a set of engine controls, such as power levelers (throttle), propeller levers, and condition levers. (***Figure 17-11***)

The first step in starting a turbine engine is to provide an adequate source of power for the starter. On smaller turbine engines, the starter is an electric motor which turns the engine through electrical power. Larger engines needed a much more powerful starter.

Electric motors would be limited by current flow and weight. Air turbine starters were developed which were lighter and produced sufficient power to turn the engine at the correct speed for starting. Where an air turbine starter is used, the starting air supply may be obtained from an auxiliary power unit onboard the aircraft, an external source (ground air cart), or an engine cross-bleed operation. In some limited cases, a low-pressure large-volume tank can provide the air for starting an engine. Many smaller turboprop engines are started using the starter/generator, which is both the engine starter and the generator.

While starting an engine, always observe the following:

- Always observe the starter duty cycle. Otherwise, the starter can overheat and be damaged.
- Assure that there is enough air pressure or electrical capacity before attempting a start.
- Do not perform a ground start if turbine inlet temperature (residual temperature) is above that specified by the manufacturer.
- Provide fuel under low pressure to the engine's fuel pump.

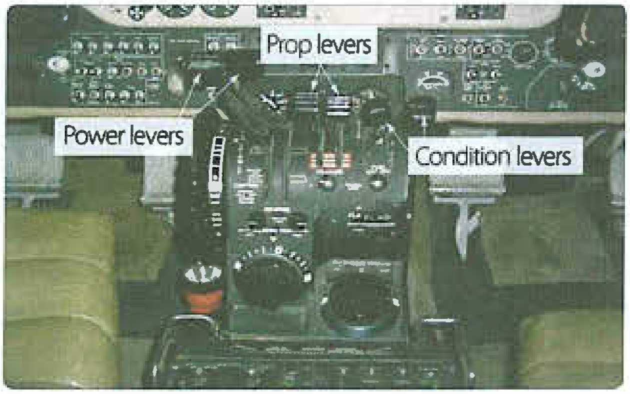


Figure 17-10. Engine controls of a turboprop aircraft.

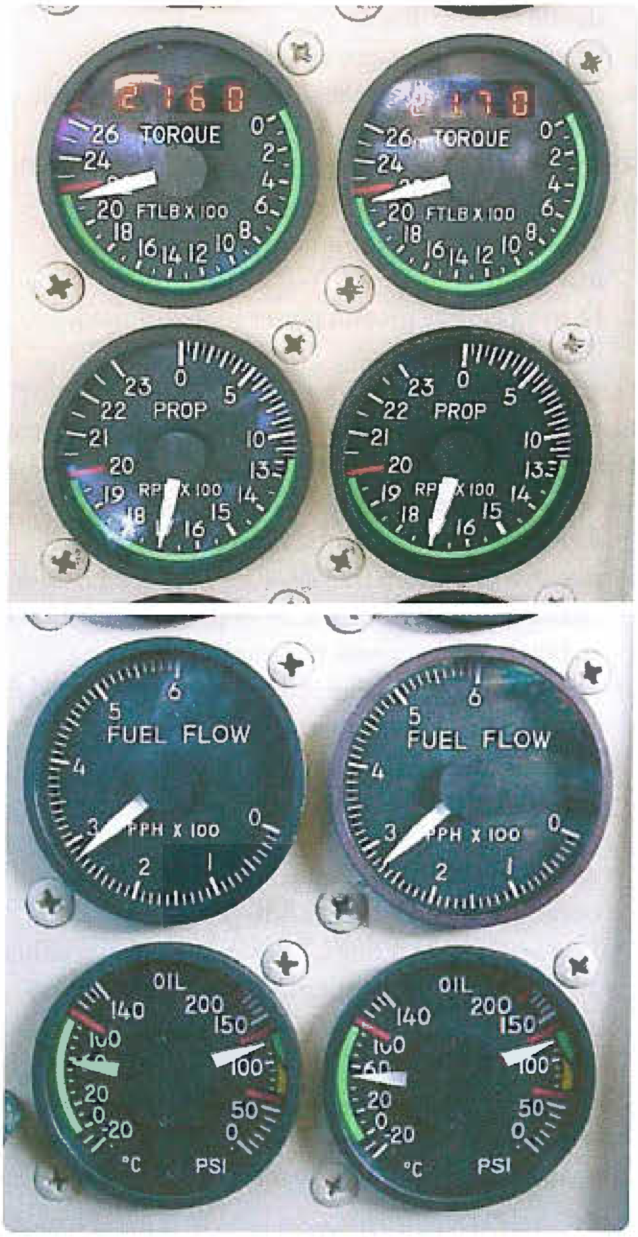


Figure 17-11. Engine controls of a turboprop aircraft.

TURBOPROP STARTING PROCEDURES

To start an engine on the ground, perform the following operations:

1. Turn the aircraft boost pumps on.
2. Make sure that the power lever is in the "start" position.
3. Place the start switch in the "start" position. (This will start the engine turning.)
4. Place the ignition switch on. (On some engines, the ignition is activated by moving the fuel lever.)
5. The fuel is now turned on. This is accomplished by moving the condition lever to the "on" position.
6. Monitor the engine lights of the exhaust temperature. If it exceeds the limits, the engine should be shut down.
7. Check the oil pressure and temperature.
8. After the engine reaches a self-sustaining speed, the starter is disengaged.
9. The engine should continue to accelerate up to idle.
10. Maintain the power lever at the "start" position until the specified minimum oil temperature is reached.
11. Disconnect the ground power supply, if used.

If any of the following conditions occur during the starting sequence, turn off the fuel and ignition switch, discontinue the start immediately, make an investigation, and record the findings.

- Turbine inlet temperature exceeds the specified maximum. Record the observed peak temperature.
- Acceleration time from start of propeller rotation to stabilized rpm exceeds the specified time.
- There is no oil pressure indication at 5000 RPM for either the reduction gear or the power unit.
- Torching (visible burning in the exhaust nozzle).
- The engine fails to ignite by 4500 RPM or maximum motoring RPM.
- Abnormal vibration is noted or compressor surge occurs (indicated by backfiring).
- Fire warning bell rings. (This may be due to either an engine fire or overheating.)

TURBOFAN ENGINES

Unlike reciprocation engine aircraft, the turbine-powered aircraft does not require a preflight run-up unless it is necessary to investigate a suspected malfunction.

Before starting, all protective covers and air inlet duct covers should be removed. If possible, the aircraft should be headed into the wind to obtain better cooling, faster starting, and smoother engine performance. It is especially important that the aircraft be headed into the wind if the engine is to be trimmed. The run-up area around the aircraft should be cleared of both personnel and loose equipment. The turbofan engine intake and exhaust hazard areas are illustrated in ***Figure 17-12***.

Exercise care to ensure that the runup area is clear of all items, such as nuts, bolts, rocks, shop towels, or other loose debris (FOD). Many very serious accidents have occurred involving personnel in the vicinity of turbine engine air inlets. Use extreme caution when starting turbine aircraft.

Check the aircraft fuel sumps for water or ice, and inspect the engine air inlet for general condition and the presence of foreign objects. Visually inspect the fan blades, forward compressor blades, and the compressor inlet guide vanes for nicks and other damage. If possible, check the fan blades for free rotation by turning the fan blades by hand. All engine controls should be operated, and engine instruments and warning lights should be checked for proper operation.

Starting a Turbofan Engine

The following procedures are typical of those used to start many turbine engines. There are, however, wide variations in the starting procedures used for turbine engines, and no attempt should be made to use these procedures in the actual starting of an engine. These procedures are presented only as a general guide for familiarization with typical procedures and methods. In the starting of all turbine engines, refer to the detailed procedures contained in the applicable manufacturer's instructions or their approved equivalent.

Most turbofan engines can be started by either air turbine or electrical starters. Air-turbine starters use compressed air from an external source as discussed earlier. Fuel is turned on either by moving the start lever to "idle/start" position or by opening a fuel shutoff valve. If an air turbine starter is used, the engine should "light off" within a predetermined time after the fuel is turned on. This time interval, if exceeded, indicates a malfunction has occurred and the start should be discontinued.

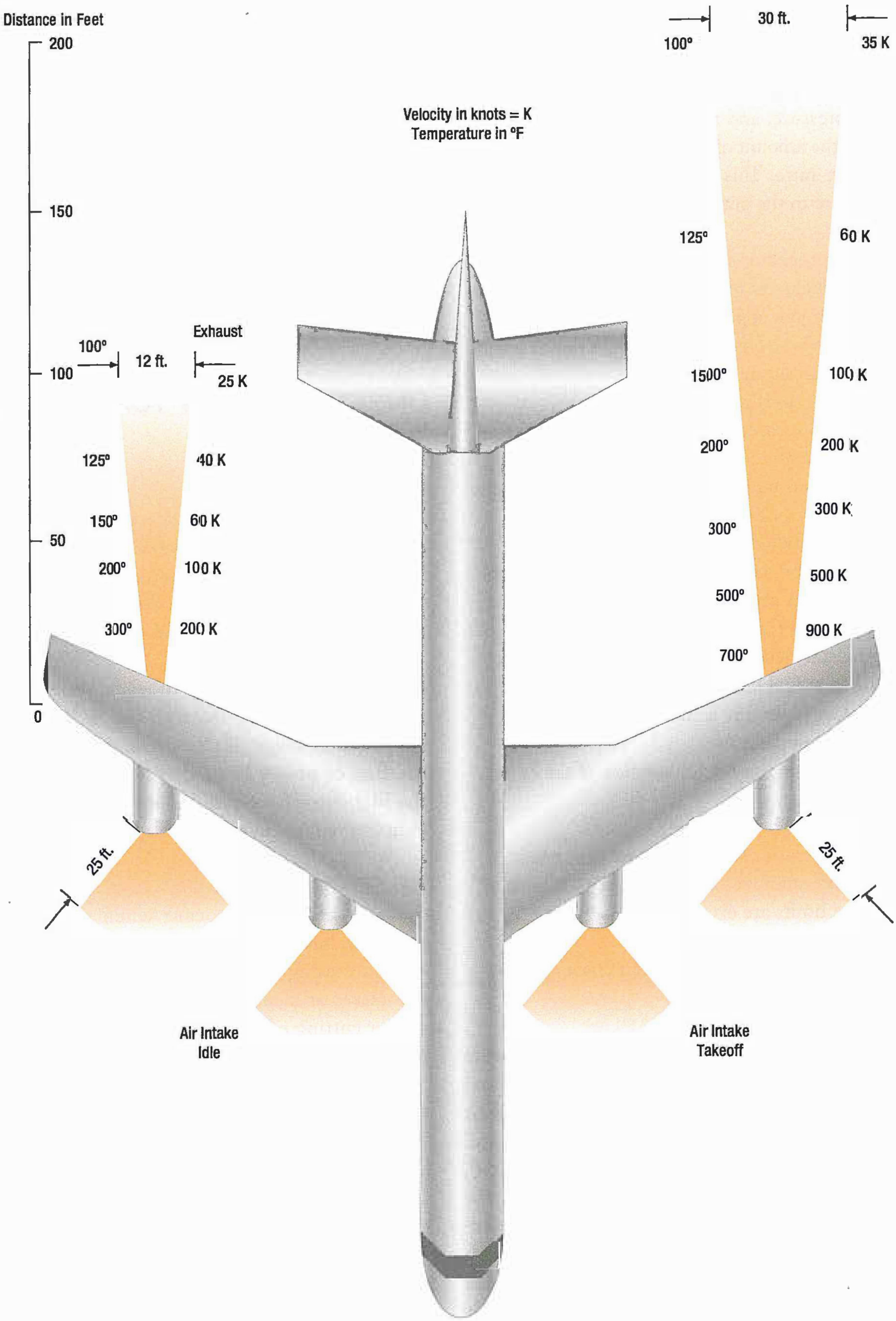


Figure 17-12. Engine intake and exhaust hazard areas.

Most turbofan engine controls consist of a power lever, reversing levers, and start levers. Newer aircraft have replaced the start levers with a fuel switch. (***Figure 17-13***) Turbofan engines also use all the normal instrument speeds, (percent of total RPM), exhaust gas temperature, fuel flow, oil pressure, and temperature. An instrument that measures the amount of thrust being delivered is the engine pressure ratio. This measures the ratio between the inlet pressure to the outlet pressure of the turbine.

The following procedures are useful only as a general guide, and are included to show the sequence of events in starting a turbofan engine.

1. If the engine is so equipped, place the power lever in the "idle" position.
2. Turn the fuel boost pump(s) switch on.
3. A fuel inlet pressure indicator reading ensures fuel is being delivered to the engine fuel pump inlet.
4. Turn engine starter switch on; note that the engine rotates to a preset limit; check for oil pressure.
5. Turn ignition switch on. (This is usually accomplished by moving the start lever toward the "on" position. A micro switch connected to the leveler turns on the ignition.)
6. Move the start lever to "idle" or "start" position; this will start fuel flow into the engine.
7. Engine start (light off) is indicated by a rise in exhaust gas temperature.
8. If a two spool engine, check rotation of fan or N1 pressure reading.
9. Check for proper oil pressure.
10. Turn engine starter switch off at proper speeds.
11. After engine stabilizes at idle, ensure that none of the engine limits are exceeded.

Newer aircraft will drop off the starter automatically.

AUXILIARY POWER UNITS (APUs)

APUs are generally smaller turbine engines that provide compressed air for starting engines, cabin heating and cooling, and electrical power while on the ground. Their operation is normally simple. By turning a switch on and up to the start position (spring loaded to on position), the engine will start automatically. During start, the exhaust gas temperature must be monitored. APUs are at idle at 100 percent rpm with no load. After the engine reaches its operating rpm, it can be used for cooling or heating the cabin and for electrical power. It is normally used to start the main engines.

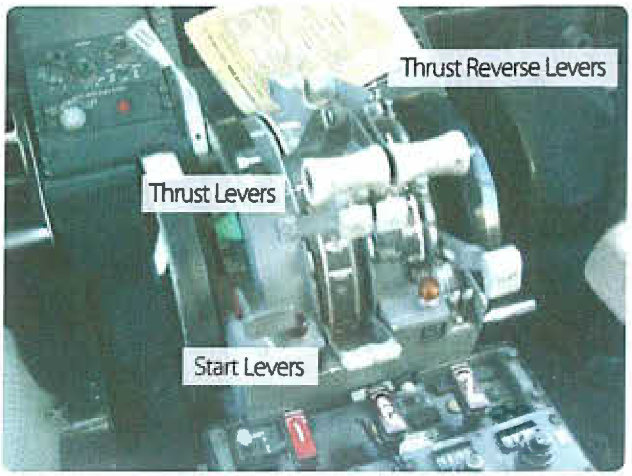


Figure 17-13. Turbofan engine control levers.

UNSATISFACTORY TURBINE ENGINE STARTS

HOT START

A hot start occurs when the engine starts, but the exhaust gas temperature exceeds specified limits. This is usually caused by an excessively rich fuel/air mixture entering the combustion chamber. This condition can be caused by either too much fuel or not enough airflow.

An important indication of a hot start is the speed at which the needle rises on the EGT (exhaust gas temperature) gauge. If the needle rises abnormally fast, the fuel or power lever should be quickly moved to the fuel cut-off position before the gauge reaches the indicator red line to avoid damage to the engine.

FALSE OR HUNG STARTS

False or hung starts occur when the engine starts normally, but the rpm remains at some low value rather than increasing to the normal starting rpm. This is often the result of insufficient power to the starter, or the starter cutting off before the engine self accelerates. In this case, the engine should be shut down.

ENGINE WILL NOT START

This can be caused by lack of fuel to the engine, insufficient or no electrical power to the exciter in the ignition system, or incorrect fuel mixer. If the engine fails to start within the prescribed time, it should be shut down.

In all cases of unsatisfactory starts the fuel and ignition should be turned off. Continue rotating the compressor for approximately 15 seconds to remove accumulated fuel from the engine. If unable to motor (rotate) the engine, allow a 30-second fuel draining period before attempting another start.

TOWING OF AIRCRAFT

Movement of large aircraft on an airport or in a hangar is usually accomplished by towing with a tow tractor (sometimes called a "tug"). In the case of small aircraft, some moving is accomplished by hand, by pushing on the correct areas of the aircraft. Aircraft may also be taxied about the flight line, but usually only by certain qualified persons.

Towing aircraft can be a hazardous operation, causing damage to the aircraft and injury to personnel, if done recklessly or carelessly. The following paragraphs outline the general procedure for towing aircraft; however, specific instructions for each model of aircraft are detailed in the manufacturer's maintenance instructions and should be followed in all instances. Before an aircraft is towed, a qualified person must be in the cockpit to operate the brakes in case the tow bar should fail or become unhooked. The aircraft can then be stopped, preventing possible damage.

Some types of tow bars available for general use can be used for many types of towing operations. (***Figure 17-14***) These bars are designed with sufficient tensile strength to pull most aircraft, but are not intended to be subjected to torsional or twisting loads. Many have small wheels that permit them to be drawn behind the towing vehicle going to or from an aircraft. When the bar is attached to the aircraft, inspect all the engaging devices for damage or malfunction before moving the aircraft. Some tow bars are designed for towing various types of aircraft; however, other special types can be used on a particular aircraft only. Such bars are usually designed and built by the aircraft manufacturer.

When towing the aircraft, the towing vehicle speed must be reasonable, and all persons involved in the operation must be alert. When the aircraft is stopped, do not rely upon the brakes of the towing vehicle alone to stop the aircraft. The person in the cockpit should coordinate the use of the aircraft brakes with those of the towing vehicle. A typical smaller aircraft tow tractor (or tug) is shown in ***Figure 17-15***.

The attachment of the tow bar varies on different types of aircraft. Aircraft equipped with tailwheels are generally towed forward by attaching the tow bar to the main landing gear. In most cases, it is permissible to tow the aircraft in reverse by attaching the tow bar to the tailwheel axle. Any time an aircraft equipped with a tailwheel is towed, the tailwheel must be unlocked or the tailwheel locking mechanism will be damaged or broken.

Figure 17-14. Tow bar for a large aircraft.

Figure 17-15. Typical smaller aircraft tow tractor.

Lights	Meaning
Flashing green	Cleared to taxi
Steady red	Stop
Flashing red	Taxi clear of runway in use
Flashing white	Return to starting point
Alternating red and green	Exercise extreme caution

Figure 17-16. Standard taxi light signals.

Aircraft equipped with tricycle landing gear are generally towed forward by attaching a tow bar to the axle of the nosewheel. They may also be towed forward or backward by attaching a towing bridle or specially designed towing bar to the towing lugs on the main landing gear. When an aircraft is towed in this manner, a steering bar is attached to the nosewheel to steer the aircraft.

The following towing and parking procedures are typical of one type of operation. They are examples, and not necessarily suited to every type of operation. Aircraft ground-handling personnel should be thoroughly familiar with all procedures pertaining to the types of aircraft being towed and local operation standards governing ground handling of aircraft. Only competent persons properly checked out should direct an aircraft towing team.

1. The towing vehicle driver is responsible for operating the vehicle in a safe manner and obeying emergency stop instructions given by any team member.
2. The person in charge should assign team personnel as wing walkers. A wing walker should be stationed at each wingtip in such a position that he or she can ensure adequate clearance of any obstruction in the path of the aircraft.
   A tail walker should be assigned when sharp turns are to be made, or when the aircraft is to be backed into position.
3. A qualified person should occupy the pilot's seat of the towed aircraft to observe and operate the brakes as required. When necessary, another qualified person is stationed to watch and maintain aircraft hydraulic system pressure.
4. The person in charge of the towing operation should verify that, on aircraft with a steerable nosewheel, the locking scissors are set to full swivel for towing. The locking device must be reset after the tow bar has been removed from the aircraft. Persons stationed in the aircraft should not attempt to steer or turn the nosewheel when the tow bar is attached to the aircraft.
5. Under no circumstances should anyone be permitted to walk or to ride between the nosewheel of an aircraft and the towing vehicle, nor ride on the outside of a moving aircraft or on the towing vehicle. In the interest of safety, no attempt to board or leave a moving aircraft or towing vehicle should be permitted.
6. The towing speed of the aircraft should not exceed that of the walking team members. The aircraft's engines usually are not operated when the aircraft is being towed into position.
7. The aircraft brake system should be charged before each towing operation. Aircraft with faulty brakes should be towed into position only for repair of brake systems, and then only with personnel standing by ready with chocks for emergency use. Chocks must be immediately available in case of an emergency throughout any towing operation.
8. To avoid possible personal injury and aircraft damage during towing operations, entrance doors should be closed, ladders retracted, and gear downlocks installed.
9. Prior to towing any aircraft, check all tires and landing gear struts for proper inflation. (Inflation of landing gear struts of aircraft in overhaul and storage is excluded.)
10. When moving aircraft, do not start and stop suddenly. For added safety, aircraft brakes must never be applied during towing except in emergencies, and then only upon command by one of the tow team members.
11. Aircraft should be parked in specified areas only. Generally, the distance between rows of parked aircraft should be great enough to allow immediate access of emergency vehicles in case of fire, as well as free movement of equipment and materials.
12. Wheel chocks should be placed fore and aft of the main landing gear of the parked aircraft.
13. Internal or external control locks (gust locks or blocks) should be used while the aircraft is parked.
14. Prior to any movement of aircraft across runways or taxiways, contact the airport control tower on the appropriate frequency for clearance to proceed.
15. An aircraft should not be parked in a hangar without immediately being statically grounded.

TAXIING AIRCRAFT

As a general rule, only rated pilots and qualified airframe and powerplant technicians are authorized to start, run up, and taxi aircraft. All taxiing operations should be performed in accordance with applicable local regulations. ***Figure 17-16*** contains the standard taxi light signals used by control towers to control and expedite the taxiing of aircraft. The following section provides detailed instructions on taxi signals and related taxi instructions.

TAXI SIGNALS

Many ground accidents have occurred as a result of improper technique in taxiing aircraft. Although the pilot is ultimately responsible for the aircraft until the engine is stopped, a taxi signalman can assist the pilot around the flight line. In some aircraft configurations, the pilot's vision is obstructed while on the ground. The pilot cannot see obstructions close to the wheels or under the wings, and has little idea of what is behind the aircraft. Consequently, the pilot depends upon the taxi signalman for directions. ***Figure 17-17*** shows a taxi signalman indicating his readiness to assume guidance of the aircraft by extending both arms at full length above his head, palms facing each other.

The standard position for a signalman is slightly ahead of and in line with the aircraft's left wingtip. As the signalman faces the aircraft, the nose of the aircraft is on the left. (***Figure 17-18***)

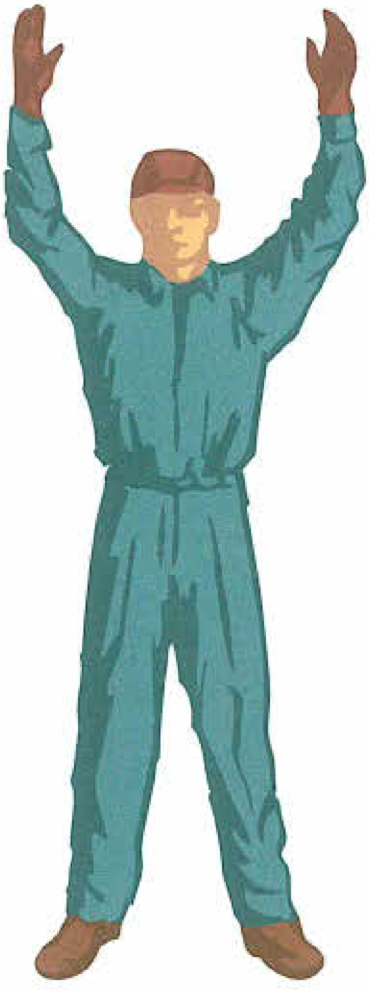


Figure 17-17. The taxi signalman.

The signalman must stay far enough ahead of the wingtip to remain in the pilot's field of vision. It is a good practice to perform a foolproof test to be sure the pilot can see all signals. If the signalman can see the pilot's eyes, the pilot can see the signals.

Figure 17-18 shows the standard aircraft taxiing signals. It should be emphasized that there are other standard signals, such as those published by the Armed Forces. In addition, operation conditions in many areas may call for a modified set of taxi signals. The signals shown in ***Figure 17-18*** represent a minimum number of the most commonly used signals. Whether this set of signals or a modified set is used is not the most important consideration, as long as each flight operational center uses a suitable, agreed-upon set of signals.

Figure 17-19 illustrates some of the most commonly used helicopter operating signals.

The taxi signals to be used should be studied until the taxi signalman can execute them clearly and precisely. The signals must be given in such a way that the pilot cannot confuse their meaning. Remember that the pilot receiving the signals is always some distance away, and must often look out and down from a difficult angle. Thus, the signalman's hands should be kept well separated, and signals should be over-exaggerated rather than risk making indistinct signals. If there is any doubt about a signal, or if the pilot does not appear to be following the signals, use the "stop" sign and begin the series of signals again.

The signalman should always try to give the pilot an indication of the approximate area in which the aircraft is to be parked. The signalman should glance behind himself or herself often when walking backward to prevent backing into a propeller or tripping over a chock, fire bottle, tiedown line, or other obstruction.

Taxi signals are usually given at night with the aid of illuminated wands attached to flashlights. (***Figure 17-20***) Night signals are made in the same manner as day signals with the exception of the stop signal. The stop signal used at night is the "emergence stop" signal. This signal is made by crossing the wands to form a lighted "X" above and in front of the head.

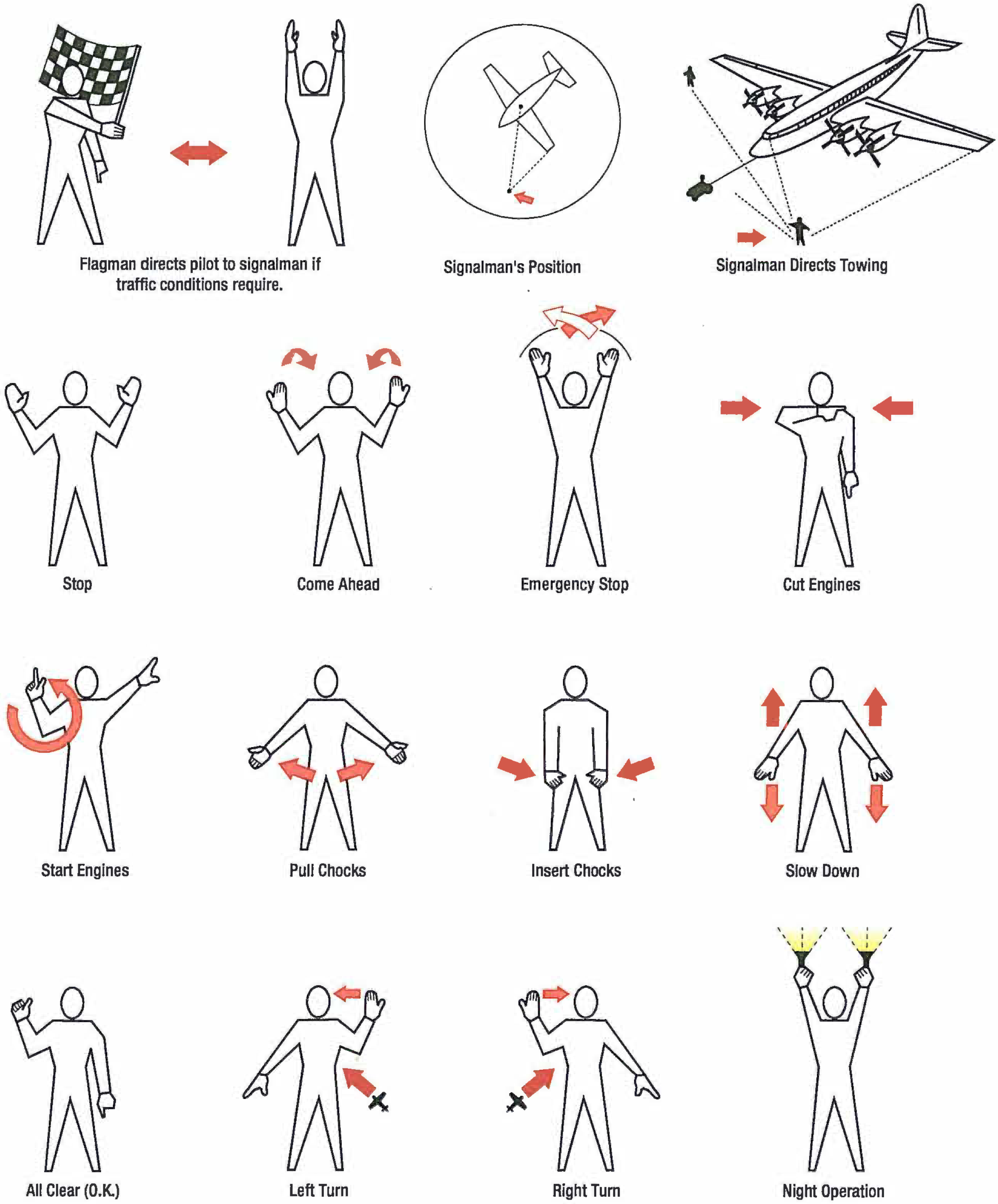


Figure 17-18. Standard hand taxi signals.

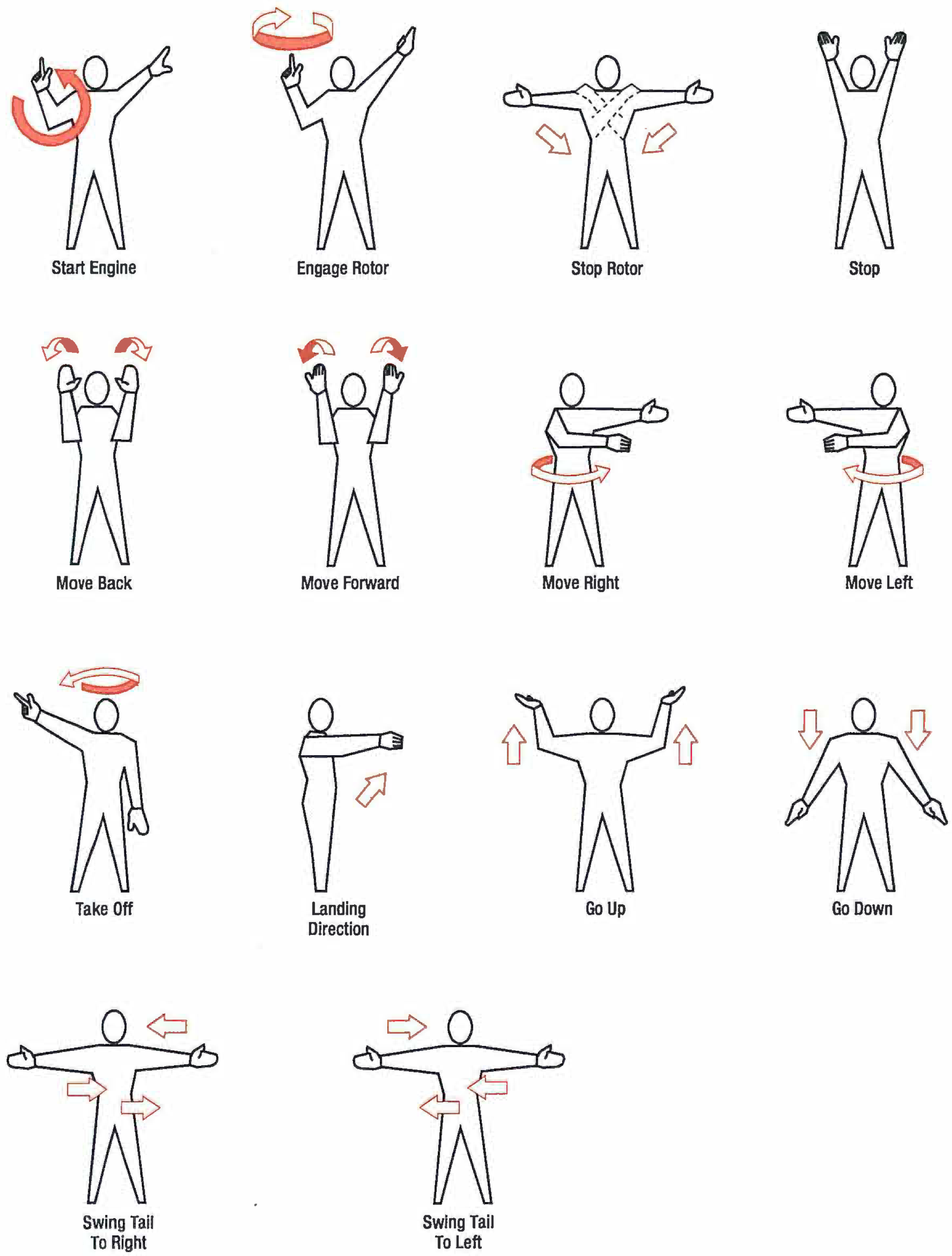


Figure 17-19. Helicopter operating signals.

Figure 17-20. Night operations with wands.

AIRCRAFT SERVICING

AIR/NITROGEN, OIL, AND FLUID SERVICING

Checking or servicing aircraft fluids is an important maintenance function. Before servicing any aircraft, consult the specific aircraft maintenance manual to determine the proper type of servicing equipment and procedures. In general, aircraft engine oil is checked with a dipstick or a sight gauge. There are markings on the stick or around the sight gauge to determine the correct level. Reciprocating engines should be checked after the engine has been inactive, while the turbine engine should be checked just after shutdown.

Dry sump oil systems tend to hide oil that has seeped from the oil tank into the gear case of the engine. This oil will not show up on the dipstick until the engine has been started or motored. If serviced before this oil is pumped back into the tank, the engine will be overfilled.

Never overfill the oil tank. Oil will foam as it is circulated through the engine. The expansion space in the oil tank allows for this foaming (oil mixing with air). Also the correct type of oil must be used for the appropriate engine being serviced. Hydraulic fluid, fuel, and oil, if spilled on clothes or skin, must be removed as soon as possible because of fire danger and health reasons.

When servicing a hydraulic reservoir the correct fluid must be used. Normally, this can be determined by the container or by color. Some reservoirs are pressurized by air which must be bled off before servicing. Efforts must be made to prevent any type of contamination during servicing. Also, if changing hydraulic filters, assure that the pressure is off the system before removing the filters. After servicing the filters (if large amounts of fluids were lost) or system quantity, air should be purged and the system checked for leaks. While servicing tires or struts with high pressure nitrogen, the technician must use caution while performing maintenance. Clean areas before connecting filling hose and do not over inflate.

GROUND SUPPORT EQUIPMENT

ELECTRIC GROUND POWER UNITS

Ground support electrical auxiliary power units vary widely in size and type. However, they can be generally classified by towed, stationary, or self-propelled items of equipment. Some units are mainly for in-hangar use during maintenance. Others are designed for use on the flight line either at a stationary gate area or towed from aircraft to aircraft. The stationary type can be powered from the electrical service of the facility. The movable type ground power unit (GPU) generally has an onboard engine that turns a generator to produce power. Some smaller units use a series of batteries.

Figure 17-21. A mobile electrical power unit.

The towed power units vary in size and range of available power. The smallest units are simply high-capacity batteries used to start light aircraft. These units are normally mounted on wheels or skids and are equipped with an extra-long electrical line terminated in a suitable plug-in adapter.

Larger units are equipped with generators. Providing a wider range of output power, these power units are normally designed to supply constant-current, variable voltage DC electrical power for starting turbine aircraft engines, and constant-voltage DC for starting reciprocating aircraft engines. Normally somewhat top-heavy, large towed power units should be towed at restricted speeds, and sharp turns should be avoided. An example of a large power unit is shown in ***Figure 17-21.***

Figure 17-22. A stationary electrical power unit.

Self-propelled power units are normally more expensive than the towed units and in most instances supply a wider range of output voltages and frequencies.

Another example, the stationary power unit shown in ***Figure 17-22*** is capable of supplying DC power in varying amounts, as well as 115/200-volt, 3-phase, 400-cycle AC power continuously for 5 minutes.

When using ground electrical power units, it is important to position the unit to prevent collision with the aircraft being serviced, or others nearby, in the event the brakes on the unit fail. It should be parked so that the service cable is extended to near its full length away from the aircraft being serviced, but not so far that the cable is stretched or undue stress is placed on the aircraft electrical receptacle.

Observe all electrical safety precautions when servicing an aircraft. Additionally, never move a power unit when service cables are attached to an aircraft or when the generator system is engaged.

HYDRAULIC GROUND POWER UNITS

Portable hydraulic test stands are manufactured in many sizes and cost ranges. (***Figure 17-23***) Some have a limited range of operation, while others can be used to perform all the system tests that fixed shop test stands are designed to perform. Hydraulic power units, sometimes called a hydraulic mule, provide hydraulic pressure to operate the aircraft systems during maintenance.

Figure 17-23. A portable hydraulic power unit.

They can be used to:

- Drain the aircraft hydraulic systems.
- Filter the aircraft system hydraulic fluid.
- Refill the aircraft system with clean fluid.
- Check the aircraft hydraulic systems for operation and leaks.

This type of portable hydraulic test unit is usually an electrically powered unit. It uses a hydraulic system capable of delivering a variable volume of fluid from zero to approximately 24 gallons per minute at variable pressures up to 3 000 psi.

Operating at pressures of 3 000 psi or more, extreme caution must be used when operating hydraulic power units. At 3 000 psi, a small stream from a leak can cut like a sharp knife. Therefore, inspect lines used with the system for cuts, frays, or any other damage, and keep them free of kinks and twists. When not in use, hydraulic power unit lines should be stored (preferably wound on a reel) and kept clean, dry, and free of contaminants.

GROUND SUPPORT AIR UNITS

Air carts are used to provide low pressure (up to 50 psi high volume flow) air which can be used for starting the engines, and heating and cooling the aircraft on the ground (using the onboard aircraft systems). It generally consists of an APU built into the cart that provides bleed air from the APU's compressor for operating aircraft systems or starting engines. (***Figure 17-24***)

Figure 17-24. A portable compressed air cart.

GROUND AIR HEATING AND AIR CONDITIONING

Most airport gates have facilities that can provide heated or cooled air. The units that cool or heat the air are permanent installations, which connect to the aircraft by a large hose that connects to the aircraft's ventilation system. Portable heating and air conditioning units can also be moved close to the aircraft and connected by a duct, which provides air to keep the cabin temperature comfortable.

OXYGEN SERVICING EQUIPMENT

Before servicing any aircraft, consult the specific aircraft maintenance manual to determine the proper type of servicing equipment to be used. Two personnel are required to service an aircraft with gaseous oxygen. One person should be stationed at the control valves of the servicing equipment and one person stationed where he or she can observe the pressure in the aircraft system. Communication between the two people is required in case of an emergency.

Aircraft should not be serviced with oxygen during fueling, defueling, or other maintenance work, which could provide a source of ignition. Oxygen servicing of aircraft should be accomplished outside hangars. Oxygen used on aircraft is available in two types: gaseous and liquid. The type to use on any specific aircraft depends on the type of equipment in the aircraft. Gaseous oxygen is stored in large steel cylinders, while liquid oxygen (commonly referred to as LOX) is stored and converted into a usable gas in a liquid oxygen converter.

Oxygen is commercially available in three general types: aviator's breathing, industrial, and medical. Only oxygen marked "Aviator's Breathing Oxygen" which meets Federal Specification BB-0-925A, Grade A, or its equivalent should be used in aircraft breathing oxygen systems. Industrial oxygen may contain impurities, which could cause the pilot, crew, and/or passengers to become sick. Medical oxygen, although pure, contains water, which can freeze in the cold temperatures found at the altitudes where oxygen is necessary.

OXYGEN HAZARDS

Gaseous oxygen is chemically stable and is nonflammable. However, combustible materials ignite more rapidly and burn with greater intensity in an oxygen- rich atmosphere. In addition, oxygen combines with oil, grease, or bituminous material to form a highly explosive mixture, which is sensitive to compression or impact.

Physical damage to, or failure of oxygen containers, valves, or plumbing can result in an explosive rupture, with extreme danger to life and property. It is imperative that the highest standard of cleanliness be observed in handling oxygen and that only qualified and authorized persons be permitted to service aircraft gaseous oxygen systems. In addition to aggravating the fire hazard, because of its low temperature (it boils at -297 °F), liquid oxygen causes severe "burns" (frostbite) if it comes in contact with the skin.

FUEL SERVICING OF AIRCRAFT

FUEL TYPES AND IDENTIFICATION

Two types of aviation fuel in general use are aviation gasoline, also known as AVGAS, and turbine fuel, also known as JET A fuel.

Aviation gasoline (AVGAS) is used in reciprocating-engine aircraft. Currently, there are three grades of fuel in general use: 80/87, 100/130, and 100LL (low lead). A fourth grade, 115/145, is in limited use in the large reciprocating-engine aircraft. The two numbers indicate the lean mixture and rich mixture octane rating numbers of the specific fuel. In other words, with 80/87 aviation gasoline, the 80 is the lean mixture rating and 87 is the rich mixture rating number. To avoid confusing the types of AVGAS, it is generally identified as grade 80, 100, 100LL, or 115. AVGAS can also be identified by a color code. The color of the fuel should match the color band on piping and fueling equipment. (*Figure 17-25*)

Turbine fuel/jet fuel is used to power turbojet and turboshaft engines. Three types of turbine fuel generally used in civilian aviation are JET A and JET A-1, which are both made from kerosene and JET B, which is a blend of kerosene and aviation gasoline. While jet fuel is identified by the color black on piping and fueling equipment, the actual color of jet fuel can be clear or straw colored.

Color	Grade
Red	80/87
Blue	100LL
Green	100/130
Clear / Straw	Jet-A

Figure 17-25. Avgas colors.

Never mix AVGAS and turbine fuel. Adding jet fuel to AVGAS will cause a decrease in the power developed by the engine and could cause damage to the engine (through detonation) and loss of life. Adding AVGAS to jet fuel, although allowed, can cause lead deposits in the turbine engine and can lead to reduced service life.

CONTAMINATION CONTROL

Contamination is anything in the fuel that is not supposed to be there. The types of contamination found in aviation fuel include water, solids, and microbial growths. The control of contamination in aviation fuel is extremely important, since contamination can lead to engine failure, or stoppage and the loss of life. The best method of controlling contamination is to prevent its introduction into the fuel system. Some forms of contamination will still occur inside the fuel system. Either way, the filter, separators, and screens should remove most of the contamination. Water in aviation fuels will generally take two forms: dissolved (vapor) and free water.

Dissolved water is not a major problem until, as the temperature lowers, it becomes free water. This then poses a problem if ice crystals form, clogging filters and other small orifices. Free water can appear as water slugs or entrained water. Water slugs are concentrations of water. This is the water that is drained after fueling an aircraft. Entrained water is suspended water droplets in the fuel. Droplets may not be visible to the eye, but will give the fuel a cloudy look. The entrained water will settle out in time.

Solid contaminants are insoluble in fuel. The more common types are rust, dirt, sand, gasket material, lint, and fragments of shop towels. The close tolerances of fuel controls and other fuel-related mechanisms can be damaged or blocked by particles as small as one-twentieth the diameter of a human hair.

Microbiological growths are a problem in jet fuel. There are a number of varieties of micro-organisms that can live in the free water in jet fuel. Some types are airborne, others live in the soil. The aircraft fuel system becomes susceptible to the introduction of these organisms each time the aircraft is fueled. Favorable conditions for the growth of micro-organisms in the fuel are warm temperatures and the presence of iron oxide and mineral salts in the water.

The effects of micro-organisms are:

- Formation of slime or sludge that can foul filters, separators, or fuel controls.
- Emulsification of the fuel.
- Corrosive compounds that can attack the fuel tank's structure. In the case of a wet wing tank, the tank is made from the aircraft's structure. They can also have offensive odors.

The best way to prevent microbial growth is to keep the fuel free of water.

FUELING HAZARDS

The volatility of aviation fuels creates a fire hazard that has plagued aviators and designers since the beginning of powered flight. Volatility is the ability of a liquid to change into a gas at a relatively low temperature. In its liquid state, aviation fuel will not burn. It is, therefore, the vapors or gaseous state to which the liquid fuel changes that is a fire hazard.

Static electricity is a byproduct of one substance rubbing against another. Fuel flowing through a fuel line causes a certain amount of static electricity. The greatest static electricity concern around aircraft is that during flight, the aircraft moving through the air causes static electricity to build in the airframe. If that static electricity is not dissipated prior to refueling, the static electricity in the airframe will try to return to ground through the fuel line from the servicing unit. The spark caused by the static electricity can ignite any vaporized fuel. Breathing the vapors from fuel can be harmful and should be limited. Any fuel spilled on the clothing or skin must be removed as soon as possible.

GROUNDING AND BONDING

Two safety procedures used in refueling aircraft are grounding and bonding. Grounding of the aircraft and fuel truck is to provide a pathway for static electricity dispersal. Bonding of the aircraft requires attaching a cable from the refueling unit to the aircraft being serviced, also to provide a path for the dispersing static electricity. Most agencies have gone away from grounding and now only use bonding. Check with your fuel supplier for approved methods of grounding and bonding in the refueling operations. Never bond onto painted or polished surfaces on an aircraft.

FUELING PROCEDURES

The proper fueling of an aircraft is the responsibility of the owner/operator. This does not, however, relieve the person doing the fueling of the responsibility to use the correct type of fuel and safe fueling procedures. There are two basic procedures when fueling an aircraft. Smaller aircraft are fueled by the over-the-wing method. This method uses the fuel hose to fill through fueling ports on the top of the wing. The method used for larger aircraft is the single point fueling system. This type of fueling system uses receptacles in the bottom leading edge of the wing, which is used to fill all the tanks from this one point. This decreases the time it takes to refuel the aircraft, limits contamination, and reduces the chance of static electricity igniting the fuel. Most pressure fueling systems consist of a pressure fueling hose and a panel of controls and gauges that permit one person to fuel or defuel any or all fuel tanks of an aircraft.

Each tank can be filled to a predetermined level. These procedures are illustrated in ***Figures 11-26 and 17-27.***

Prior to fueling, the person fueling should check the following:

1. Ensure all aircraft electrical systems and electronic devices, including radar, are turned off.
2. Do not carry anything in the shirt pockets. These items could fall into the fuel tanks.
3. Ensure no flame-producing devices are carried by anyone engaged in the fueling operation. A moment of carelessness could cause an accident.
4. Ensure that the proper type and grade of fuel is used. Do not mix AVGAS and JET fuel.
5. Ensure that all the sumps have been drained.
6. Wear eye protection. Although generally not as critical as eye protection, other forms of protection, such as rubber gloves and aprons, can protect the skin from the effects of spilled or splashed fuel.
7. Do not fuel aircraft if there is danger of other aircraft in the vicinity blowing dirt in the direction of the aircraft being fueled. Blown dirt, dust, or other contaminants can enter an open fuel tank, contaminating the entire contents of the tank.
8. Do not fuel an aircraft when there is lightning within 5 miles.
9. Do not fuel an aircraft within 500 feet of operating ground radar.

When using mobile fueling equipment:

1. Approach the aircraft with caution, positioning the fuel truck so that if it is necessary to depart quickly, no backing will be needed.
2. Set the hand brake of the fuel truck, and chock the wheels to prevent rolling.
3. Ground the aircraft and then ground the truck. Next, ground or bond them together by running a connecting wire between the aircraft and fuel truck. This may be done by three separate ground wires or by a "Y" cable from the fuel truck.
4. Ensure that the grounds are in contact with bare metal or are in the proper grounding points on the aircraft. Do not use the engine exhaust or propeller as grounding points. Damage to the propeller can result, and there is no way of quickly ensuring a positive bond between the engine and the airframe.
5. Ground the nozzle to the aircraft, by gently touching the fuel nozzle to the bare metal then open the fuel tank.
6. Protect the wing and any other item on the aircraft from damage caused by spilled fuel or careless handling of the nozzle, hose, or grounding wires.
7. Check the fuel cap for proper installation and security before leaving the aircraft.
8. Remove the grounding wires in the reverse order. If the aircraft is not going to be flown or moved soon, the aircraft ground wire can be left attached.

Figure 17-26. Refueling an aircraft by the over-the-wing method.

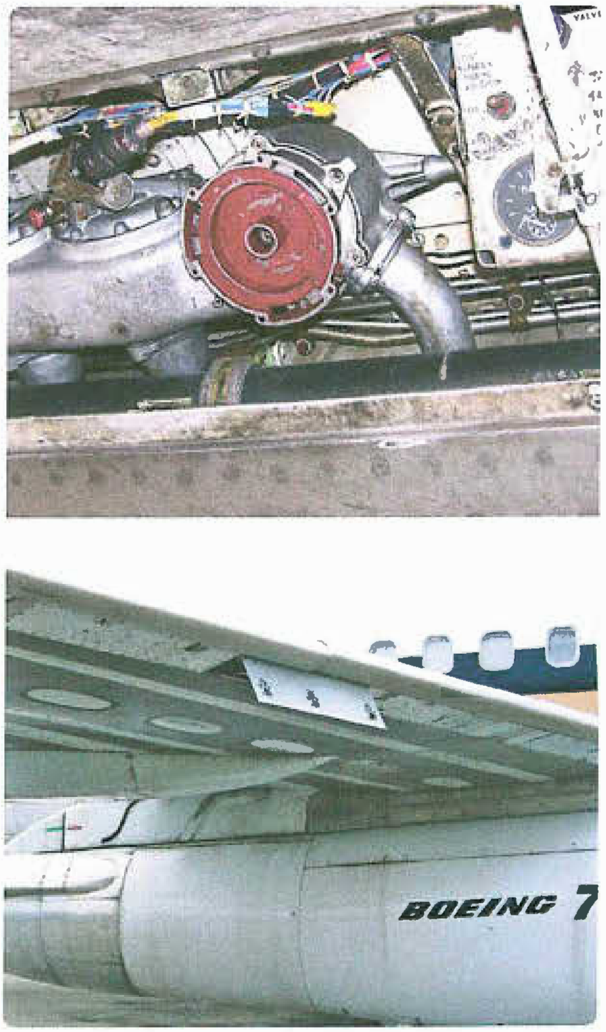


Figure 17-27. Single point refueling station of a large aircraft.

When fueling from pits or cabinets, follow the same procedures as when using a truck. Pits or cabinets are usually designed with permanent grounding, eliminating the need to ground the equipment. However, the aircraft still must be grounded, and then the equipment must be grounded to the aircraft as it was with mobile equipment.

DEFUELING

Defueling procedures differ with different types of aircraft. Before defueling an aircraft, check the maintenance/service manual for specific procedures and cautions. (***Figure 17-28***)

Defueling can be accomplished by gravity defueling or by pumping the fuel out of the tanks. When the gravity method is used, it is necessary to have a method of collecting the fuel. When the pumping method is used, care must be taken not to damage the tanks, and the removed fuel should not be mixed with fresh fuel.

General precautions when defueling are:

- Ground the aircraft and defueling equipment.
- Turn off all electrical and electronic equipment.
- Have the correct type of fire extinguisher available.
- Wear eye protection.

Figure 17-28. Defueling an aircraft.

Question: 17-1
When tying down an aircraft off the ramp, the nose of the aircraft should be facing ________________.

Question: 17-2
An aircraft must be in the proper ________________ for jacking to prevent structural damage.

Question: 17-3
________________ is the estimated time that deicing/anti-icing fluid prevents the formation of frost or ice and the accumulation of snow on the critical surfaces of an aircraft.

Question: 17-4
As the engine accelerates, it will reach a ________________ speed and the starter is disengaged.

Question: 17-5
After an APU engine reaches its operating rpm, it can be used for cooling or heating the cabin and for ________________ power.

Question: 17-6
To avoid possible personal injury and aircraft damage during towing operations, entrance doors should be closed, ladders retracted, and gear ________________. installed.

Question: 17-7
Some reservoirs are pressurized by air which must be ________________ before servicing.

Question: 17-8
It is imperative that the highest standard of ________________ be observed when handling oxygen.

ANSWERS

Answer: 17-1
in to the wind.

Answer: 17-2
configuration.

Answer: 17-3
Holdover time.

Answer: 17-4
self sustaining.

Answer: 17-5
electrical.

Answer: 17-6
downlocks.

Answer: 17-7
bled off.

Answer: 17-8
cleanliness.

MAINTENANCE PRACTICES

DISASSEMBLY, INSPECTION, REPAIR, AND ASSEMBLY TECHNIQUES

SUB-MODULE 18

PART-66 SYLLABUS LEVELS		
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 18 DISASSEMBLY, INSPECTION, REPAIR, AND ASSEMBLY TECHNIQUES Knowledge Requirements		
7.18 - Disassembly, Inspection, Repair and Assembly Techniques		
(a) Types of defects and visual inspection techniques; Corrosion removal, assessment and reprotection;	3	3
(b) General repair methods, Structural Repair Manual; Aging, fatigue and corrosion control programs;	2	-
(c) Non destructive inspection techniques including, penetrant, radiographic, eddy current, ultrasonic and boroscope methods;	2	1
(d) Disassembly and re-assembly techniques;	2	2
(e) Trouble shooting techniques.	2	2

Level 1
A familiarization with the principal elements of the subject.

Objectives:
(a) The applicant should be familiar with the basic elements of the subject.
(b) The applicant should be able to give a simple description of the whole subject, using common words and examples.
(c) The applicant should be able to use typical terms.

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

Level 3
A detailed knowledge of the theoretical and practical aspects of the subject and a capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:
(a) The applicant should know the theory of the subject and interrelationships with other subjects.
(b) The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
(c) The applicant should understand and be able to use mathematical formula related to the subject.
(d) The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.
(f) The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

DISASSEMBLY, INSPECTION, REPAIR AND ASSEMBLY TECHNIQUES

Inspections are visual examinations and manual checks to determine the condition of an aircraft or component. An aircraft inspection can range from a casual walk-around to a detailed inspection involving complete disassembly and the use of complex inspection aids. An inspection system consists of several processes, including reports made by mechanics or the pilot or crew flying an aircraft and regularly scheduled inspections of an aircraft.

An inspection system is designed to maintain an aircraft in the best possible condition. Thorough and repeated inspections must be considered the backbone of a good maintenance program. Irregular and haphazard inspection will invariably result in gradual and certain deterioration of an aircraft. The time spent in repairing an abused aircraft often totals far more than any time saved in hurrying through routine inspections and maintenance.

It has been proven that regularly scheduled inspections and preventive maintenance assure airworthiness. Operating failures and malfunctions of equipment are appreciably reduced if excessive wear or minor defects are detected and corrected early. The importance of inspections and the proper use of records concerning these inspections cannot be overemphasized.

Airframe and engine inspections may range from preflight inspections to detailed inspections. The time intervals for the inspection periods vary with the models of aircraft involved and the types of operations being conducted. The airframe and engine manufacturer's instructions should be consulted when establishing inspection intervals.

Aircraft may be inspected using flight hours as a basis for scheduling, or on a calendar inspection system. Under the calendar inspection system, the appropriate inspection is performed on the expiration of a specified number of calendar weeks. The calendar inspection system is an efficient system from a maintenance management standpoint. Scheduled replacement of components with stated hourly operating limitations is normally accomplished during the calendar inspection falling nearest the hourly limitation.

In some instances, a flight hour limitation is established to limit the number of hours that may be flown during the calendar interval.

Aircraft operating under the flight hour system are inspected when a specified number of flight hours are accumulated. Components with stated hourly operating limitations are normally replaced during the inspection that falls nearest the hourly limitation.

BASIC INSPECTION TECHNIQUES/ PRACTICES

Before starting an inspection, be certain all plates, access doors, fairings, and cowling have been opened or removed and the structure cleaned. When opening inspection plates and cowling and before cleaning the area, take note of any oil or other evidence of fluid leakage.

PREPARATION

In order to conduct a thorough inspection, a great deal of paperwork and/or reference information must be accessed and studied before actually proceeding to the aircraft to conduct the inspection. The aircraft logbooks must be reviewed to provide background information and a maintenance history of the particular aircraft. The appropriate checklist or checklists must be utilized to ensure that no items will be forgotten or overlooked during the inspection. Also, many additional publications must be available, either in hard copy or in electronic format to assist in the inspections.

These additional publications may include information provided by the aircraft and engine manufacturers, appliance manufacturers, parts vendors, the national aviation authority, or EASA.

AIRCRAFT LOGS

"Aircraft logs," as used in this module series, is an inclusive term which applies to the aircraft logbook and all supplemental records concerned with the aircraft. They may come in a variety of formats.

For a small aircraft, the log may indeed be a small 5"×8" logbook. For larger aircraft, the logbooks are often larger, in the form of three-ring binders. Aircraft that have been in service for a long time are likely to have several logbooks. Electronic logbooks and logbook systems are also available for flight and maintenance data recording for aircraft of all sizes.

The aircraft logbook is the record in which all data concerning the aircraft is recorded. Information gathered in this log is used to determine the aircraft condition, date of inspections, time on airframe, engines and propellers. It reflects a history of all significant events occurring to the aircraft, its components, and accessories, and provides a place for indicating compliance airworthiness directives or manufacturers' service bulletins. The more comprehensive the logbook, the easier it is to understand the aircraft's maintenance history.

When the inspections are completed, appropriate entries must be made in the aircraft logbook certifying that the aircraft is in an airworthy condition and may be returned to service. When making logbook entries, exercise special care to ensure that the entry can be clearly understood by anyone having a need to read it in the future. Also, if making a hand-written entry, use good penmanship and write legibly. To some degree, the organization, comprehensiveness, and appearance of the aircraft logbooks have an impact on the value of the aircraft. High quality logbooks can mean a higher value for the aircraft.

CHECKLISTS

Always use a checklist when performing an inspection. The checklist may be of your own design, one provided by the manufacturer of the equipment being inspected, or one obtained from some other source. Like the manufacturers, large operators of transport category aircraft may have their own approved checklists constructed with the knowledge gained from years of maintenance and operating experience on a particular aircraft.

An example checklist for a general inspection of an aircraft follows:

1. Fuselage and Hull
   a. Fabric and skin—for deterioration, distortion, other evidence of failure, and defective or insecure attachment of fittings.
   b. Systems and components—for proper installation, apparent defects, and satisfactory operation.
   c. Envelope gas bags, ballast tanks, and related parts—for condition.
2. Cabin and Cockpit
   a. Generally—for cleanliness and loose equipment that should be secured.
   b. Seats and safety belts—for condition and security.
   c. Windows and windshields—for deterioration and breakage.
   d. Instruments—for condition, mounting, marking, and (where practicable) for proper operation.
   e. Flight and engine controls—for proper installation and operation.
   f. Batteries—for proper installation and charge.
   g. All systems—for proper installation, general condition, apparent defects, and security of attachment.
3. Engine and Nacelle
   a. Engine section—for visual evidence of excessive oil, fuel, or hydraulic leaks, and sources of such leaks.
   b. Studs and nuts—for proper torquing and obvious defects.
   c. Internal engine—for cylinder compression and for metal particles or foreign matter on screens and sump drain plugs. If cylinder compression is weak, check for improper internal condition and improper internal tolerances.
   d. Engine mount—for cracks, looseness of mounting, and looseness of engine to mount.
   e. Flexible vibration dampeners—for condition and deterioration.
   f. Engine controls—for defects, proper travel, and proper safetying.
   g. Lines, hoses, and clamps—for leaks, condition, and looseness.
   h. Exhaust stacks—for cracks, defects, and proper attachment.
   i. Accessories—for apparent defects in security of mounting.
   j. All systems—for proper installation, general condition defects, and secure attachment.
   k. Cowling—for cracks and defects.
   l. Ground run-up and functional check—check all powerplant controls and systems for correct response, all instruments for proper operation and indication.
4. Landing Gear
   a. All units for condition and security of attachment.
   b. Shock absorbing devices for proper oleo fluid level.
   c. Linkage, trusses, and members—for undue or excessive wear, fatigue, and distortion.
   d. Retracting and locking mechanism—for proper operation.

e. Hydraulic lines—for leakage.
f. Electrical system—for chafing and proper operation of switches.
g. Wheels—for cracks, defects, and condition of bearings.
h. Tires—for wear and cuts.
i. Brakes—for proper adjustment.
j. Floats and skis—for security of attachment and obvious defects.

5. Wing and Center Section.
a. All components—for condition and security.
b. Fabric and skin—for deterioration, distortion, other evidence of failure, and security of attachment.
c. Internal structure (spars, ribs compression members)—for cracks, bends, and security.
d. Movable surfaces—for damage or obvious defects, unsatisfactory fabric or skin attachment and proper travel.
e. Control mechanism—for freedom of movement, alignment, and security.
f. Control cables—for proper tension, fraying, wear and proper routing through fairleads and pulleys.

6. Empennage
a. Fixed surfaces—for damage or obvious defects, loose fasteners, and security of attachment.
b. Movable control surfaces—for damage or obvious defects, loose fasteners, loose fabric, or skin distortion.
c. Fabric or skin—for abrasion, tears, cuts or defects, distortion, and deterioration.

7. Propeller
a. Propeller assembly—for cracks, nicks, bends, and oil leakage.
b. Bolts—for proper torquing and safetying.
c. Anti-icing devices—for proper operation and obvious defects.
d. Control mechanisms—for proper operation, secure mounting, and travel.

8. Communication and Navigation
a. Radio and electronic equipment—for proper installation and secure mounting.
b. Wiring and conduits—for proper routing, secure mounting, and obvious defects.
c. Bonding and shielding—for proper installation and condition.
d. Antennas—for condition, secure mounting, and proper operation.

9. Miscellaneous.
a. Emergency and first aid equipment—for general condition and proper stowage.
b. Parachutes, life rafts, flares, and so forth—inspect in accordance with the manufacturer's recommendations.
c. Autopilot system—for general condition, security of attachment, and proper operation.

PUBLICATIONS

Aeronautical publications are the sources of information for guiding aviation engineers in the operation and maintenance of aircraft and related equipment. The proper use of these publications will greatly aid in the efficient operation and maintenance of all aircraft. These include; manufacturers' service bulletins, manuals, and catalogs; FAA and EASA; airworthiness directives; advisory circulars; and aircraft, engine and propeller specifications.

MANUFACTURERS' SERVICE BULLETINS/ INSTRUCTIONS

Service bulletins or service instructions are two of several types of publications issued by airframe, engine, and component manufacturers. The bulletins may include: (1) purpose for issuing the publication, (2) name of the applicable airframe, engine, or component, (3) detailed instructions for service, adjustment, modification or inspection, and source of parts, if required and (4) estimated number of man-hours required to accomplish the job.

MAINTENANCE MANUAL

The manufacturer's aircraft maintenance manual contains complete instructions for maintenance of all systems and components installed in the aircraft. It contains information for the technician who normally works on components, assemblies, and systems while they are installed in the aircraft, but not for the overhaul mechanic.

A typical aircraft maintenance manual contains:
- A description of the systems (i.e., electrical, hydraulic, fuel, control)
- Lubrication instructions setting forth the frequency and the lubricants and fluids which are to be used in the various systems,
- Pressures and electrical loads applicable to the various systems,
- Tolerances and adjustments necessary to proper functioning of the airplane,
- Methods of leveling, raising, and towing,
- Methods of balancing control surfaces,

- Identification of primary and secondary structures,
- Frequency and extent of inspections necessary to the proper operation of the airplane,
- Special repair methods applicable to the airplane,
- Special inspection techniques requiring x-ray, ultrasonic, or magnetic particle inspection, and
- A list of special tools.

Overhaul Manual
The manufacturer's overhaul manual contains brief descriptive information and detailed step by step instructions covering work normally performed on a unit that has been removed from the aircraft. Simple, inexpensive items, such as switches and relays on which overhaul is uneconomical, are not covered in the overhaul manual.

Structural Repair Manual
This manual contains the manufacturer's information and specific instructions for repairing primary and secondary structures. Typical skin, frame, rib, and stringer repairs are covered in this manual. Also included are material and fastener substitutions and special repair techniques.

Illustrated Parts Catalog
This catalog presents component breakdowns of structure and equipment in disassembly sequence. Also included are exploded views or cutaway illustrations for all parts and equipment manufactured by the aircraft manufacturer.

VISUAL INSPECTION TECHNIQUES

When performing a visual inspection, use a checklist, flashlight, magnifying glass, gauge, mirror or other device that will aid in determining if a defect exists. In the next section, an example list of defects is presented, followed by frequently inspected parts of the aircraft that have their own particular set of visual inspection criterion.

TYPES OF DEFECTS
A defect is any event or condition which reduces the serviceability of the aircraft. There are nearly countless defects that could occur on an aircraft. However, manufacturers typically specify the areas needed to be inspected and the type of defect expected to be found. This does not relieve the technician of the responsibility to look for any sign of abnormality. A partial list of the types of defects encountered during a visual inspection follows.

Metal Parts Defects:
Cleanliness and external evidence of damage
- Leaks and discharge
- Overheating
- Fluid ingress
- Obstruction of drainage or vent holes or overflow pipe orifices
- Correct seating of panels and fairings and serviceability of fasteners
- Distortion, dents, scores, and chafing
- Pulled or missing fasteners, rivets, bolts or screws
- Evidence of cracks or wear
- Separation of adhesive bonding
- Failures of welds or spot welds
- Deterioration of protective treatment and corrosion
- Security of attachments, fasteners, connections, locking and bonding.

Rubber, Fabric, Glass Fiber and Plastic
Part Defects:
- Cleanliness
- Cracks, cuts, chafing, kinking, twisting, crushing, contraction - sufficient free length
- Deterioration, crazing, loss of flexibility
- Overheating
- Fluid soakage
- Security of attachment, correct connections and locking.

Control System Components Defects:
- Correct alignment
- Free movement, distortion, evidence of bowing
- Scores, chafing, fraying, kinking
- Evidence of wear, flattening
- Cracks, loose rivets, deterioration of protective treatment and corrosion
- Electrical bonding correctly positioned, undamaged and secure
- Attachments, end connections and locking secure.

Electrical Component Defects:
- Cleanliness, obvious damage
- Evidence of overheating
- Corrosion and security of attachments and connections
- Cleanliness, scoring and worn brushes, adequate spring tension after removal of protective covers
- Overheating and fluid ingress
- Cleanliness, burning and pitting of contacts
- Evidence of overheating and security of contacts after removal of protective covers

COMMON VISUALLY INSPECTED AREAS

EXTERNAL DAMAGE

The most common reasons for damage to the outside of the airframe is by being struck by ground equipment or severe hail in flight. During ground servicing many vehicles need to be maneuvered close to the airframe and some have to be in light contact with it to work properly. Contact with the airframe by any of these vehicles can cause dents or puncturing of the pressure hull, resulting in a time-consuming repair.

INLETS AND EXHAUSTS

Any inlet or exhaust can be a potential nest site for wildlife. The damage done by these birds, rodents and insects can be very expensive to rectify. Other items that have been known to block access holes include branches, leaves and polythene bags. A careful check of all inlets and exhausts, during inspections, must be made, to ensure that there is nothing blocking them. A blocked duct can result in the overheating of equipment, or major damage to the internal working parts of the engine.

LIQUID SYSTEMS

Liquid systems usually have gauges to ascertain the quantity in that particular system. A physical quantity check is often done in addition to using the gauges, as the gauges are not always reliable. These systems usually include oil tanks for the engine, APU and Integrated Drive Generators (IDG), and also the hydraulics, fuel and potable water tanks.

The cause of a lower-than-expected level should be immediately investigated, bearing in mind that some systems consume specific amounts of fluids during normal operation. The consumption rate must be calculated before any trouble-shooting. A low hydraulic system should not be replenished without first investigating the cause of the leak.

External leaks of oil and fuel systems are normally easy to locate. The rectification of an external leak is usually achieved by simply replacing the component, seal or pipe work at fault, and completing any tests required by the aircraft maintenance manual. If the leak is internal, then a much more thorough inspection of the component must be made, as the problem is more difficult to find. The symptoms are usually signaled by a slower movement of the services or by the erratic operation of services, due to the return line being pressurized.

Potable water tanks are often permanently pressurized, so that a leak that starts somewhere between the tank and the services will continue, even if the aircraft is not flying. Once the pressure is removed, the leak can be investigated, cured and the tank re-filled. The physical signs of water inside the aircraft or dripping from the hull should be the signs of a leak that requires investigation. The unpredictable passenger consumption of water means that the tank level is no indication of a leak in the system.

Liquid windscreen de-icers are usually in the form of a pressurized container, which supplies fluid on demand to the spray nozzles. If the fluid leaks onto the flight deck it will give off a distinctive odor in the enclosed space. As the containers are replaced when low, it is more likely that the pipe work will be the likely cause of the leak.

GASEOUS SYSTEMS

These include gases such as oxygen, nitrogen and air. Usually a built in gauge can be checked for an indication of correct volume or pressure. A leak from an oxygen system is extremely dangerous due to the chances of an explosion if it comes into contact with oil or grease. Once the leak has been cured, the system can be recharged and leak tested.

Accumulators assist the hydraulic system as an emergency backup, which only works correctly if it is charged to the correct pressure. Nitrogen, used in hydraulic accumulators, can leak into the liquid part of the hydraulic system. This will make the hydraulic system feel spongy and reduce the response of the operating actuators. If the gas leaks into the atmosphere, the system will not function correctly and the efficiency of the system may be reduced. The main cause of accumulators leaking externally is due to faulty seals or gauges.

LANDING GEAR

Proper landing gear strut servicing is typically inspected visually by observing the linear amount of inner strut cylinder that is exposed.

A 6 inch rule may be needed. To determine if the aircraft tires are properly serviced, a pressure gauge is required. The physical condition of the tread and sidewalls can be checked visually. Cuts, blisters, and creep are easily seen. Creep is the slipping of the tire's position on the wheel. It is particularly important when inner tubes are used so that the valve stem of the tube does not shear. Wheels are susceptible to damage from hard landing or foreign object damage. A visual inspection is sufficient to notice this type of damage as well as corrosion. If the wheel bolts and nuts are not all present and secure, further inspection is needed as this is a dangerous and abnormal condition. Most aircraft brakes can also be visually inspected for wear and condition.

Manufacturers have different ways to check brake wear. A go no-go gauge can be used or a 6 inch rule in most cases. Physical damage to the brakes is also a visual inspection item. Always ensure that ground safety locks are properly installed in the landing gear mechanism and that the warning streamers are intact to notify the flight crew that they must be removed before flight. (***Figure 18-1***)

Figure 18-1. Boeing 737 brake, showing wear-pins.

SYSTEM INDICATORS AND GAUGES

Various systems have checkable indicators/gauges used during visual inspection to gain some idea of system condition. Gauges and warning devices are located around the aircraft to be visually inspected. Fire extinguishing agent, oxygen, and hydraulic accumulator pressure gauges are among these. (***Figure 18-2***)

Figure 18-2. Boeing 737 APU extinguisher bottle indicators.

PROBES

Pitot tubes, angle of attack indicators, and other probes are inspected for obstruction and condition. Since these typically incorporate a heating mechanism, they should be checked for signs of over heating. (***Figure 18-3***)

HANDLES, LATCHES, PANELS AND DOORS

Used frequently, handles and latches on aircraft will wear and eventually malfunction. Here, in addition to the way the device looks, it is important to operate a handle or latch during inspection. All panels on the aircraft must fit properly and securely as designed. Follow manufacturer's instruction for wear and replace if needed. The loss of a door or panel during flight is a very serious condition.

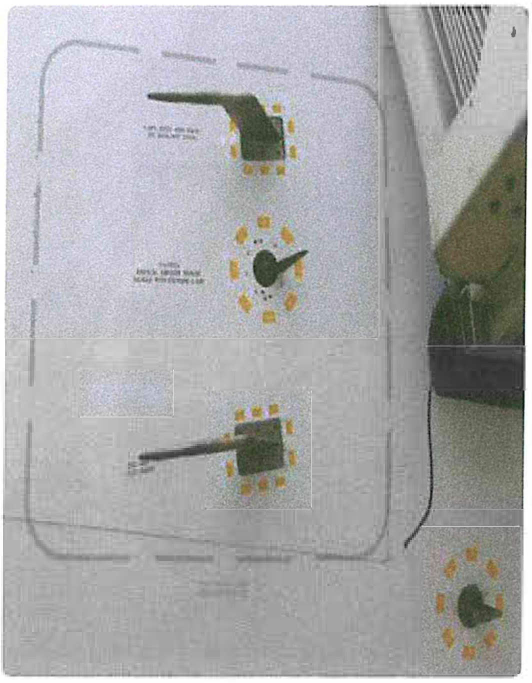


Figure 18-3. Boeing 737 pilot probes and alpha vane.

OTHER INSPECTION ITEMS

The following are items that must also be inspected by the technician:

- Moving Parts - All moving parts on an aircraft should have proper lubrication, security of attachment, proper safety wiring, proper operation and adjustment, proper installation, and correct travel. Visual inspection may identify binding, excessive wear, cracked fittings, loose hinges, defective bearings, corrosion, deformation, and improper sealing.
- Fluid Lines - All fluid lines and hoses are inspected for proper hose or rigid tubing material, proper fittings, correct fitting torque, leaks, tears, cracks, dents, kinks, chafing, proper bend radius, security, corrosion, deterioration, obstructions and foreign matter, and proper installation.
- Electrical wiring should also be inspected for proper type and gauge, security, chafing, burning, defective insulation, loose or broken terminals, heat deterioration, corroded terminals, and proper installation.
- Bolts are inspected for correct torque, elongation of bearing surfaces, deformation, shear damage, tension damage, proper installation, proper size and type and corrosion.
- Filters, screens, and fluids - for cleanliness, contamination, replacement times, proper types, and proper installation.
- Powerplants - engine mount security, mount bolt torque, spark plug security, ignition harness security, oil leaks, exhaust leaks, muffler cracks and wear, security of all engine accessories, engine case cracks, oil breather obstructions, firewall condition, and proper operation of mechanical controls.
- Propellers - nicks, dent cracks, cleanliness, lubrication, gouges, proper blade angles, blade tracking, proper dimensions, governor leaks and operation and control linkages for proper tension and installation. Nicks on the leading edge of the blade are important items to inspect for: they produce stress concentrations that need to be removed immediately upon discovery in order to prevent the blade separating at the nick.
- Ground runs - engine temperatures and pressures, static RPM, magneto drop, engine response to the changes of power, unusual engine noises, ignition switch operation, fuel shutoff/selector valves, idle speed and mixture settings, suction gauge, fuel flow indicator operation.

LIFE LIMITED ITEMS

There are a number of parts and components on the aircraft that have a specific length of time in service (known as a 'life'). These items are required to be changed when their service life expires, regardless of their appearance and functioning status. Some items have dates stamped on the outside of the unit on a placard which the technician uses in combination with maintenance records to identify and replace the units.

Light Bulbs and Indicators must be kept in proper working order. Bulbs with important functions like fire warning lights and undercarriage indication will be duplicated which underscores the importance of their always being serviceable. Inspection checklists typically require an operational check to ensure all illuminated indicators and lights are functioning.

CORROSION REMOVAL, ASSESSMENT AND REPROTECTION

PREVENTIVE MAINTENANCE

Much has been done to improve the corrosion resistance of aircraft: improvements in materials, surface treatments, insulation, and in particular, modern protective finishes. All of these have been aimed at reducing the overall maintenance effort, as well as improving reliability. In spite of these improvements, corrosion and its control is a very real problem that requires continuous preventive maintenance. During any corrosion control maintenance, consult the Material Safety Data Sheet (MSDS) for information on any chemicals used in the process.

Corrosion preventive maintenance includes the following specific functions:

1. Adequate cleaning.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touchup of damaged paint areas.
5. Keeping drain holes free of obstructions.
6. Daily draining of fuel cell sumps.
7. Daily wipe down of exposed critical areas.
8. Sealing of aircraft against water during foul weather and proper ventilation on warm sunny days.
9. Maximum use of protective covers on parked aircraft.

After any period during which regular corrosion preventive maintenance is interrupted, the amount of maintenance required to repair accumulated corrosion damage and bring the aircraft back up to standard will usually be quite high.

CORROSION REMOVAL

In general, any complete corrosion treatment involves the following: (1) cleaning and stripping of the corroded area, (2) removing as much of the corrosion products as practicable, (3) neutralizing any residual materials remaining in pits and crevices, (4) restoring protective surface films, and (5) applying temporary or permanent coatings or paint finishes.

The following paragraphs deal with the correction of corrosive attack on aircraft surface and components where deterioration has not progressed to the point requiring rework or structural repair of the part involved.

SURFACE CLEANING AND PAINT REMOVAL

The removal of corrosion necessarily includes removal of surface finishes covering the attacked or suspected area. To assure maximum efficiency of the stripping compound, the area must be cleaned of grease, oil, dirt, or preservatives. This preliminary cleaning operation is also an aid in determining the extent of the spread of the corrosion, since the stripping operation will be held to the minimum consistent with full exposure of the corrosion damage. Extensive corrosion spread on any panel should be corrected by fully treating the entire section.

The selection of the type of materials to be used in cleaning will depend on the nature of the matter to be removed. Modern environmental standards encourage the use of water-based, non-toxic cleaning compounds whenever possible. In some locations, local or state laws may require the use of such products, and prohibit the use of solvents that contain volatile organic compounds (VOCs). Where permitted, dry cleaning solvent (P-D-680) may be used for removing oil, grease, or soft preservative compounds. For heavy-duty removal of thick or dried preservatives, other compounds of the solvent emulsion type are available. The use of a general purpose, water rinseable stripper can be used for most applications. There are other methods for paint removal that have minimal impact upon the aircraft structure, and are considered "environmentally friendly."

Wherever practicable, chemical paint removal from any large area should be accomplished outside (in open air) and preferably in shaded areas. If inside removal is necessary, adequate ventilation must be assured. Synthetic rubber surfaces, including aircraft tires, fabric, and acrylics, must be thoroughly protected against possible contact with paint remover. Care must be exercised in using paint remover. Care must also be exercised in using paint remover around gas or watertight seam sealants, since the stripper will tend to soften and destroy the integrity of these sealants.

Mask off any opening that would permit the stripping compound to get into aircraft interiors or critical cavities. Paint stripper is toxic and contains ingredients harmful to both skin and eyes. Therefore, wear rubber gloves, aprons of acid repellent material, and goggle-type eyeglasses.

The following is a general stripping procedure:

1. Brush the entire area to be stripped with a cover of stripper to a depth of ¹⁄₃₂ to ¹⁄₁₆ inch. Any paintbrush makes a satisfactory applicator, except that the bristles will be loosened by the effect of paint remover on the binder, and the brush should not be used for other purposes after being exposed to paint remover.
2. Allow the stripper to remain on the surface for a sufficient length of time to wrinkle and lift the paint. This may be from 10 minutes to several hours, depending on both the temperature and humidity, and the condition of the paint coat being removed. Scrub the surface with a bristle brush saturated with paint remover to further loosen finish that may still be adhering to the metal.
3. Reapply the stripper as necessary in areas where the paint remains tightly adhered or where the stripper has dried, and repeat the above process. Only nonmetallic scrapers should be used to assist in removing persistent paint finishes. Non-woven abrasive pads intended for paint stripping may also prove to be useful in removing the loosened paint.
4. Remove the loosened paint and residual stripper by washing and scrubbing the surface with water and a broom, brush or fresh non-woven abrasive pad. If water spray is available, use a low to medium pressure stream of water directly on the area being scrubbed. If steam-cleaning equipment is available and the area is sufficiently large, cleaning may be accomplished using this equipment together with a solution of steam-cleaning compound. On small areas, any method may be used that will assure complete rinsing of the cleaned area. Use care to dispose of the stripped residue in accordance with environmental laws.

CORROSION OF FERROUS METALS

One of the most familiar types of corrosion is ferrous oxide (rust), generally resulting from atmospheric oxidation of steel surfaces. Some metal oxides protect the underlying base metal, but rust is not a protective coating in any sense of the word. Its presence actually promotes additional attack by attracting moisture from the air and acting as a catalyst for additional corrosion. If complete control of the corrosive attack is to be realized, all rust must be removed from steel surfaces.

Rust first appears on bolt heads, hold-down nuts, or other unprotected aircraft hardware. Its presence in these areas is generally not dangerous and has no immediate effect on the structural strength of any major components. The residue from the rust may also contaminate other ferrous components, promoting corrosion of those parts. The rust is indicative of a need for maintenance and of possible corrosive attack in more critical areas. It is also a factor in the general appearance of the equipment. When paint failures occur or mechanical damage exposes highly stressed steel surfaces to the atmosphere, even the smallest amount of rusting is potentially dangerous in these areas and must be removed and controlled.

Rust removal from structural components, followed by an inspection and damage assessment, must be done as soon as feasible. (***Figure 18-4 and Figure 18-5***)

Figure 18-4. Rust.

Figure 18-5. Rust on structural components.

MECHANICAL REMOVAL OF IRON RUST

The most practicable means of controlling the corrosion of steel is the complete removal of corrosion products by mechanical means and restoring corrosion preventive coatings. Except on highly stressed steel surfaces, the use of abrasive papers and compounds, small power buffers and buffing compounds, hand wire brushing, or steel wool are all acceptable cleanup procedures. However, it should be recognized that in any such use of abrasives, residual rust usually remains in the bottom of small pits and other crevices. It is practically impossible to remove all corrosion products by abrasive or polishing methods alone. As a result, once a part cleaned in such a manner has rusted, it usually corrodes again more easily than it did the first time.

The introduction of variations of the non-woven abrasive pad has also increased the options available for the removal of surface rust. (***Figure 18-6***) Flap wheels, pads intended for use with rotary or oscillating power tools, and hand-held non-woven abrasive pads all can be used alone or with light oils to remove corrosion from ferrous components.

CHEMICAL REMOVAL OF RUST

As environmental concerns have been addressed in recent years, interest in non-caustic chemical rust removal has increased. A variety of commercial products, which actively remove the iron oxide without chemically etching the base metal, are available and should be considered for use. Generally speaking, if at all possible, the steel part should be removed from the airframe for treatment, as it can be nearly impossible to remove all residues. The use of any caustic rust removal product will require the isolation of the part from any nonferrous metals during treatment, and will probably require inspection for proper dimensions.

Figure 18-6. Nonwoven abrasive pads.

CHEMICAL SURFACE TREATMENT OF STEEL

There are approved methods for converting active rust to phosphates and other protective coatings. Other commercial preparations are effective rust converters where tolerances are not critical and where thorough rinsing and neutralizing of residual acid is possible. These situations are generally not applicable to assembled aircraft, and the use of chemical inhibitors on installed steel parts is not only undesirable but also very dangerous. The danger of entrapment of corrosive solutions and the resulting uncontrolled attack, which could occur when such materials are used under field conditions, outweigh any advantages to be gained from their use.

REMOVAL OF CORROSION FROM HIGHLY STRESSED STEEL PARTS

Any corrosion on the surface of a highly stressed steel part is potentially dangerous, and the careful removal of corrosion products is required. Surface scratches or change in surface structure from overheating can also cause sudden failure of these parts. Corrosion products must be removed by careful processing, using mild abrasive papers such as rouge or fine grit aluminum oxide, or fine buffing compounds on cloth buffing wheels. Non-woven abrasive pads can also be used. It is essential that steel surfaces not be overheated during buffing. After careful removal of surface corrosion, reapply protective paint finishes immediately.

CORROSION OF ALUMINUM AND ALUMINUM ALLOYS

Corrosion on aluminum surfaces is usually quite obvious, since the products of corrosion are white and generally more voluminous than the original base metal. Even in its early stages, aluminum corrosion is evident as general etching, pitting, or roughness of the aluminum surfaces.

NOTE: Aluminum alloys commonly form a smooth surface oxidation that is from 0.001 to 0.0025 inch thick. This is not considered detrimental; the coating provides a hard shell barrier to the introduction of corrosive elements. Such oxidation is not to be confused with the severe corrosion discussed in this paragraph.

General surface attack of aluminum penetrates relatively slowly, but is sped up in the presence of dissolved salts. Considerable evidence of corrosion can usually take place before serious loss of structural strength develops.

At least three forms of attack on aluminum alloys are particularly serious: (1) the penetrating pit-type corrosion through the walls of aluminum tubing, (2) stress corrosion cracking of materials under sustained stress, and (3) intergranular corrosion which is characteristic of certain improperly heat-treated aluminum alloys.

In general, corrosion of aluminum can be more effectively treated in place compared to corrosion occurring on other structural materials used in aircraft. Treatment includes the mechanical removal of as much of the corrosion products as practicable, and the inhibition of residual materials by chemical means, followed by the restoration of permanent surface coatings.

TREATMENT OF UNPAINTED ALUMINUM SURFACES

Relatively pure aluminum has considerably more corrosion resistance compared with the stronger aluminum alloys. To take advantage of this characteristic, a thin coating of relatively pure aluminum is applied over the base aluminum alloy. The protection obtained is good, and the pure-aluminum clad surface (commonly called "Alclad") can be maintained in a polished condition. In cleaning such surfaces, however, care must be taken to prevent staining and marring of the exposed aluminum and, more important from a protection standpoint, to avoid unnecessary mechanical removal of the protective Alclad layer and the exposure of the more susceptible aluminum alloy base material. A typical aluminum corrosion treatment sequence follows:

1. Remove oil and surface dirt from the aluminum surface using any suitable mild cleaner. Use caution when choosing a cleaner; many commercial consumer products are actually caustic enough to induce corrosion if trapped between aluminum lap joints. Choose a neutral Ph product.
2. Hand polish the corroded areas with fine abrasives or with metal polish. Metal polish intended for use on clad aluminum aircraft surfaces must not be used on anodized aluminum since it is abrasive enough to actually remove the protective anodized film. It effectively removes stains and produces a highly polished, lasting surface on unpainted Alclad. If a surface is particularly difficult to clean, a cleaner and brightener compound for aluminum can be used before polishing to shorten the time and lessen the effort necessary to get a clean surface.
3. Treat any superficial corrosion present, using an inhibitive wipe down material. An alternate treatment is processing with a solution of sodium dichromate and chromium trioxide. Allow these solutions to remain on the corroded area for 5 to 20 minutes, then remove the excess by rinsing and wiping the surface dry with a clean cloth.
4. Overcoat the polished surfaces with waterproof wax.

Aluminum surfaces that are to be subsequently painted can be exposed to more severe cleaning procedures and can also be given more thorough corrective treatment prior to painting.

The following sequence is generally used:

1. Thoroughly clean the affected surfaces of all soil and grease residues prior to processing. Any general aircraft cleaning procedure may be used.
2. If residual paint films remain, strip the area to be treated. Procedures for the use of paint removers and the precautions to observe were previously mentioned in this chapter under "Surface Cleaning and Paint Removal."
3. Treat superficially corroded areas with a 10 percent solution of chromic acid and sulfuric acid. Apply the solution by swab or brush. Scrub the corroded area with the brush while it is still damp. While chromic acid is a good inhibitor for aluminum alloys, even when corrosion products have not been completely removed, it is important that the solution penetrate to the bottom of all pits and underneath any corrosion that may be present. Thorough brushing with a stiff fiber brush should loosen or remove most existing corrosion and assure complete penetration of the inhibitor into crevices and pits. Allow the chromic acid to remain in place for at least 5 minutes, and then remove the excess by flushing with water or wiping with a wet cloth. There are several commercial chemical surface treatment compounds, similar to the type described above, which may also be used.
4. Dry the treated surface and restore recommended permanent protective coatings as required in accordance with the aircraft manufacturer's procedures. Restoration of paint coatings should immediately follow any surface treatment performed. In any case, make sure that corrosion treatment is accomplished or is reapplied on the same day that paint refinishing is scheduled.

TREATMENT OF ANODIZED SURFACES

As previously stated, anodizing is a common surface treatment of aluminum alloys. When this coating is damaged in service, it can only be partially restored by chemical surface treatment. Therefore, any corrosion correction of anodized surfaces should avoid destruction of the oxide film in the unaffected area. Do not use steel wool or steel wire brushes. NOTE: Do not use severe abrasive materials.

Non-woven abrasive pads have generally replaced aluminum wool, aluminum wire brushes, or fiber bristle brushes as the tools used for cleaning corroded anodized surfaces. Care must be exercised in any cleaning process to avoid unnecessary breaking of the adjacent protective film. Take every precaution to maintain as much of the protective coating as practicable. Otherwise, treat anodized surfaces in the same manner as other aluminum finishes. Chromic acid and other inhibitive treatments can be used to restore the oxide film.

TREATMENT OF INTERGRANULAR CORROSION IN HEAT-TREATED ALUMINUM ALLOY SURFACES

Previously described, intergranular corrosion is an attack along grain boundaries of improperly or inadequately heat-treated alloys, resulting from precipitation of dissimilar constituents following heat treatment. In its most severe form, actual lifting of metal layers occurs.

More severe cleaning is a must when intergranular corrosion is present. The mechanical removal of all corrosion products and visible delaminated metal layers must be accomplished to determine the extent of the destruction and to evaluate the remaining structural strength of the component. Corrosion depth and removal limits have been established for some aircraft. Any loss of structural strength should be evaluated prior to repair or replacement of the part.

CORROSION OF MAGNESIUM ALLOYS

Magnesium is the most chemically active of the metals used in aircraft construction and is the most difficult to protect. When a failure in the protective coating does occur, the prompt and complete correction of the coating failure is imperative if serious structural damage is to be avoided. Magnesium attack is probably the easiest type of corrosion to detect in its early stages, since magnesium corrosion products occupy several times the volume of the original magnesium metal destroyed. The beginning of attack shows as a lifting of the paint films and white spots on the magnesium surface. These rapidly develop into snow-like mounds or even "white whiskers." Reprotection involves the removal of corrosion products, the partial restoration of surface coatings by chemical treatment, and a reapplication of protective coatings. (*Figure 18-7*)

TREATMENT OF WROUGHT MAGNESIUM SHEET AND FORGINGS

Magnesium skin corrosion usually occurs around edges of skin panels, underneath washers, or in areas physically damaged by shearing, drilling, abrasion, or impact. If the skin section can be removed easily, this should be done to assure complete inhibition and treatment. If insulating washers are involved, screws should at least be sufficiently loosened, to permit brush treatment of the magnesium under the insulating washer.

Complete mechanical removal of corrosion products should be practiced insofar as practicable. Limit such mechanical cleaning to the use of stiff, hog bristle brushes, and similar nonmetallic cleaning tools (including non-woven abrasive pads), particularly if treatment is to be performed under field conditions. Like aluminum, under no circumstances are steel or aluminum tools, steel, bronze or aluminum wool or other cleaning abrasive pads used on different metal surfaces to be used in cleaning magnesium. Any entrapment

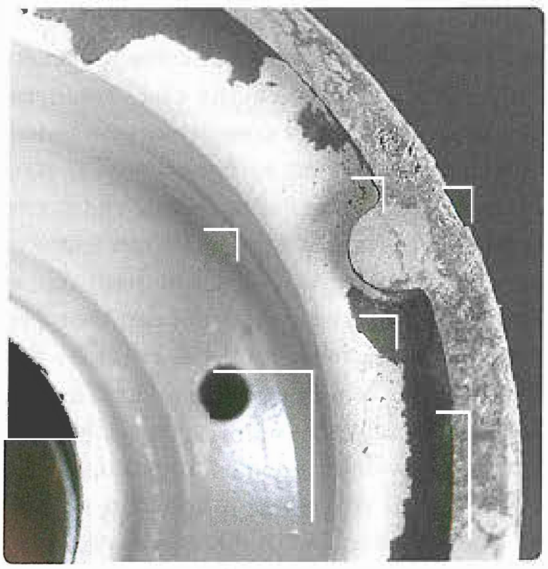


Figure 18-7. Magnesium corrosion.

of particles from steel wire brushes or steel tools, or contamination of treated surfaces by dirty abrasives, can cause more trouble than the initial corrosive attack.

Corroded magnesium may be treated as follows:
1. Clean and strip the paint from the area to be treated.
2. Using a stiff, hog bristle brush or non-woven abrasive pad, break loose and remove as much of the corrosion products as practicable. Steel wire brushes, carborundum abrasives, or steel cutting tools must not be used.
3. Treat the corroded area liberally with a chromic acid solution, to which has been added sulfuric acid, and work into pits and crevices by brushing the area while still wet with chromic acid, again using a nonmetallic brush.
4. Allow the chromic acid to remain in place for 5 to 20 minutes before wiping up the excess with a clean, damp cloth. Do not allow the excess solution to dry and remain on the surface, as paint lifting will be caused by such deposits.
5. As soon as the surfaces are dry, restore the original protective paint.

TREATMENT OF INSTALLED MAGNESIUM CASTINGS

Magnesium castings, in general, are more porous and more prone to penetrating attack than wrought magnesium skins. For all practical purposes, however, treatment is the same for all magnesium areas. Engine cases, bellcranks, fittings, numerous covers, plates, and handles are the most common magnesium castings.

When attack occurs on a casting, the earliest practicable treatment is required if dangerous corrosive penetration is to be avoided. In fact, engine cases submerged in saltwater overnight can be completely penetrated. If it is at all practicable, parting surfaces should be separated to effectively treat the existing attack and prevent its further progress. The same general treatment sequence in the preceding paragraph for magnesium skin should be followed. If extensive removal of corrosion products from a structural casting is involved, a decision from the manufacturer may be necessary to evaluate the adequacy of structural strength remaining. Specific structural repair manuals usually include dimensional tolerance limits for critical structural members and should be referred to, if any question of safety is involved.

TREATMENT OF TITANIUM AND TITANIUM ALLOYS

Attack on titanium surfaces is generally difficult to detect. Titanium is, by nature, highly corrosion resistant, but it may show deterioration from the presence of salt deposits and metal impurities, particularly at high temperatures. Therefore, the use of steel wool, iron scrapers, or steel brushes for cleaning or for the removal of corrosion from titanium parts is prohibited.

If titanium surfaces require cleaning, hand polishing with aluminum polish or a mild abrasive is permissible, if fiber brushes only are used and if the surface is treated following cleaning with a suitable solution of sodium dichromate. Wipe the treated surface with dry cloths to remove excess solution, but do not use a water rinse.

PROTECTION OF DISSIMILAR METAL CONTACTS

Certain metals are subject to corrosion when placed in contact with other metals. This is commonly referred to as electrolytic or dissimilar metals corrosion. Contact of different bare metals creates an electrolytic action when moisture is present. If this moisture is salt water, the electrolytic action is accelerated. The result of dissimilar metal contact is oxidation (decomposition) of one or both metals. The chart shown in ***Figure 18-8*** lists the metal combinations requiring a protective separator. The separating materials may be metal primer, aluminum tape, washers, grease, or sealant, depending on the metals involved.

CONTACTS NOT INVOLVING MAGNESIUM

All dissimilar joints not involving magnesium are protected by the application of a minimum of two coats of zinc chromate or, preferably, epoxy primer in addition to normal primer requirements. Primer is applied by brush or spray and allowed to air dry 6 hours between coats.

CONTACTS INVOLVING MAGNESIUM

To prevent corrosion between dissimilar metal joints in which magnesium alloy is involved, each surface is insulated as follows:

At least two coats of zinc chromate or, preferably, epoxy primer are applied to each surface. Next, a layer of pressure sensitive vinyl tape 0.003 inch thick is applied smoothly and firmly enough to prevent air bubbles and wrinkles. To avoid creep back, the tape is

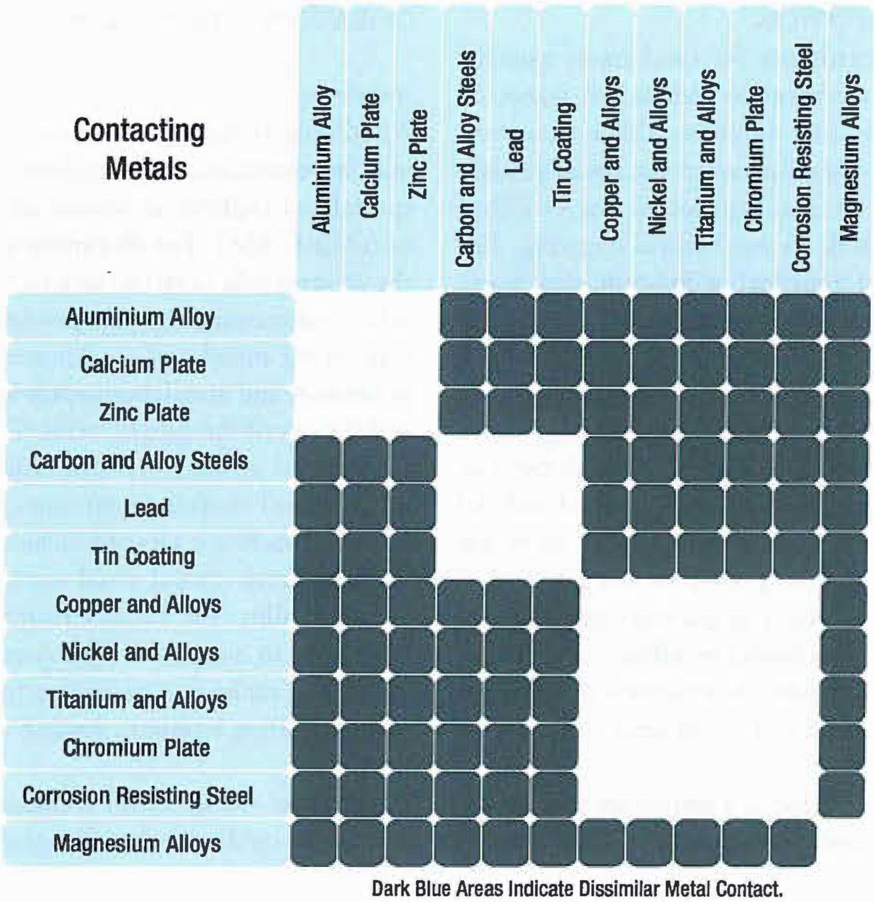


Figure 18-8. Dissimilar metal contacts that will result in electrolytic corrosion.

not stretched during application. When the thickness of the tape interferes with the assembly of parts, where relative motion exists between parts, or when service temperatures above 250 °F are anticipated, the use of tape is eliminated and extra coats (minimum of three) of primer are applied.

CORROSION LIMITS

Corrosion, however slight, is damage. Therefore, corrosion damage is classified under the four standard types, as is any other damage. These types are:

1. Negligible damage,
2. Damage repairable by patching,
3. Damage repairable by insertion, and
4. Damage necessitating replacement of parts.

The term "negligible," as used here, does not imply that little or nothing should be done. The corroded surface should be cleaned, treated, and painted as appropriate. Negligible damage, generally, is corrosion that has scarred or eaten away the surface protective coats and begun to etch the metal. Corrosion damage extending to classifications of "repairable by patching" and "repairable by insertion" should be repaired in accordance with the applicable structural repair manual. When corrosion damage exceeds the damage limits to the extent that repair is not possible, the component or structure should be replaced.

PROCESSES AND MATERIALS USED IN CORROSION CONTROL METAL FINISHING

Aircraft parts are almost always given some type of surface finish by the manufacturer. The main purpose is to provide corrosion resistance; however, surface finishes may also be applied to increase wear resistance or to provide a suitable base for paint.

In most instances, the original finishes described in the following paragraphs cannot be restored in the field due to unavailable equipment or other limitations. However, an understanding of the various types of metal finishes is necessary if they are to be properly maintained in the field and if the partial restoration techniques used in corrosion control are to be effective.

SURFACE PREPARATION

Original surface treatments for steel parts usually include a cleaning treatment to remove all traces of dirt, oil, grease, oxides, and moisture. This is necessary to provide an effective bond between the metal surface and the final finish. The cleaning process may be either mechanical or chemical. In mechanical cleaning, the following methods are employed: wire brush, steel wool, emery cloth, sandblasting, or vapor blasting.

Chemical cleaning is preferred over mechanical since none of the base metal is removed by cleaning. There are various chemical processes now in use, and the type used will depend on the material being cleaned and the type of foreign matter being removed. Steel parts are pickled to remove scale, rust, or other foreign matter, particularly before plating. The pickling solution can be either muriatic (hydrochloric) or sulfuric acid. Cost-wise, sulfuric acid is preferable, but muriatic acid is more effective in removing certain types of scale.

The pickling solution is kept in a stoneware tank and is usually heated by means of a steam coil. Parts not to be electroplated after pickling are immersed in a lime bath to neutralize the acid from the pickling solution.

Electrocleaning is another type of chemical cleaning used to remove grease, oil, or organic matter. In this cleaning process, the metal is suspended in a hot alkaline solution containing special wetting agents, inhibitors, and materials to provide the necessary electrical conductivity. An electric current is then passed through the solution in a manner similar to that used in electroplating.

Aluminum and magnesium parts are also cleaned by using some of the foregoing methods. Blast cleaning using abrasive media is not applicable to thin aluminum sheets, particularly Alclad. Steel grits are not used on aluminum or corrosion resistant metals. Polishing, buffing, and coloring of metal surfaces play a very important part in the finishing of metal surfaces. Polishing and buffing operations are sometimes used when preparing a metal surface for electroplating, and all three operations are used when the metal surface requires a high luster finish.

CHEMICAL TREATMENTS

Anodizing

Anodizing is the most common surface treatment of nonclad aluminum alloy surfaces. It is typically done in specialized facilities in accordance with Mil-C- 5541E or AMS-C-5541. The aluminum alloy sheet or casting is the positive pole in an electrolytic bath in which chromic acid or other oxidizing agent produces an aluminum oxide film on the metal surface. Aluminum oxide is naturally protective, and anodizing merely increases the thickness and density of the natural oxide film. When this coating is damaged in service, it can only be partially restored by chemical surface treatments. Therefore, when an anodized surface is cleaned including corrosion removal, the technician should avoid unnecessary destruction of the oxide film. The anodized coating provides excellent resistance to corrosion. The coating is soft and easily scratched, making it necessary to use extreme caution when handling it prior to coating it with primer.

Aluminum wool, nylon webbing impregnated with aluminum oxide abrasive, fine grade non-woven abrasive pads or fiber bristle brushes are the approved tools for cleaning anodized surfaces. The use of steel wool, steel wire brushes, or harsh abrasive materials on any aluminum surfaces is prohibited. Producing a buffed or wire brush finish by any means is also prohibited. Otherwise, anodized surfaces are treated in much the same manner as other aluminum finishes.

In addition to its corrosion resistant qualities, the anodic coating is also an excellent bond for paint. In most cases, parts are primed and painted as soon as possible after anodizing. The anodic coating is a poor conductor of electricity; therefore, if parts require bonding, the coating is removed where the bonding wire is to be attached. Alclad surfaces that are to be left unpainted require no anodic treatment; however, if the Alclad surface is to be painted, it is usually anodized to provide a bond for the paint.

Alodizing

Alodizing is a simple chemical treatment for all aluminum alloys to increase their corrosion resistance and to improve their paint bonding qualities. Because of its simplicity, it is rapidly replacing anodizing in aircraft work.

The process consists of precleaning with an acidic or alkaline metal cleaner that is applied by either dipping or spraying. The parts are then rinsed with fresh water under pressure for 10 to 15 seconds. After thorough rinsing, Alodine® is applied by dipping, spraying, or brushing. A thin, hard coating results which ranges in color from light, bluish green with a slight iridescence on copper free alloys to an olive green on copper bearing alloys. The Alodine is first rinsed with clear, cold or warm water for a period of 15 to 30 seconds. An additional 10 to 15 second rinse is then given in a Deoxylyte® bath. This bath is to counteract alkaline material and to make the alodined aluminum surface slightly acidic on drying.

Chemical Surface Treatment and Inhibitors

As previously described, aluminum and magnesium alloys in particular are protected originally by a variety of surface treatments. Steels may have been treated on the surface during manufacture. Most of these coatings can only be restored by processes that are completely impractical in the field. But, corroded areas where such protective films have been destroyed require some type of treatment prior to refinishing.

The labels on the containers of surface treatment chemicals will provide warnings if a material is toxic or flammable. However, the label might not be large enough to accommodate a list of all the possible hazards which may ensue if the materials are mixed with incompatible substances. The Material Safety Data Sheet (MSDS) should also be consulted for information. For example, some chemicals used in surface treatments will react violently if inadvertently mixed with paint thinners. Chemical surface treatment materials must be handled with extreme care and mixed exactly according to directions.

Chromic Acid Inhibitor

A 10 percent solution by weight of chromic acid, activated by a small amount of sulfuric acid, is particularly effective in treating exposed or corroded aluminum surfaces. It may also be used to treat corroded magnesium. This treatment tends to restore the protective oxide coating on the metal surface. Such treatment must be followed by regular paint finishes as soon as practicable, and never later than the same day as the latest chromic acid treatment. Chromium trioxide flake is a powerful oxidizing agent and a fairly strong acid. It must be stored away from organic solvents and other combustibles. Either thoroughly rinse or dispose of wiping cloths used in chromic acid pickup.

Sodium Dichromate Solution

A less active chemical mixture for surface treatment of aluminum is a solution of sodium dichromate and chromic acid. Entrapped solutions of this mixture are less likely to corrode metal surfaces than chromic acid inhibitor solutions.

Chemical Surface Treatments

Several commercial, activated chromate acid mixtures are available under Specification MIL-C-5541 for field treatment of damaged or corroded aluminum surfaces. Take precautions to make sure that sponges or cloths used are thoroughly rinsed to avoid a possible fire hazard after drying.

Protective Paint Finishes

A good, intact paint finish is the most effective barrier between metal surfaces and corrosive media. The most common finishes include catalyzed polyurethane enamel, waterborne polyurethane enamel, and two-part epoxy paint. As new regulations regarding the emission of volatile organic compounds (VOCs) are put into effect, the use of waterborne paint systems have increased in popularity. Also, still available are nitrate and butyrate dope finishes for fabric-covered aircraft. In addition, high visibility fluorescent materials may also be used, along with a variety of miscellaneous combinations of special materials. There may also be rain erosion resistant coatings on metal leading edges, and several different baked enamel finishes on engine cases and wheels.

GENERAL REPAIR METHODS

To cover the numerous specific methods of repairs to aircraft structural elements is beyond the scope of this Module. Each transport category aircraft Structural Repair Manual is hundreds of pages long encompassing nearly every conceivable repair to any aspect of the airframe the manufacturer deems appropriate. Some basic tenets of repair methods are covered here. Always consult the manufacturer's maintenance manual including the structural repair manual (SRM) before beginning a repair on the aircraft and follow the instructions for the correct repair method.

Aircraft structural members are designed to perform a specific function or to serve a definite purpose. The primary objective of aircraft repair is to restore damaged parts to their original condition. Very often, replacement is the only way this can be done effectively. When repair of a damaged part is possible, first study the part carefully to fully understand its purpose or function.

Strength may be the principal requirement in the repair of certain structures, while others may need entirely different qualities. For example, fuel tanks and floats must be protected against leakage; cowlings, fairings, and similar parts must have such properties as neat appearance, streamlined shape, and accessibility. The function of any damaged part must be carefully determined to ensure the repair meets the requirements.

INSPECTION

An inspection of the damage and accurate estimate of the type of repair required are the most important steps in repairing structural damage. The inspection includes an estimate of the best type and shape of repair patch to use; the type, size, and number of rivets needed; and the strength, thickness, and the kind of material required to make the repaired member no heavier (or only slightly heavier) and just as strong as the original.

When investigating damage to an aircraft, it is necessary to make an extensive inspection of the structure. When any component or group of components has been damaged, it is essential that both the damaged members and the attaching structure be investigated, since the damaging force may have been transmitted over a large area, sometimes quite remote from the point of original damage.

Wrinkled skin, elongated or damaged bolt or rivet holes, or distortion of members usually appears in the immediate area of such damage, and any one of these conditions calls for a close inspection of the adjacent area. Check all skin, dents, and wrinkles for any cracks or abrasions.

Nondestructive inspection methods (NDI) are used as required when inspecting damage. NDI methods serve as tools of prevention that allow defects to be detected before they develop into serious or hazardous failures. A trained and experienced technician can detect flaws or defects with a high degree of accuracy and reliability. Some of the defects found by NDI include corrosion, pitting, heat/stress cracks, and discontinuity of metals.

When investigating damage, proceed as follows:

- Remove all dirt, grease, and paint from the damaged and surrounding areas to determine the exact condition of each rivet, bolt, and weld.
- Inspect skin for wrinkles throughout a large area.
- Check the operation of all movable parts.
- Determine if repair would be the best procedure.

Types of damage and defects that may be observed on aircraft parts are defined as follows:

- Brinelling—occurrence of shallow, spherical depressions in a surface, usually produced by a part having a small radius in contact with the surface under high load.
- Burnishing—polishing of one surface by sliding contact with a smooth, harder surface. Usually there is no displacement or removal of metal.
- Burr—a small, thin section of metal extending beyond a regular surface, usually located at a corner or on the edge of a hole.
- Corrosion—loss of metal from the surface by chemical or electrochemical action. The corrosion products generally are easily removed by mechanical means. Iron rust is an example of corrosion.
- Crack—a physical separation of two adjacent portions of metal, evidenced by a fine or thin line across the surface caused by excessive stress at that point. It may extend inward from the surface from a few thousandths of an inch to completely through the section thickness.
- Cut—loss of metal, usually to an appreciable depth over a relatively long and narrow area, by mechanical means, as would occur with the use of a saw blade, chisel, or sharp-edged stone striking a glancing blow.
- Dent—indentation in a metal surface produced by an object striking with force. The surface surrounding the indentation is usually slightly upset.

- Erosion—loss of metal from the surface by mechanical action of foreign objects, such as grit or fine sand. The eroded area is rough and may be lined in the direction in which the foreign material moved relative to the surface.
- Chattering—breakdown or deterioration of metal surface by vibratory or chattering action. Although chattering may give the general appearance of metal loss or surface cracking, usually, neither has occurred.
- Galling—breakdown (or build-up) of metal surfaces due to excessive friction between two parts having relative motion. Particles of the softer metal are torn loose and welded to the harder metal.
- Gouge—groove in, or breakdown of, a metal surface from contact with foreign material under heavy pressure. Usually it indicates metal loss but may be largely the displacement of material.
- Inclusion—presence of foreign or extraneous material wholly within a portion of metal. Such material is introduced during the manufacture of rod, bar or tubing by rolling or forging.
- Nick—local break or notch on an edge. Usually it involves the displacement of metal rather than loss.
- Pitting—sharp, localized breakdown (small, deep cavity) of metal surface, usually with defined edges.
- Scratch—slight tear or break in metal surface from light, momentary contact by foreign material.
- Score—deeper (than scratch) tear or break in metal surface from contact under pressure. May show discoloration from temperature produced by friction.
- Stain—a change in color, locally causing a noticeably different appearance from the surrounding area.
- Upsetting—a displacement of material beyond the normal contour or surface (a local bulge or bump). Usually it indicates no metal loss.

CLASSIFICATION OF DAMAGE

Damages may be grouped into four general classes. In many cases, the availabilities of repair materials and time are the most important factors in determining if a part should be repaired or replaced.

Negligible Damage

Negligible damage consists of visually apparent, surface damage that do not affect the structural integrity of the component involved. Negligible damage may be left as is or may be corrected by a simple procedure without restricting flight. In both cases, some corrective action must be taken to keep the damage from spreading. Negligible or minor damage areas must be inspected frequently to ensure the damage does not spread. Permissible limits for negligible damage vary for different components of different aircraft and should be carefully researched on an individual basis. Failure to ensure that damages within the specified limit of negligible damage may result in insufficient structural strength of the affected support member for critical flight conditions.

Small dents, scratches, cracks, and holes that can be repaired by smoothing, sanding, stop drilling, or hammering out, or otherwise repaired without the use of additional materials, fall in this classification. (***Figure 18-9***)

Damage Repairable by Patching

Damage repairable by patching is any damage exceeding negligible damage limits that can be repaired by installing splice members to bridge the damaged portion of a structural part. The splice members are designed to span the damaged areas and to overlap the existing undamaged surrounding structure. The splice or patch material used in internal riveted and bolted repairs is normally the same type of material as the damaged part, but one gauge heavier. In a patch repair, filler plates of the same gauge and type of material as that

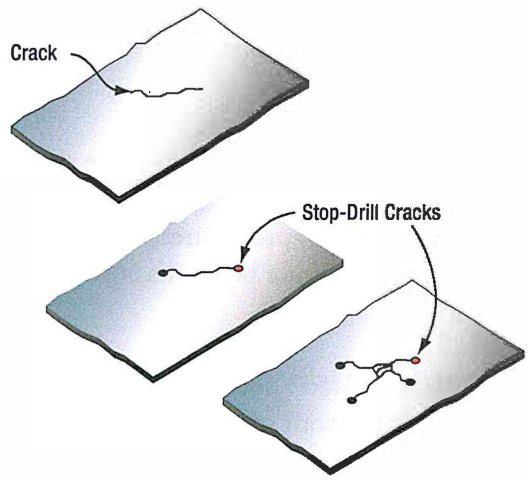


Figure 18-9. Repair of cracks by stop-drilling.

in the damaged component may be used for bearing purposes or to return the damaged part to its original contour. Structural fasteners are applied to members and the surrounding structure to restore the original load-carrying characteristics of the damaged area. The use of patching depends on the extent of the damage and the accessibility of the component to be repaired.

Damage Repairable by Insertion

Damage must be repaired by insertion when the area is too large to be patched or the structure is arranged such that repair members would interfere with structural alignment (e.g., in a hinge or bulkhead). In this type of repair, the damaged portion is removed from the structure and replaced by a member identical in material and shape. Splice connections at each end of the insertion member provide for load transfer to the original structure.

Damage Necessitating Replacement of Parts

Components must be replaced when their location or extent of damage makes repair impractical, when replacement is more economical than repair, or when the damaged part is relatively easy to replace. For example, replacing damaged castings, forgings, hinges, and small structural members, when available, is more practical than repairing them. Some highly stressed members must be replaced because repair would not restore an adequate margin of safety.

REPAIRABILITY OF SHEET METAL STRUCTURE

The following criteria can be used to help an aircraft technician decide upon the repairability of a sheet metal structure:

- Type of damage.
- Type of original material.
- Location of the damage.
- Type of repair required.
- Tools and equipment available to make the repair.

The following methods, procedures, and materials are only typical and should not be used as the authority for a repair.

STRUCTURAL SUPPORT DURING REPAIR

During repair, the aircraft must be adequately supported to prevent further distortion or damage. It is also important that the structure adjacent to the repair is supported when it is subject to static loads. The aircraft structure can be supported adequately by the landing gear or by jacks where the work involves a repair, such as removing the control surfaces, wing panels, or stabilizers. Cradles must be prepared to hold these components while they are removed from the aircraft. When the work involves extensive repair of the fuselage, landing gear, or wing center section, a jig (a device for holding parts in position to maintain their shape) may be constructed to distribute the loads while repairs are being accomplished. ***Figure 18-10*** shows a typical aircraft jig. Always check the applicable aircraft maintenance manual for specific support requirements.

ASSESSMENT OF DAMAGE

Before starting any repair, the extent of damage must be fully evaluated to determine if repair is authorized or even practical. This evaluation should identify the original material used and the type of repair required. The assessment of the damage begins with an inspection of riveted joints and an inspection for corrosion.

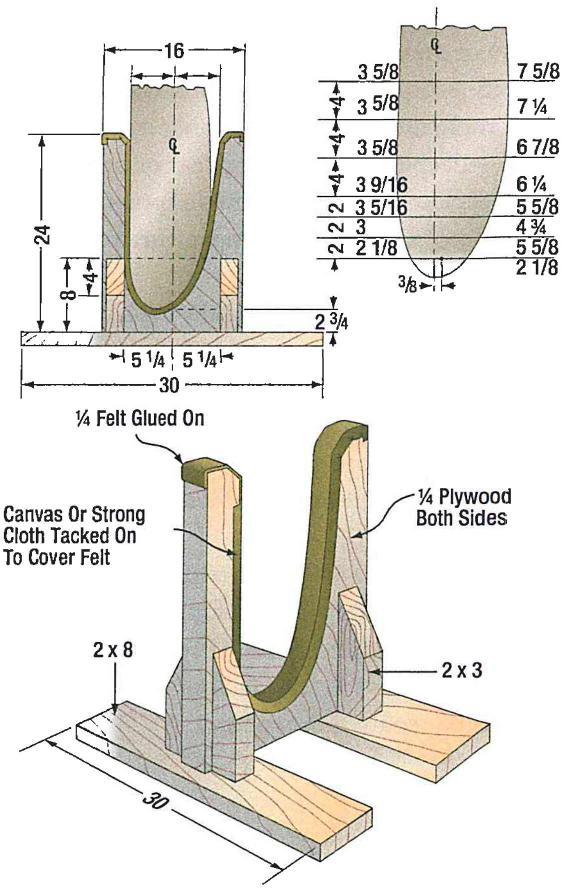


Figure 18-10. Aircraft jig used to hold components during repairs.

In any aircraft sheet metal repair, it is critical to:

- Maintain original strength,
- Maintain original contour, and
- Minimize weight.

MAINTAINING ORIGINAL STRENGTH

Certain fundamental rules must be observed if the original strength of the structure is to be maintained.

Ensure that the cross-sectional area of a splice or patch is at least equal to or greater than that of the damaged part. Avoid abrupt changes in cross-sectional area. Eliminate dangerous stress concentration by tapering splices. To reduce the possibility of cracks starting from the corners of cutouts, try to make cutouts either circular or oval in shape. Where it is necessary to use a rectangular cutout, make the radius of curvature at each corner no smaller than ½ inch. If the member is subjected to compression or bending loads, the patch should be placed on the outside of the member to obtain a higher resistance to such loads. If the patch cannot be placed there, material one gauge thicker than the original shall be used for the repair.

A buckled part of a structure shall not be depended upon to carry its load. Replace buckled or bent members, or reinforce them by attaching a splice over the affected area.

The material used in all replacements or reinforcements must be similar to that used in the original structure. If an alloy weaker than the original must be substituted for it, a heavier thickness must be used to give equivalent cross-sectional strength. A material that is stronger, but thinner, cannot be substituted for the original because one material can have greater tensile strength but less compressive strength than another, or vice versa. Also, the buckling and torsional strength of many sheet metal and tubular parts depends primarily on the thickness of the material rather than its allowable compressive and shear strengths. The manufacturer's SRM often indicates what material can be used as a substitution and how much thicker the material needs to be. ***Figure 18-11*** is an example of a substitution table found in an SRM.

Care must be taken when forming. Heat-treated and cold-worked aluminum alloys stand very little bending without cracking. On the other hand, soft alloys are easily formed, but they are not strong enough for primary structure. Strong alloys can be formed in their annealed (heated and allowed to cool slowly) condition, and heat treated before assembling to develop their strength.

The size of rivets for any repair can be determined by referring to the rivets used by the manufacturer in the next parallel rivet row inboard on the wing or forward on the fuselage. Another method of determining the size of rivets to be used is to multiply the thickness of the skin by three and use the next larger size rivet corresponding to that figure.

For example, if the skin thickness is 0.040-inch, multiply 0.040-inch by 3, which equals 0.120-inch; use the next larger size rivet, ⅛ inch (0.125-inch). The number of rivets to be used for a repair can be found in tables in manufacturer's SRMs. ***Figure 18-12*** is a table that is used to calculate the number of rivets required for a repair.

Extensive repairs that are made too strong can be as undesirable as repairs weaker than the original structure. All aircraft structure must flex slightly to withstand the forces imposed during takeoff, flight, and landing. If a repaired area is too strong, excessive flexing occurs at the edge of the completed repair, causing acceleration of metal fatigue.

SHEAR STRENGTH AND BEARING STRENGTH

Aircraft structural joint design involves an attempt to find the optimum strength relationship between being critical in shear and critical in bearing. These are determined by the failure mode affecting the joint. The joint is critical in shear if less than the optimum number of fasteners of a given size are installed. This means that the rivets will fail, and not the sheet, if the joint fails. The joint is critical in bearing if more than the optimum number of fasteners of a given size are installed; the material may crack and tear between holes, or fastener holes may distort and stretch while the fasteners remain intact.

MAINTAINING ORIGINAL CONTOUR

Form all repairs in such a manner to fit the original contour perfectly. A smooth contour is especially desirable when making patches on the smooth external skin of high-speed aircraft.

Shape	Initial Material	Replacement Material
Sheet 0.016 to 0.125	Clad 2024–T42 (F)	Clad 2024–T3 2024–T3 Clad 7075–T6 (A) 7075–T6 (A)
	Clad 2024–T3	2024–T3 Clad 7075–T6 (A) 7075–T6 (A)
	Clad 7075–T6	7075–T6
Formed or extruded section	2024–T42 (F)	7075–T6 (A) (B)

Sheet Material To Be Replaced	Material Replacement Factor									
	7075–T6	Clad 7075–T6	2024–T3		Clad 2024–T3		(F) 2024–T4 2024–T42		(F) Clad 2024–T4 Clad 2024–T42	
	(C)	(C) (H)	(D)	(E)	(D)	(E)	(D)	(E)	(D)	(E)
7075–T6	1.00	1.10	1.20	1.78	1.30	1.83	1.20	1.78	1.24	1.84
Clad 7075–T6	1.00	1.00	1.13	1.70	1.22	1.76	1.13	1.71	1.16	1.76
2024–T3	1.00 (A)	1.00 (A)	1.00	1.00	1.09	1.10	1.00	1.10	1.03	1.14
Clad 2024–T3	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.00
2024–T42	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.14
Clad 2024–T42	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7178–T6	1.28	1.28	1.50	1.90	1.63	2.00	1.86	1.90	1.96	1.98
Clad 7178–T6	1.08	1.18	1.41	1.75	1.52	1.83	1.75	1.75	1.81	1.81
5052–H34 (G) (H)	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes:

- All dimensions are in inches, unless otherwise specified.
- It is possible that more protection from corrosion is necessary when bare mineral is used to replace clad material.
- It is possible for the material replacement factor to be a lower value for a specific location on the airplane. To get that value, contact Boeing for a case-by-case analysis.
- Refer to Figure 4-81 for minimun bend radii.
- Example:
  To refer 0.040 thick 7075–T6 with clad 7075–T6, multiply the gauge by the material replacement factor to get the replacement gauge
  0.040 x 1.10 = 0.045.

(A) Cannot be used as replacement for the initial material in areas that are pressured.

(B) Cannot be used in the wing interspar structure at the wing center section structure.

(C) Use the next thicker standard gauge when using a formed section as a replacement for an extrusion.

(D) For all gauges of flat sheet and formed sections.

(E) For flat sheet < 0.071 thick.

(F) For flat sheet ≥ 0.071 thick and for formed sections.

(G) 2024-T4 and 2024-T42 are equivalent.

(H) A compound to give protection from corrosion must be applied to bare material that is used to replace 5052–H34.

Figure 18-11. Material substitution.

KEEPING WEIGHT TO A MINIMUM

Keep the weight of all repairs to a minimum. Make the size of the patches as small as practicable and use no more rivets than are necessary. In many cases, repairs disturb the original balance of the structure. The addition of excessive weight in each repair may unbalance the aircraft, requiring adjustment of the trim-and-balance tabs. In areas such as the spinner on the propeller, a repair requires application of balancing patches in order to maintain a perfect balance of the propeller. When flight controls are repaired and weight is added, it is very important to perform a balancing check to determine if the flight control is still within its balance limitations. Failure to do so could result in flight control flutter.

Thickness "T" in inches	No. of 2117–T4 (AD) Protruding Head Rivets Required per Inch of Width "W"					No. of Bolts
	Rivet Size					
	3/32	1/8	5/32	3/16	1/4	AN–3
.016	6.5	4.9	- -	- -	- -	- -
.020	6.5	4.9	3.9	- -	- -	- -
.025	6.9	4.9	3.9	- -	- -	- -
.032	8.9	4.9	3.9	3.3	- -	- -
.036	10.0	5.6	3.9	3.3	2.4	- -
.040	11.1	6.2	4.0	3.3	2.4	- -
.051	- -	7.9	5.1	3.6	2.4	3.3
.064	- -	9.9	6.5	4.5	2.5	3.3
.081	- -	12.5	8.1	5.7	3.1	3.3
.091	- -	- -	9.1	6.3	3.5	3.3
.102	- -	- -	10.3	7.1	3.9	3.3
.128	- -	- -	12.9	8.9	4.9	3.3

Notes:

a. For stringer in the upper surface of a wing, or in a fuselage, 80 percent of the number of rivets shown in the table may be used.
b. For intermediate frames, 60 percent of the number shown may be used.
c. For single lap sheet joints, 75 percent of the number shown may be used.

Engineering Notes

a. The load per inch of width of material was calculated by assuming a strip 1 inch wide in tension.
b. Number of rivets required was calculated for 2117–T4 (AD) rivets, based on a rivet allowable shear stress equal to percent of the sheet allowable tensile stress, and a sheet allowable bearing stress equal to 160 percent of the sheet allowable tensile stress, using nominal hole diameters for rivets.
c. Combinations of shoot thickness and rivet size above the underlined numbers are critical in (i.e., will fail by) bearing on the sheet; those below are critical in shearing of the rivets.
d. The number of AN–3 bolts required below the underlined number was calculated based on a sheet allowable tensile stress of 55.000 psi and a bolt allowable single shear load of 2.126 pounds.

Figure 18-12. Rivet calculation table.

FLUTTER AND VIBRATION PRECAUTIONS

To prevent severe vibration or flutter of flight control surfaces during flight, precautions must be taken to stay within the design balance limitations when performing maintenance or repair. The importance of retaining the proper balance and rigidity of aircraft control surfaces cannot be overemphasized. The effect of repair or weight change on the balance and CG is proportionately greater on lighter surfaces than on the older heavier designs. As a general rule, repair the control surface in such a manner that the weight distribution is not affected in any way, in order to preclude the occurrence of flutter of the control surface in flight. Under certain conditions, counterbalance weight is added forward of the hinge line to maintain balance. Add or remove balance weights only when necessary in accordance with the manufacturer's instructions.

Flight testing must be accomplished to ensure flutter is not a problem. Failure to check and retain control surface balance within the original or maximum allowable value could result in a serious flight hazard.

Aircraft manufacturers use different repair techniques and repairs designed and approved for one type of aircraft are not automatically approved for other types of aircraft. When repairing a damaged component or part, consult the applicable section of the manufacturer's SRM for the aircraft. Usually the SRM contains an illustration for a similar repair along with a list of the types of material, rivets and rivet spacing, and the methods and procedures to be used. Any additional knowledge needed to make a repair is also detailed. If the necessary information is not found in the SRM, attempt to find a similar repair or assembly installed by the manufacturer of the aircraft.

DAMAGE REMOVAL

To prepare a damaged area for repair:

1. Remove all distorted skin and structure in damaged area.
2. Remove damaged material so that the edges of the completed repair match existing structure and aircraft lines.
3. Round all square corners.
4. Smooth out any abrasions and/or dents.
5. Remove and incorporate into the new repair any previous repairs joining the area of the new repair.

REPAIR MATERIAL SELECTION

The repair material must duplicate the strength of the original structure. If an alloy weaker than the original material has to be used, a heavier gauge must be used to give equivalent cross-sectional strength. A lighter gauge material should not be used even when using a stronger alloy.

REPAIR PARTS LAYOUT

All new sections fabricated for repairing or replacing damaged parts in a given aircraft should be carefully laid out to the dimensions listed in the applicable aircraft manual before fitting the parts into the structure.

RIVET SELECTION

Normally, the rivet size and material should be the same as the original rivets in the part being repaired. If a rivet hole has been enlarged or deformed, the next larger size rivet must be used after reworking the hole. When this is done, the proper edge distance for the larger rivet must be maintained. Where access to the inside of the structure is impossible and blind rivets must be used in making the repair, always consult the applicable aircraft maintenance manual for the recommended type, size, spacing, and number of rivets needed to replace either the original installed rivets or those that are required for the type of repair being performed.

RIVET SPACING AND EDGE DISTANCE

The rivet pattern for a repair must conform to instructions in the applicable aircraft manual. The existing rivet pattern is used whenever possible.

CORROSION TREATMENT

Prior to assembly of repair or replacement parts, make certain that all existing corrosion has been removed in the area and that the parts are properly insulated one from the other.

REPAIR OF STRESSED SKIN STRUCTURE

In aircraft construction, stressed skin is a form of construction in which the external covering (skin) of an aircraft carries part or all of the main loads. Stressed skin is made from high strength rolled aluminum sheets. Stressed skin carries a large portion of the load imposed upon an aircraft structure. Various specific skin areas are classified as highly critical, semi-critical, or noncritical.

To determine specific repair requirements for these areas, refer to the applicable aircraft maintenance manual.

Minor damage to the outside skin of the aircraft can be repaired by applying a patch to the inside of the damaged sheet. A filler plug must be installed in the hole made by the removal of the damaged skin area. It plugs the hole and forms a smooth outside surface necessary for aerodynamic smoothness of the aircraft. The size and shape of the patch is determined in general by the number of rivets required in the repair. If not otherwise specified, calculate the required number of rivets by using the rivet formula. Make the patch plate of the same material as the original skin and of the same thickness or of the next greater thickness.

PATCHES

Skin patches may be classified as two types:

- Lap or scab patch
- Flush patch

LAP OR SCAB PATCH

The lap or scab type of patch is an external patch where the edges of the patch and the skin overlap each other. The overlapping portion of the patch is riveted to the skin. Lap patches may be used in most areas where aerodynamic smoothness is not important. ***Figure 18-13*** shows a typical patch for a crack and or for a hole.

When repairing cracks or small holes with a lap or scab patch, the damage must be cleaned and smoothed. In repairing cracks, a small hole must be drilled in each end and sharp bend of the crack before applying the patch. These holes relieve the stress at these points and

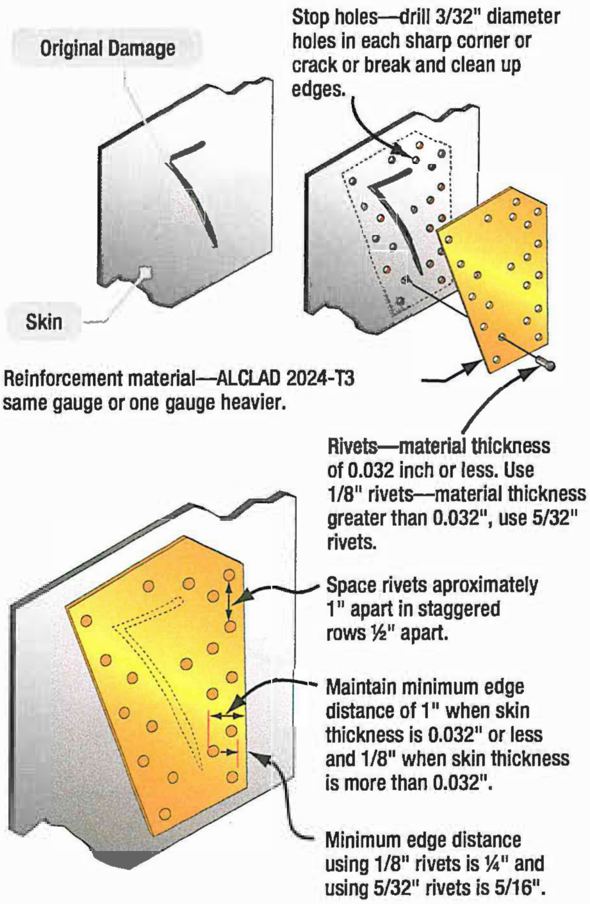


Figure 18-13. Lap or scab patch (crack).

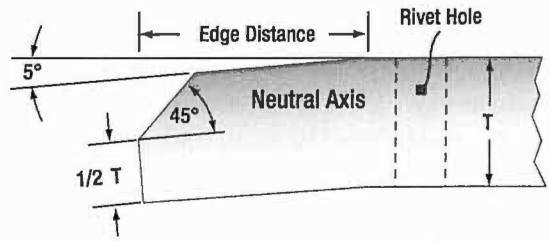


Figure 18-14. Lap patch edge preparation.

prevent the crack from spreading. The patch must be large enough to install the required number of rivets. It may be cut circular, square, or rectangular. If it is cut square or rectangular, the corners are rounded to a radius no smaller than ¼ inch. The edges must be chamfered to an angle of 45° for ½ the thickness of the material, and bent down 5° over the edge distance to seal the edges. This reduces the chance that the repair is affected by the airflow over it. These dimensions are shown in ***Figure 18-14***.

FLUSH PATCH

A flush patch is a filler patch that is flush to the skin when applied it is supported by and riveted to a reinforcement plate which is, in turn, riveted to the inside of the skin. ***Figure 18-15*** shows a typical flush patch repair. The doubler is inserted through the opening and rotated until it slides in place under the skin. The filler must be of the same gauge and material as the original skin. The doubler should be of material one gauge heavier than the skin.

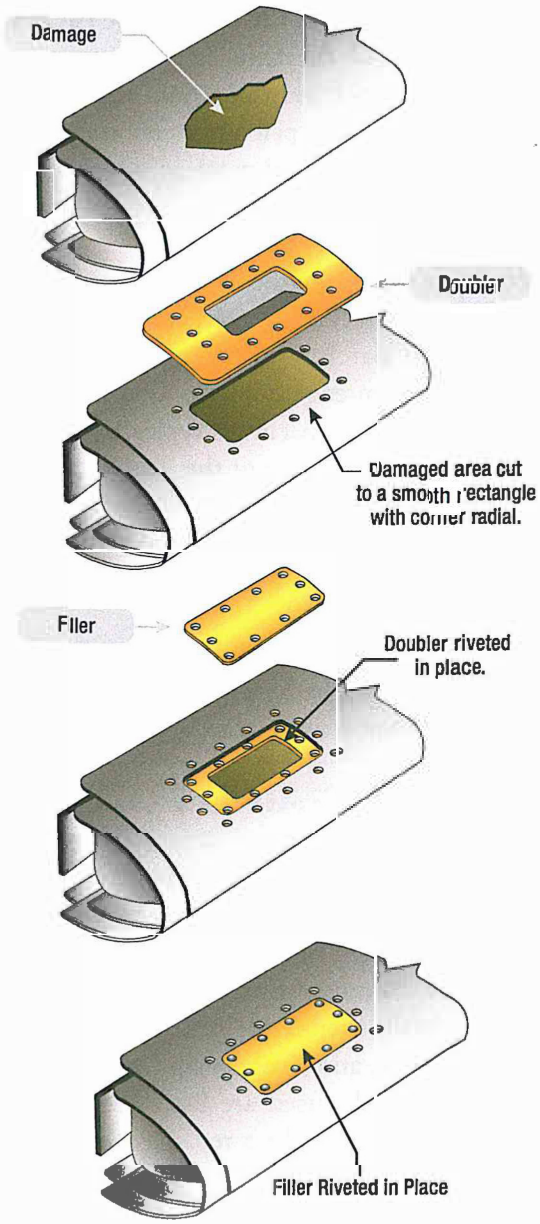


Figure 18-15. Typical flush patch repair.

OPEN AND CLOSED SKIN AREA REPAIR

The factors that determine the methods to be used in skin repair are accessibility to the damaged area and the instructions found in the aircraft maintenance manual. The skin on most areas of an aircraft is inaccessible for making the repair from the inside and is known as closed skin. Skin that is accessible from both sides is called open skin. Usually, repairs to open skin can be made in the conventional manner using standard rivets, but in repairing closed skin, some type of special fastener must be used. The exact type to be used depends on the type of repair being made and the recommendations of the aircraft manufacturer.

DESIGN OF A PATCH FOR A NON-PRESSURIZED AREA

Damage to the aircraft skin in a non-pressurized area can be repaired by a flush patch if a smooth skin surface is required or by an external patch in noncritical areas. (*Figure 18-16*)

The first step is to remove the damage. Cut the damage to a round, oval, or rectangular shape. Round all corners of a rectangular patch to a minimum radius of 0.5-inch. The minimum edge distance used is 2 times the diameter and the rivet spacing is typically between 4-6 times the diameter. The size of the doubler depends on the edge distance and rivet spacing. The doubler material is of the same material as the damaged skin, but of one thickness greater than the damaged skin.

'The size of the doubler depends on the edge distance and rivet spacing. The insert is made of the same material and thickness as the damaged skin.

The size and type of rivets should be the same as rivets used for similar joints on the aircraft. The SRM indicates what size and type of rivets to use.

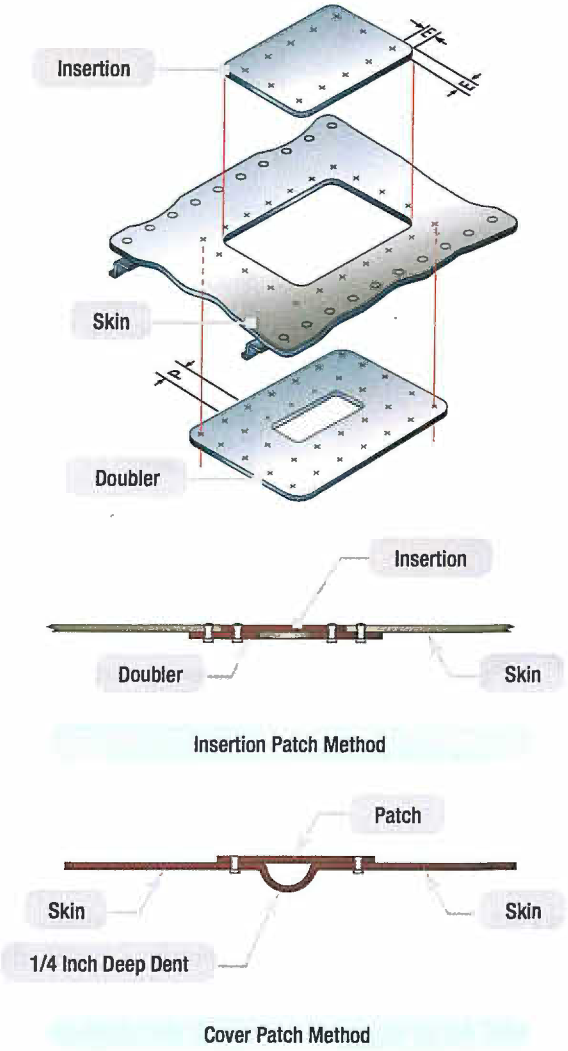


Figure 18-16. Repair patch for a non-pressurized area.

TYPICAL REPAIRS FOR AIRCRAFT STRUCTURES

This section describes typical repairs of the major structural parts of an airplane. When repairing a damaged component or part, consult the applicable section of the manufacturer's SRM for the aircraft. Normally, a similar repair is illustrated, and the types of material, rivets, and rivet spacing and the methods and procedures to be used are listed. Any additional knowledge needed to make a repair is also detailed. If the necessary information is not found in the SRM, attempt to find a similar repair or assembly installed by the manufacturer of the aircraft.

FLOATS

To maintain the float in an airworthy condition, periodic and frequent inspections should be made because of the rapidity of corrosion on metal parts, particularly when the aircraft is operated in salt water. Inspection of floats and hulls involves examination for damage due to corrosion, collision with other objects, hard landings, and other conditions that may lead to failure.

NOTE: Blind rivets should not be used on floats or amphibian hulls below the water line.

Sheet-metal floats should be repaired using approved practices; however, the seams between sections of sheet metal should be waterproofed with suitable fabric and sealing compound. A float that has undergone hull repairs should be tested by filling it with water and allowing it to stand for at least 24 hours to see if any leaks develop. (***Figure 18-17***)

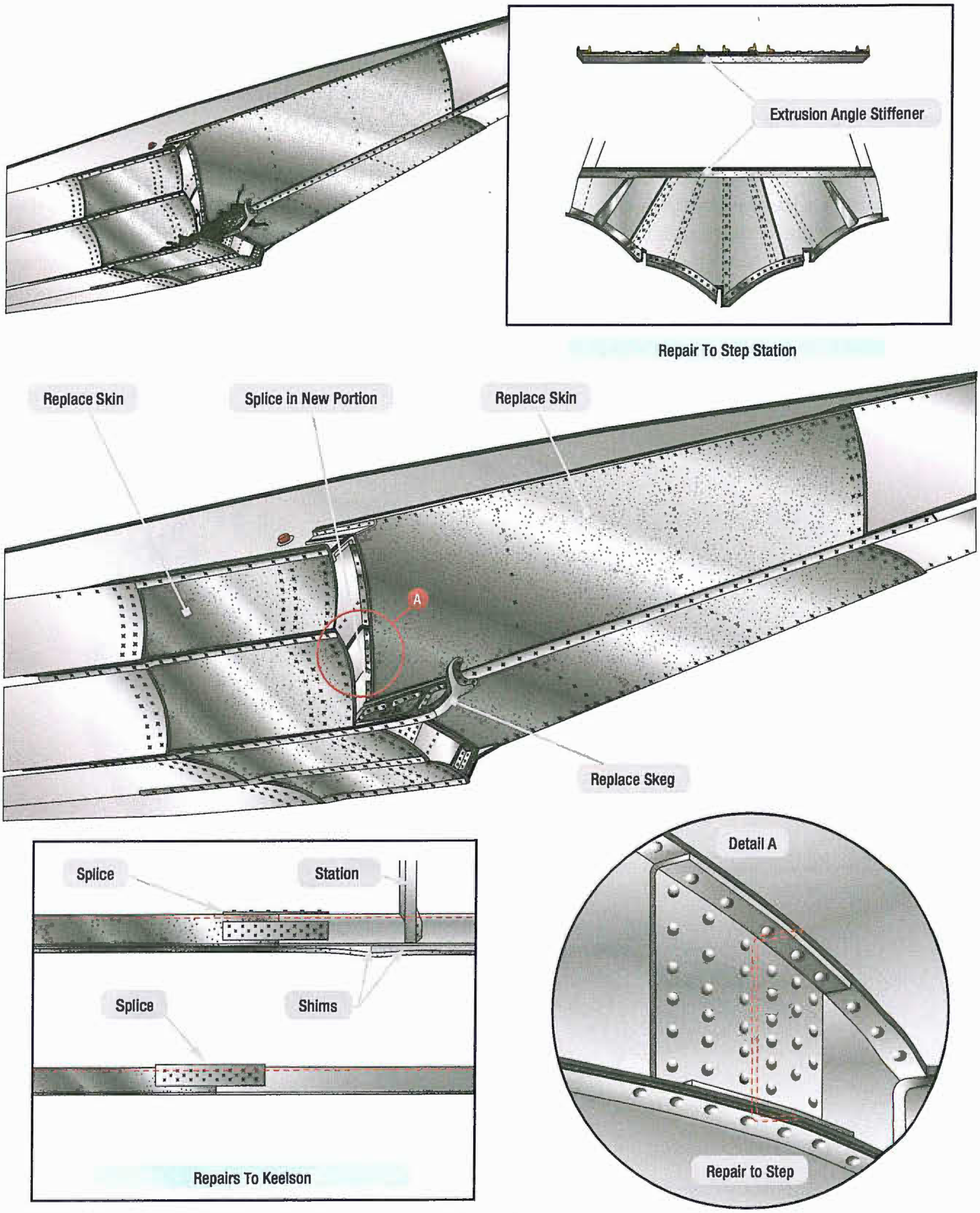


Figure 18-17. Float repair.

CORRUGATED SKIN REPAIR

Some of the flight controls of smaller general aviation aircraft have beads in their skin panels. The beads give some stiffness to the thin skin panels. The beads for the repair patch can be formed with a rotary former or press brake. (***Figure 18-18***)

REPLACEMENT OF A PANEL

Damage to metal aircraft skin that exceeds repairable limits requires replacement of the entire panel. (***Figure 18-19***) A panel must also be replaced when there are too many previous repairs in a given section or area. In aircraft construction, a panel is any single sheet of metal covering. A panel section is the part of a panel between adjacent stringers and bulk heads.

Where a section of skin is damaged to such an extent that it is impossible to install a standard skin repair, a special type of repair is necessary. The particular type of repair required depends on whether the damage is repairable outside the member, inside the member, or to the edges of the panel.

OUTSIDE THE MEMBER

For damage that, after being trimmed, has 8½ rivet diameters or more of material, extend the patch to include the manufacturer's row of rivets and add an extra row inside the members.

INSIDE THE MEMBER

For damage that, after being trimmed, has less than 8½ manufacturer's rivet diameters of material inside the members, use a patch that extends over the members and an extra row of rivets along the outside of the members.

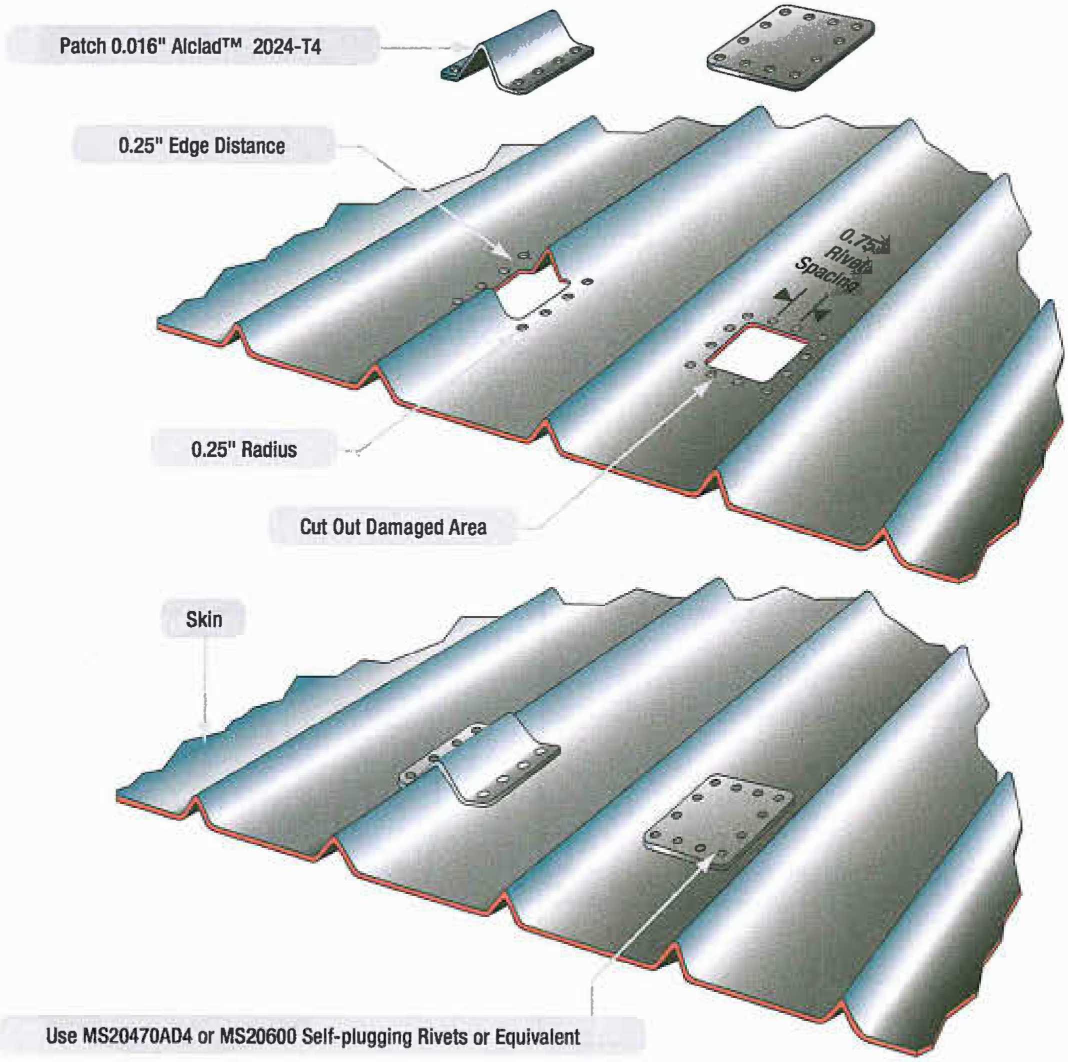


Figure 18-18. Beaded skin repair on corrugated surfaces.

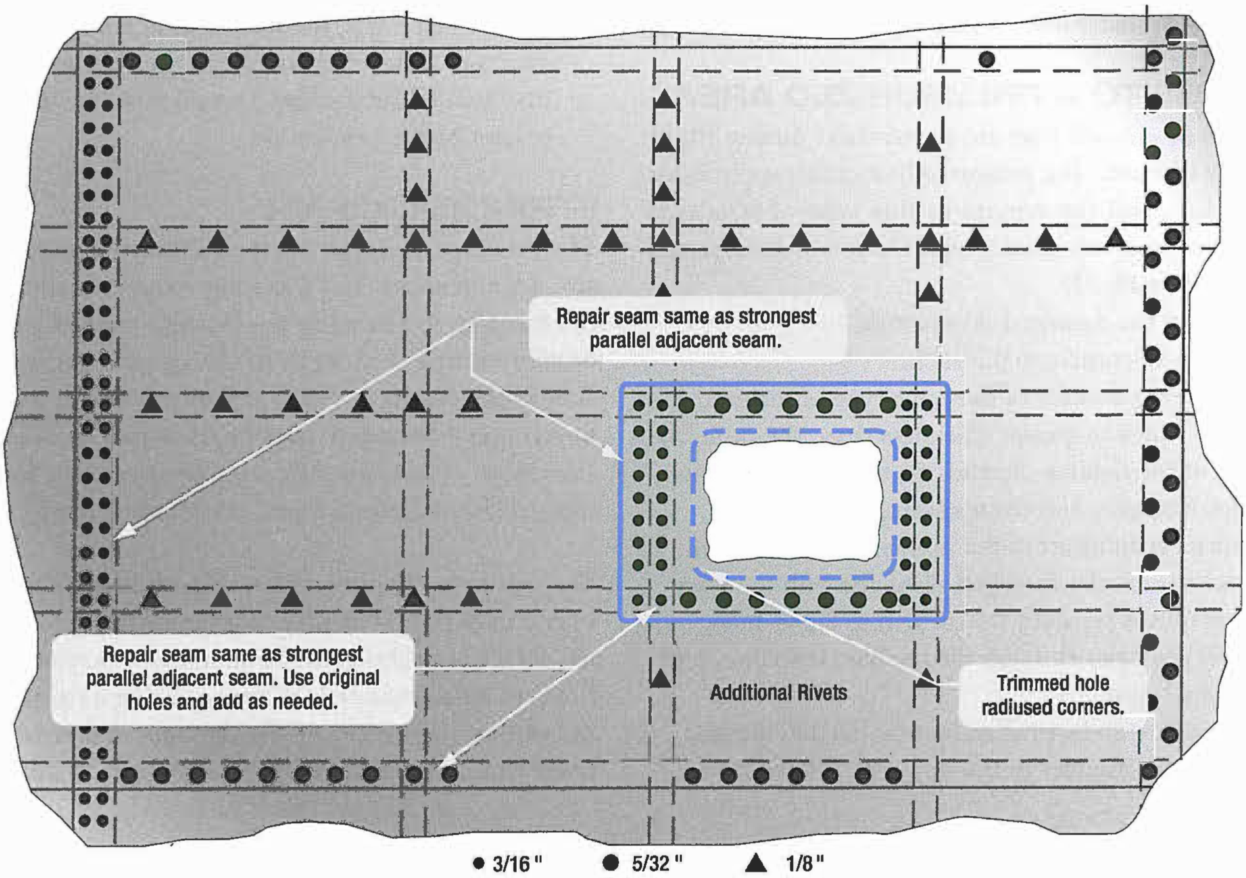


Figure 18-19. Replacement of an entire panel.

EDGES OF THE PANEL

For damage that extends to the edge of a panel, use only one row of rivets along the panel edge, unless the manufacturer used more than one row. The repair procedure for the other edges of the damage follows the previously explained methods.

The procedures for making all three types of panel repairs are similar. Trim out the damaged portion to the allowances mentioned in the preceding paragraphs. For relief of stresses at the corners of the trim-out, round them to a minimum radius of ½-inch. Lay out the new rivet row with a transverse pitch of approximately five rivet diameters and stagger the rivets with those put in by the manufacturer. Cut the patch plate from material of the same thickness as the original or the next greater thickness, allowing an edge distance of 2½ rivet diameters. At the corners, strike arcs having the radius equal to the edge distance.

Chamfer the edges of the patch plate for a 45° angle and form the plate to fit the contour of the original structure. Turn the edges downward slightly so that the edges fit closely. Place the patch plate in its correct position, drill one rivet hole, and temporarily fasten the plate in place with a fastener. Using a hole finder, locate the position of a second hole, drill it, and insert a second fastener. Then, from the back side and through the original holes, locate and drill the remaining holes. Remove the burrs from the rivet holes and apply corrosion protective material to the contacting surfaces before riveting the patch into place.

REPAIR OF LIGHTENING HOLES

As discussed earlier, lightening holes are cut in rib sections, fuselage frames, and other structural parts to reduce the weight of the part. The holes are flanged to make the web stiffer. Cracks can develop around flanged lightening holes, and these cracks need to be repaired with a repair plate. The damaged area (crack) needs to be stop drilled or the damage must be removed.

The repair plate is made of the same material and thickness as the damaged part. Rivets are the same as in surrounding structure and the minimum edge distance is 2 times the diameter and spacing is between four to six times the diameter.

Figure 18-20 illustrates a typical lightening hole repair.

REPAIRS TO A PRESSURIZED AREA

The skin of aircraft that are pressurized during flight is highly stressed. The pressurization cycles apply loads to the skin, and the repairs to this type of structure requires more rivets than a repair to a non-pressurized skin. (*Figure 18-21*)

1. Remove the damaged skin section.
2. Radius all corners to 0.5-inch.
3. Fabricate a doubler of the same type of material as, but of one size greater thickness than, the skin. The size of the doubler depends on the number of rows, edge distance, and rivets spacing.
4. Fabricate an insert of the same material and same thickness as the damaged skin. The skin to insert clearance is typically 0.015-inch to 0.035-inch.
5. Drill the holes through the doubler, insertion, and original skin.
6. Spread a thin layer of sealant on the doubler and secure the doubler to the skin with Clecos.
7. Use the same type of fastener as in the surrounding area, and install the doubler to the skin and the insertion to the doubler. Dip all fasteners in the sealant before installation.

STRINGER REPAIR

The fuselage stringers extend from the nose of the aircraft to the tail, and the wing stringers extend from the fuselage to the wing tip. Surface control stringers usually extend the length of the control surface. The skin of the fuselage, wing, or control surface is riveted to stringers. Stringers may be damaged by vibration, corrosion, or collision. Because stringers are made in many different shapes, repair procedures differ.

The repair may require the use of preformed or extruded repair material, or it may require material formed by the airframe technician. Some repairs may need both kinds of repair material. When repairing a stringer, first determine the extent of the damage and remove the rivets from the surrounding area. (*Figure 18-22*)

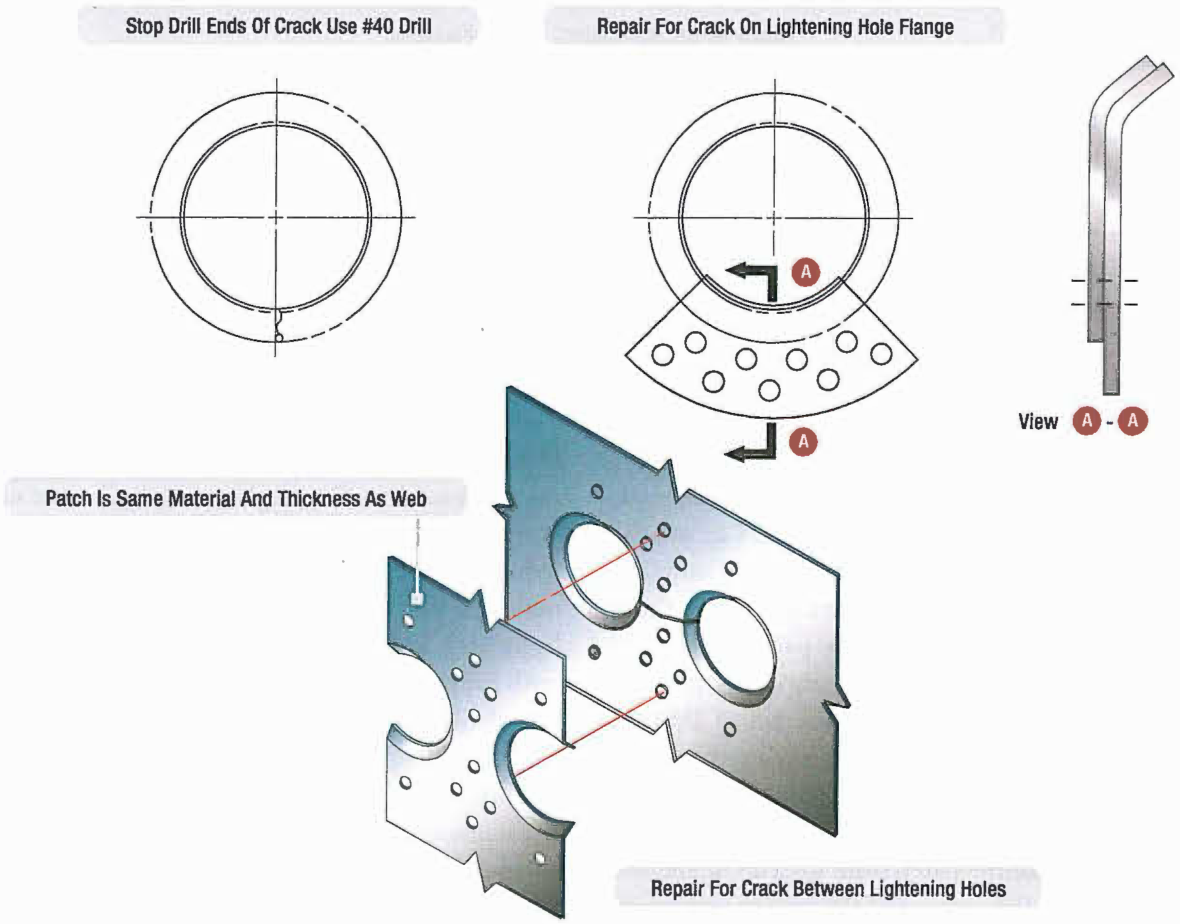


Figure 18-20. Repair of lightening holes.

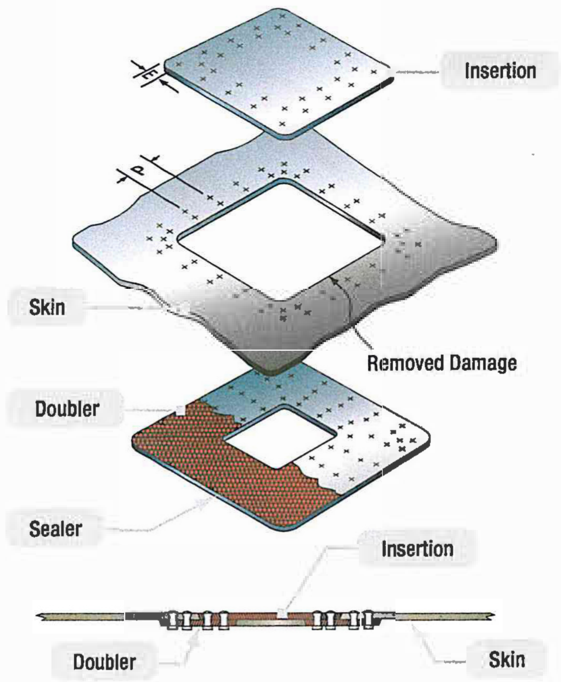


Figure 18-21. Pressurized skin repair.

Then, remove the damaged area by using a hacksaw, keyhole saw, drill, or file. In most cases, a stringer repair requires the use of insert and splice angle. When locating the splice angle on the stringer during repair, be sure to consult the applicable structural repair manual for the repair piece's position. Some stringers are repaired by placing the splice angle on the inside, whereas others are repaired by placing it on the outside.

Extrusions and preformed materials are commonly used to repair angles and insertions or fillers. If repair angles and fillers must be formed from flat sheet stock, use the brake. It may be necessary to use bend allowance and sight lines when making the layout and bends for these formed parts. For repairs to curved stringers, make the repair parts so that they fit the original contour.

Figure 18-23 shows a stringer repair by patching. This repair is permissible when the damage does not exceed two-thirds of the width of one leg and is not more than 12-inch long. Damage exceeding these limits can be repaired by one of the following methods. *Figure 18-24* illustrates repair by insertion where damage exceeds two-thirds of the width of one leg and after a portion of the stringer is removed. *Figure 18-25* shows repair by insertion when the damage affects only one stringer and exceeds 12 inch in length. *Figure 18-26* illustrates repair by an insertion when damage affects more than one stringer.

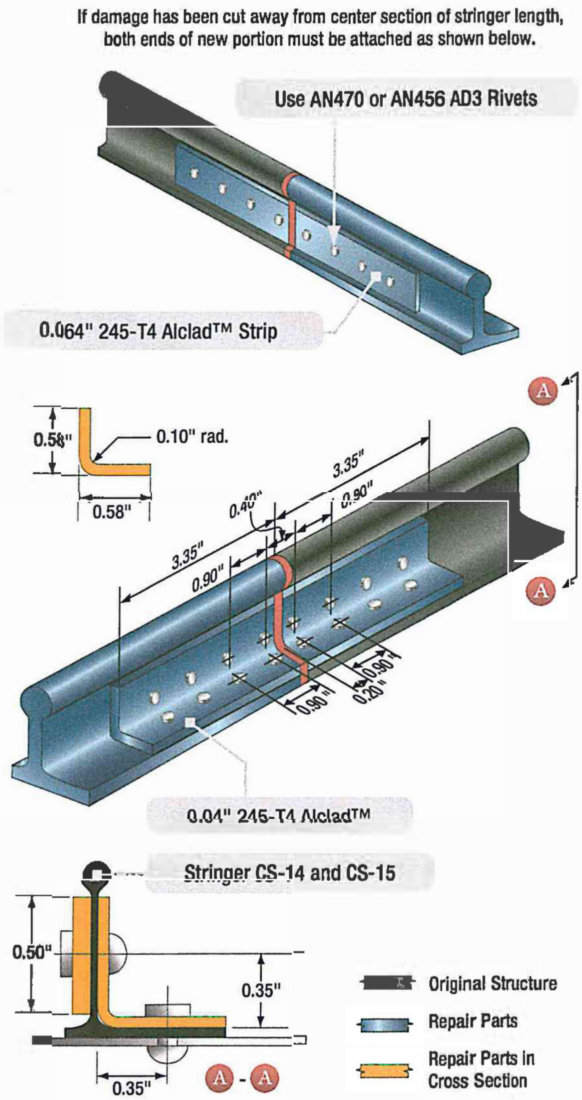


Figure 18-22. Stringer repair.

FORMER OR BULKHEAD REPAIR

Bulkheads are the oval-shaped members of the fuselage that give form to and maintain the shape of the structure. Bulkheads or formers are often called forming rings, body frames, circumferential rings, belt frames, and other similar names. They are designed to carry concentrated stressed loads.

There are various types of bulkheads. The most common type is a curved channel formed from sheet stock with stiffeners added. Others have a web made from sheet stock with extruded angles riveted in place as stiffeners and flanges. Most of these members are made from aluminum alloy. Corrosion-resistant steel formers are used in areas that are exposed to high temperatures.

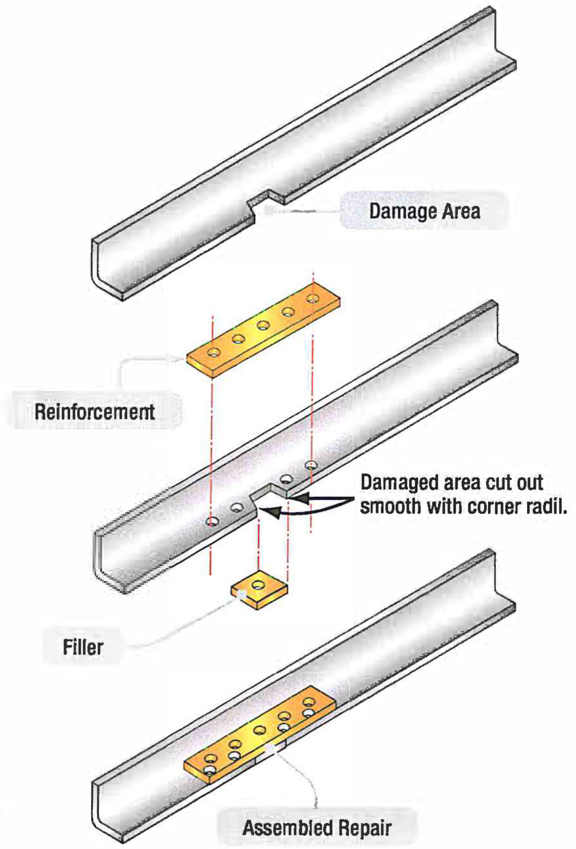


Figure 18-23. Stringer repair by patching.

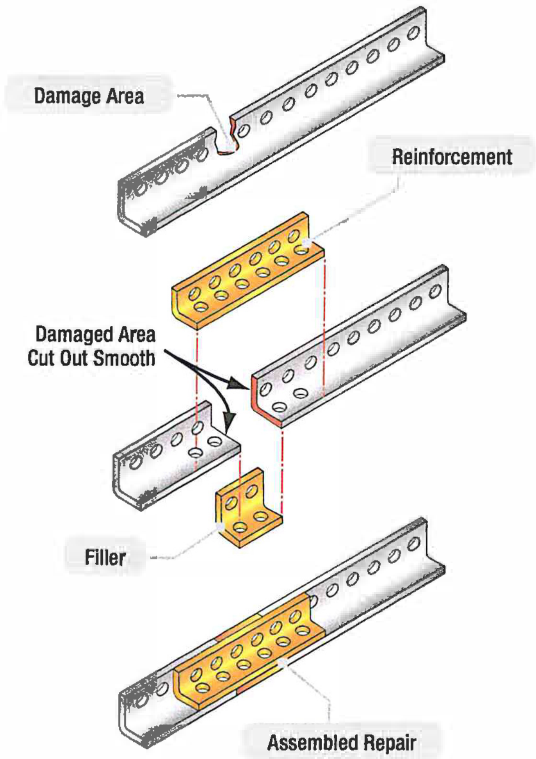


Figure 18-24. Stringer repair by insertion when damage exceeds two-thirds of one leg in width.

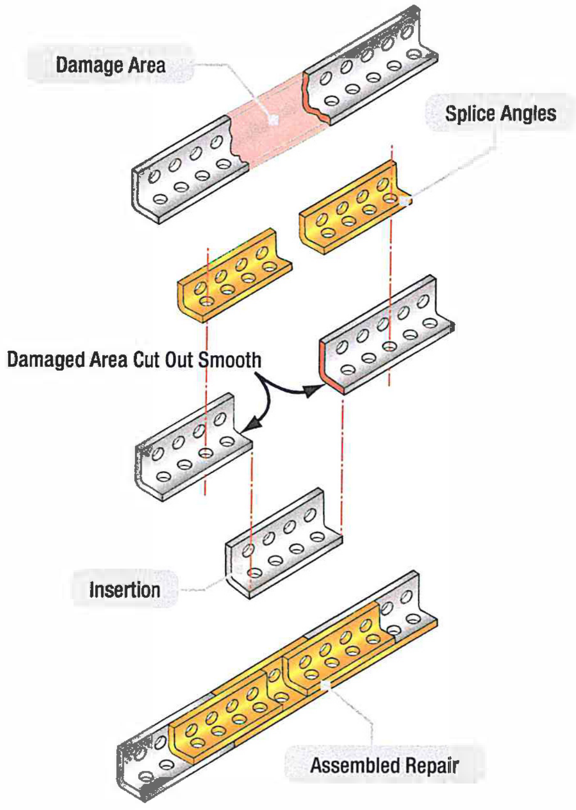


Figure 18-25. Stringer repair by insertion when damage affects only one stringer.

Bulkhead damages are classified in the same manner as other damages. Specifications for each type of damage are established by the manufacturer and specific information is given in the maintenance manual or SRM for the aircraft. Bulkheads are identified with station numbers that are very helpful in locating repair information.

Figure 18-27 is an example of a typical repair for a former, frame section, or bulkhead repair.

1. Stop drill the crack ends with a No. 40 size drill.
2. Fabricate a doubler of the same material but one size thicker than the part being repaired. The doubler should be of a size large enough to accommodate ⅛ inch rivet holes spaced one inch apart, with a minimum edge distance of 0.30-inch and 0.50-inch spacing between staggered rows. (***Figure 18-28***)
3. Attach the doubler to the part with clamps and drill holes.
4. Install rivets.

Most repairs to bulkheads are made from flat sheet stock if spare parts are not available. When fabricating the repair from flat sheet, remember the substitute material must provide cross-sectional tensile, compressive, shear,

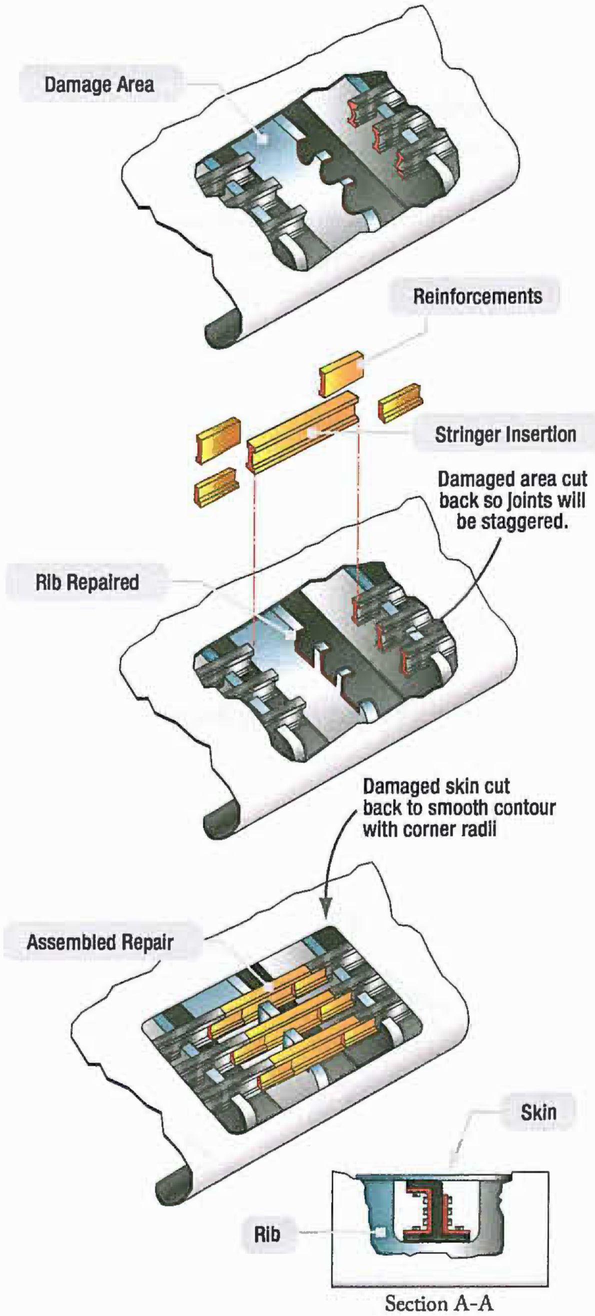


Figure 18-26. Stringer repair by insertion when damage affects more than one stringer.

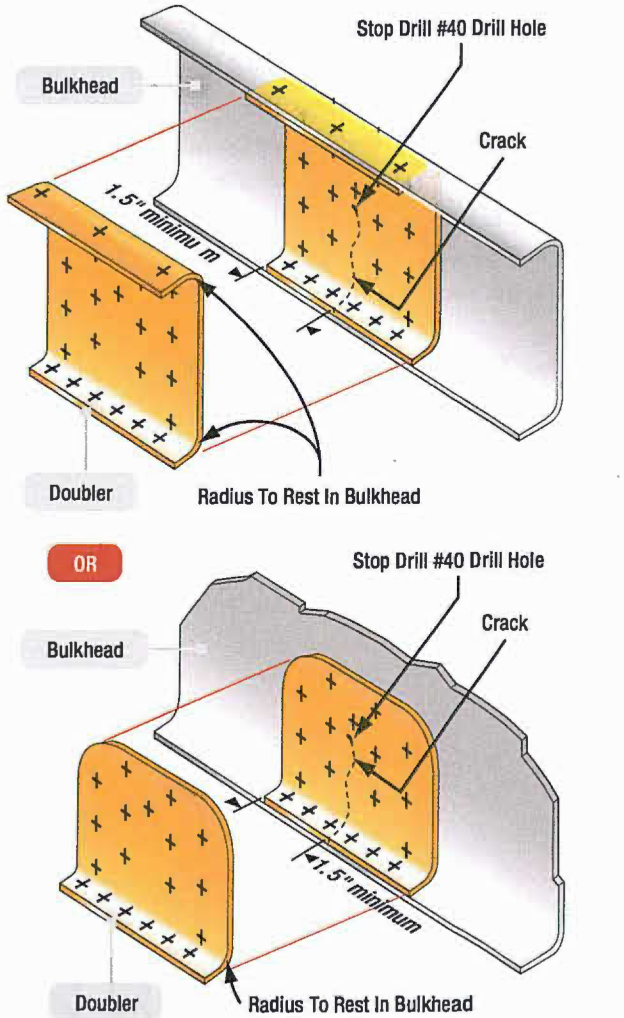


Figure 18-27. Stringer repair by patching.

and bearing strength equal to the original material. Never substitute material that is thinner or has a cross-sectional area less than the original material. Curved repair parts made from flat sheet must be in the "0" condition before forming, and then must be heat treated before installation.

LONGERON REPAIR

Generally, longerons are comparatively heavy members that serve approximately the same function as stringers. Consequently, longeron repair is similar to stringer repair. Because the longeron is a heavy member and more strength is needed than with a stringer, heavy rivets are used in the repair. Sometimes bolts are used to install a longeron repair. Due to the need for greater accuracy, bolts are not as suitable as rivets. Also, bolts require more time for installation. If the longeron consists of a formed section and an extruded angle section, consider each section separately. A longeron repair is similar to a stringer repair, but keep the rivet pitch between 4 and 6 rivet diameters. If bolts are used, drill the bolt holes for a light drive fit.

SPAR REPAIR

The spar is the main supporting member of the wing. Other components may also have supporting members called spars that serve the same function as the spar does in the wing. Think of spars as the hub, or base, of the section in which they are located, even though they are not in the center. The spar is usually the first member located during the construction of the section, and the other components are fastened directly or indirectly to it. Because of the load the spar carries, it is very important that particular care be taken when repairing this member to ensure the original strength of the structure is not impaired. The spar is constructed so that two general classes of repairs, web repairs and cap strip repairs, are usually necessary.

Figures 18-28 and 18-29 are examples of typical spar repairs. The damage to the spar web can be repaired with a round or rectangular doubler.

Damage smaller than 1 inch is typically repaired with a round doubler and larger damage is repaired with a rectangular doubler.

1. Remove the damage and radius all corners to ½-inch.
2. Fabricate doubler; use same material and thickness. The doubler size depends on edge distance (minimum of 2D) and rivet spacing (4-6D).
3. Drill through the doubler and the original skin and secure doubler with Clecos.
4. Install rivets.

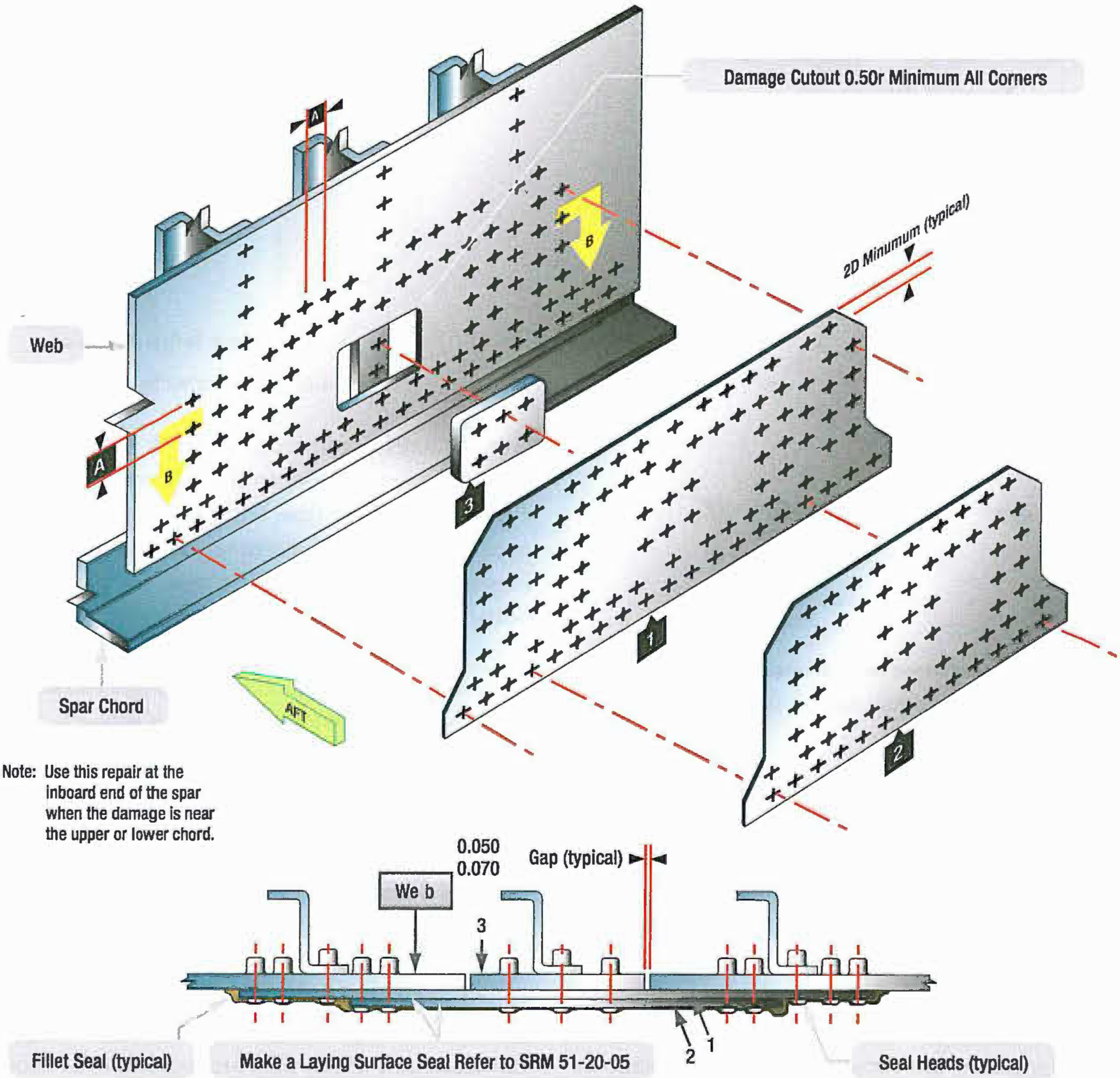
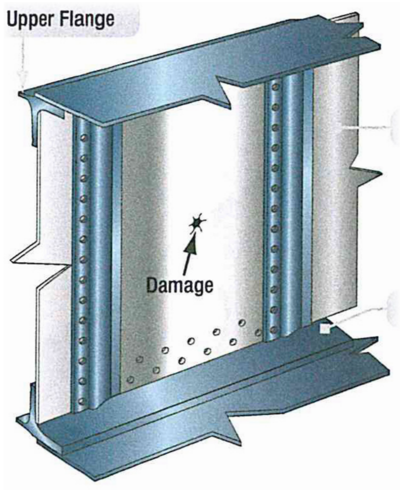


Figure 18-28. Wing spar repair.



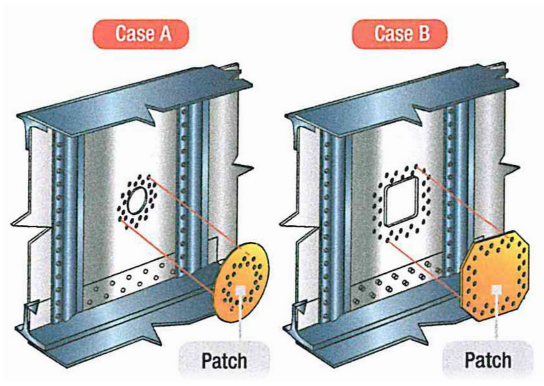


Figure 18-29. Wing spar repair.

RIB AND WEB REPAIR

Web repairs can be classified into two types:

1. Those made to web sections considered critical, such as those in the wing ribs.
2. Those considered less critical, such as those in elevators, rudders, flaps, and the like.

Web sections must be repaired in such a way that the original strength of the member is restored. In the construction of a member using a web, the web member is usually a light gauge aluminum alloy sheet forming the principal depth of the member. The web is bounded by heavy aluminum alloy extrusions known as cap strips. These extrusions carry the loads caused by bending and also provide a foundation for attaching the skin. The web may be stiffened by stamped beads, formed angles, or extruded sections riveted at regular intervals along the web.

The stamped beads are a part of the web itself and are stamped in when the web is made. Stiffeners help to withstand the compressive loads exerted upon the critically stressed web members. Often, ribs are formed by stamping the entire piece from sheet stock. That is, the rib lacks a cap strip, but does have a flange around the entire piece, plus lightening holes in the web of the rib.

Ribs may be formed with stamped beads for stiffeners, or they may have extruded angles riveted on the web for stiffeners. Most damages involve two or more members, but only one member may be damaged and need repairing. Generally, if the web is damaged, cleaning out the damaged area and installing a patch plate are all that is required.

The patch plate should be of sufficient size to ensure room for at least two rows of rivets around the perimeter of the damage that includes proper edge distance, pitch, and transverse pitch for the rivets. The patch plate should be of material having the same thickness and composition as the original member. If any forming is necessary when making the patch plate, such as fitting the contour of a lightening hole, use material in the "0" condition and then heat treat it after forming.

Damage to ribs and webs, that require a repair larger than a simple plate, probably needs a patch plate, splice plates, or angles and an insertion. (***Figure 18-30***)

LEADING EDGE REPAIR

The leading edge is the front section of a wing, stabilizer, or other airfoil. The purpose of the leading edge is to streamline the forward section of the wings or control surfaces to ensure effective airflow. The space within the leading edge is sometimes used to store fuel. This space may also house extra equipment, such as landing lights, plumbing lines, or thermal anti-icing systems.

The construction of the leading edge section varies with the type of aircraft. Generally, it consists of cap strips, nose ribs, stringers, and skin. The cap strips are the main lengthwise extrusions, and they stiffen the leading edges and furnish a base for the nose ribs and skin. They also fasten the leading edge to the front spar.

The nose ribs are stamped from aluminum alloy sheet or machined parts. These ribs are U-shaped and may have their web sections stiffened. Regardless of their design, their purpose is to give contour to the leading edge.

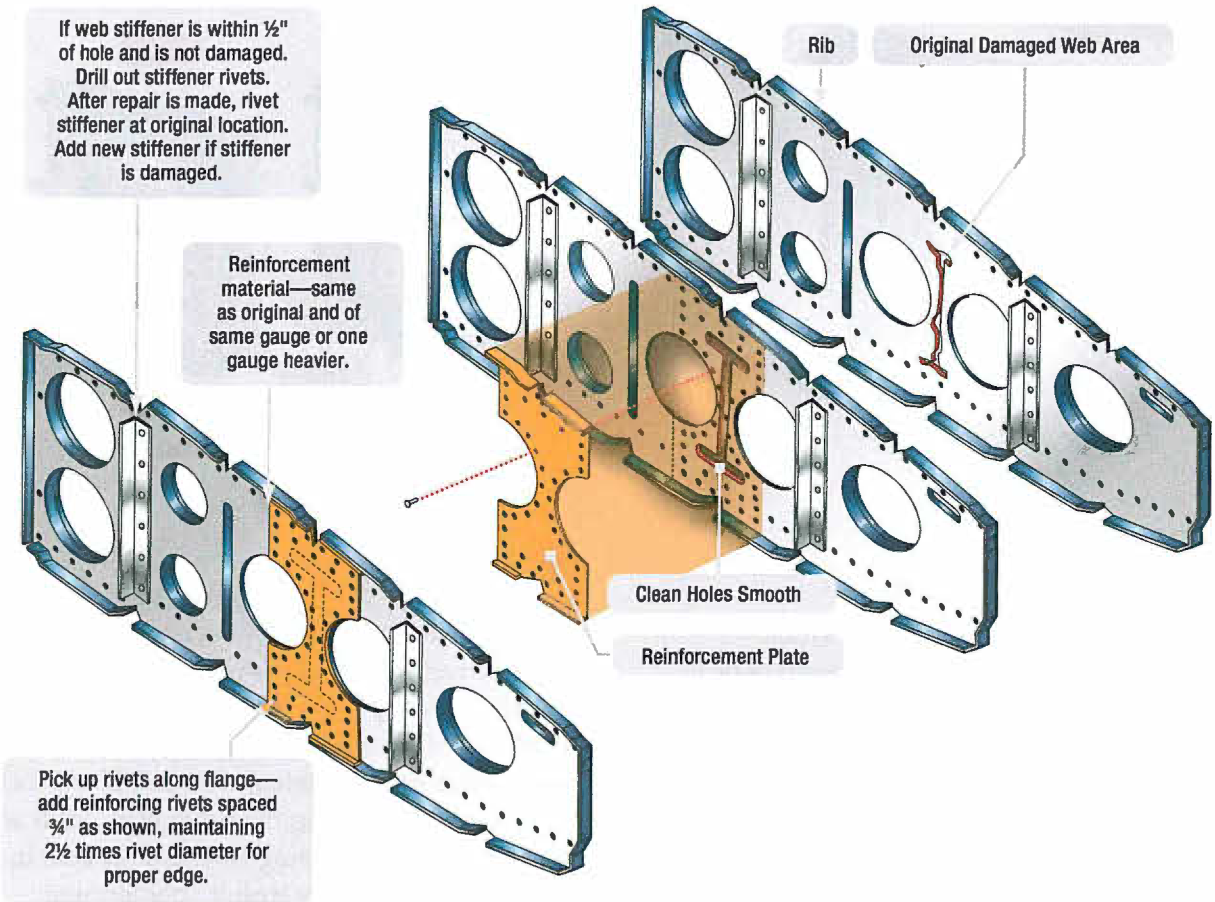


Figure 18-30. Wing rib repair.

Stiffeners are used to stiffen the leading edge and supply a base for fastening the nose skin. When fastening the nose skin, use only flush rivets.

Leading edges constructed with thermal anti-icing systems consist of two layers of skin separated by a thin air space. The inner skin, sometimes corrugated for strength, is perforated to conduct the hot air to the nose skin for anti-icing purposes. Damage can be caused by contact with other objects, namely, pebbles, birds, and hail. However, the major cause of damage is carelessness while the aircraft is on the ground.

A damaged leading edge usually involves several structural parts. FOD probably involves the nose skin, nose ribs, stringers, and possibly the cap strip. Damage involving all of these members necessitates installing an access door to make the repair possible. First, the damaged area has to be removed and repair procedures established. The repair needs insertions and splice pieces. If the damage is serious enough, it may require repair of the cap strip and stringer, a new nose rib, and a skin panel. When repairing a leading edge, follow the procedures prescribed in the appropriate repair manual for this type of repair. (***Figure 18-31***) Repairs to leading edges are more difficult to accomplish than repairs to flat and straight structures because the repair parts need to be formed to fit the existing structure.

TRAILING EDGE REPAIR

A trailing edge is the rearmost part of an airfoil found on the wings, ailerons, rudders, elevators, and stabilizers. It is usually a metal strip that forms the shape of the edge by tying the ends of a rib section together and joining the upper and lower skins.

Trailing edges are not structural members, but they are considered to be highly stressed in all cases.

Damage to a trailing edge may be limited to one point or extended over the entire length between two or more rib sections. Besides damage resulting from collision and careless handling, corrosion damage is often present. Trailing edges are particularly subject to corrosion because moisture collects or is trapped in them.

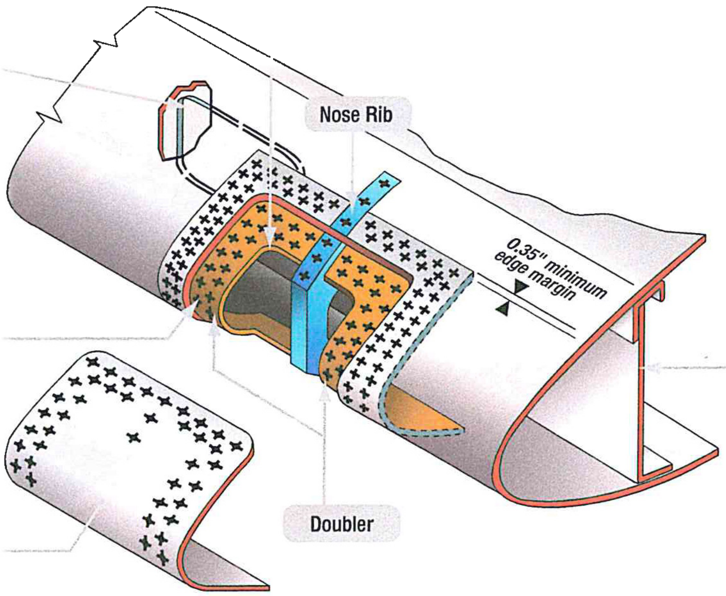


Figure 18-31. Leading edge repair.

Thoroughly inspect the damaged area before starting repairs, and determine the extent of damage, the type of repair required, and the manner in which the repair should be performed. When making trailing edge repairs, remember that the repaired area must have the same contour and be made of material with the same composition and temper as the original section.

The repair must also be made to retain the design characteristics of the airfoil. (*Figure 18-32*)

SPECIALIZED REPAIRS

Figures 18-33 through 18-37 are examples of repairs for various structural members. Specific dimensions are not included since the illustrations are intended to present the basic design philosophy of general repairs rather than be used as repair guidelines for actual structures. Remember to consult the SRM for specific aircraft to obtain the maximum allowable damage that may be repaired and the suggested method for accomplishing the repair.

INSPECTION OPENINGS

If it is permitted by the applicable aircraft maintenance manual, installation of a flush access door for inspection purposes sometimes makes it easier to repair the internal structure as well as damage to the skin in certain areas. This installation consists of a doubler and a stressed cover plate. A single row of nut plates is riveted to the doubler, and the doubler is riveted to the skin with two staggered rows of rivets. (*Figure 18-38*) The cover plate is then attached to the doubler with machine screws.

AGING, FATIGUE, AND CORROSION CONTROL PROGRAMS

As aircraft age, more scrutiny of the structure is required to ensure airworthiness. Corrosion is a main factor. In addition to more time passing and therefore more exposure to conditions which cause corrosion, aircraft designed and built many years ago were not constructed with prevention of corrosion in mind. A simple item like drain-hole design may have overlooked the effects of moisture and corrosion formation around the drain after 20, 30, or even 40 plus years of service. Metal fatigue is also a concern.

Repeated stress over extended periods of time can cause weakness, cracks and failure of metal structure and components. Dramatic failures on older aircraft due to corrosion and fatigue are well documented. Most national aviation authorities addressed the issues of aging aircraft before EASA was formed.

EASA regulations continue the endeavor. Manufacturers are a key part of the effort to ensure inspection and maintenance of older aircraft is performed so that these aircraft safely continue in service.

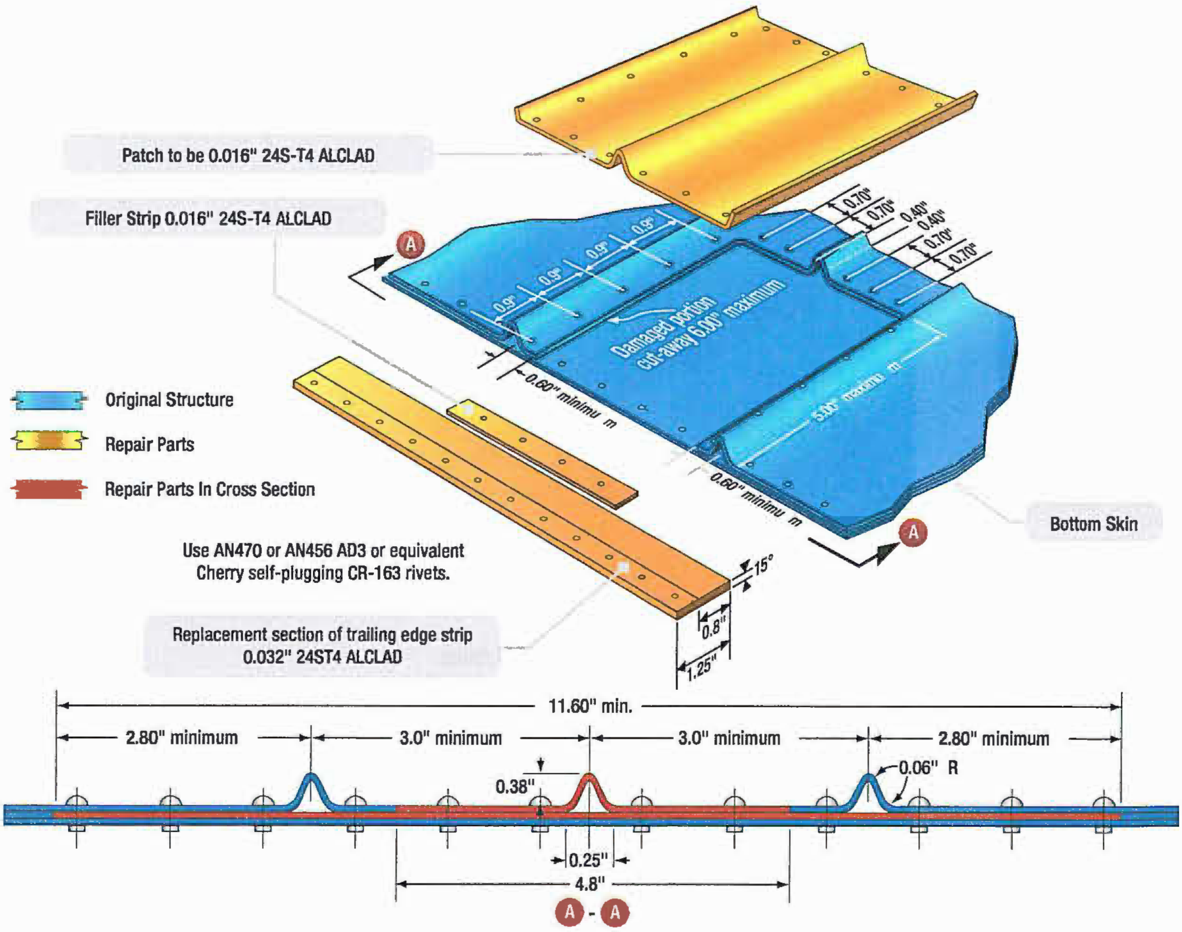


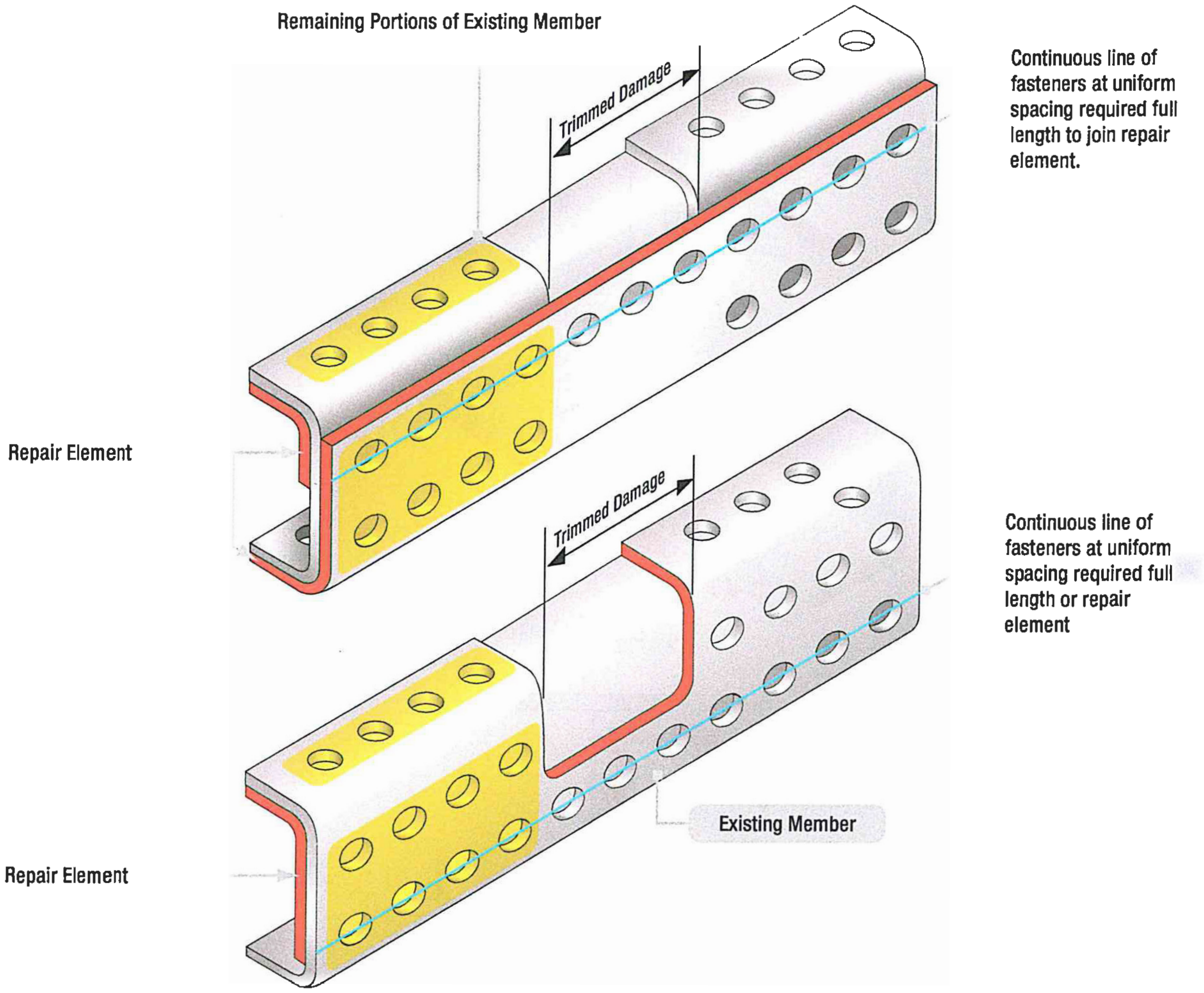
Figure 18-32. Trailing edge repair.

Numerous airworthiness directives have been issued to alert operators of any newly discovered areas of concern and required maintenance on older aircraft. Manufacturers have developed detailed inspection and maintenance programs designed for specific aircraft beyond certain ages. Operators may develop their own programs as well. The Boeing 737, for example, has a long history as a workhorse in the airline industry. Many of these aircraft manufactured in the 1980's are still in service today. Boeing, with the help of the FAA and 737 operators, has constructed mandatory procedures for inspection and airframe modification on this aircraft. A different program is followed for 747's based on historical knowledge gained from incidents in the field on this aircraft. It is incumbent on all manufacturers to address the unique maintenance issues of aging aircraft in their approved maintenance data.

It should be noted that some airframes have been given limited service lives after which they must be retired from flight.

NONDESTRUCTIVE INSPECTION/TESTING

The preceding information in this chapter provided general information regarding aircraft inspection. The remainder of this chapter deals with several methods often used on specific components or areas on an aircraft when carrying out the more specific inspections. They are referred to as nondestructive inspection (NDI) or nondestructive testing (NDT). The objective of NDI and NDT is to determine the airworthiness of a component without damaging it, which would render it unairworthy. Some of these methods are simple, requiring little additional expertise, while others are highly sophisticated and require that the technician be highly trained and specially certified.



The required quantity of fasteners used to install the repair element is equal on both sides of the trimmed damage.

Figure 18-33. C-channel repair.

GENERAL TECHNIQUES

Before conducting NDI, it is necessary to follow preparatory steps in accordance with procedures specific to that type of inspection. Generally, the parts or areas must be thoroughly cleaned. Some parts must be removed from the aircraft or engine. Others might need to have any paint or protective coating stripped. A complete knowledge of the equipment and procedures is essential and if required, calibration and inspection of the equipment must be current.

VISUAL INSPECTION

Visual inspection can be enhanced by looking at the suspect area with a bright light, a magnifying glass, and a mirror (when required). Some defects might be so obvious that further inspection methods are not required. The lack of visible defects does not necessarily mean further inspection is unnecessary. Some defects may lie beneath the surface or may be so small that the human eye, even with the assistance of a magnifying glass, cannot detect them.

BORESCOPE

Inspection by use of a borescope is essentially a visual inspection. A borescope is a device that enables the inspector to see inside areas that could not otherwise be inspected without disassembly. An example of an area that can be inspected with a borescope is the inside of a reciprocating engine cylinder. The borescope can be inserted into an open spark plug hole to detect damaged pistons, cylinder walls, or valves. Another example would be the hot section of a turbine engine to which access could be gained through the hole of a removed igniter or removed access plugs specifically installed for inspection purposes.

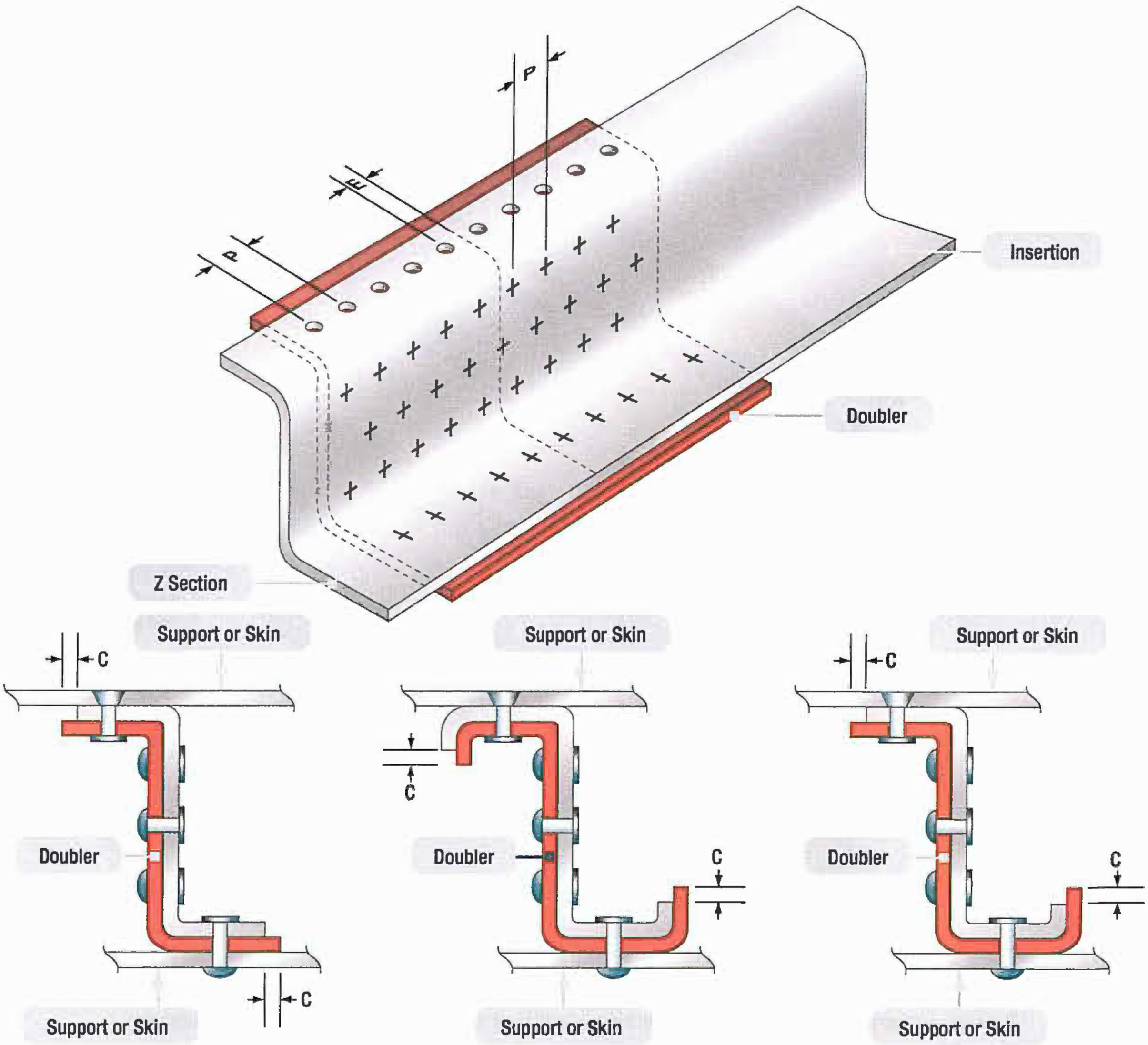


Figure 18-34. Primary Z-section repair.

Borescopes are available in two basic configurations. The simpler of the two is a rigid type of small diameter telescope with a tiny mirror at the end that enables the user to see around corners. The other type uses fiber optics that enables greater flexibility. Many borescopes provide images that can be displayed on a computer or video monitor for better interpretation of what is being viewed and to record images for future reference. Most borescopes also include a light to illuminate the area being viewed.

LIQUID PENETRANT INSPECTION

Penetrant inspection is a nondestructive test for defects open to the surface in parts made of any nonporous material. It is used with equal success on such metals as aluminum, magnesium, brass, copper, cast iron, stainless steel, and titanium. It may also be used on ceramics, plastics, molded rubber, and glass.

Penetrant inspection will detect such defects as surface cracks or porosity. These defects may be caused by fatigue cracks, shrinkage cracks, shrinkage porosity, cold shuts, grinding and heat treat cracks, seams, forging laps, and bursts. Penetrant inspection will also indicate a lack of bond between joined metals.

The main disadvantage of penetrant inspection is that the defect must be open to the surface in order to let the penetrant get into the defect. For this reason, if the part in question is made of material which is magnetic, the use of magnetic particle inspection is generally recommended. Penetrant inspection uses a penetrating liquid that enters a surface opening and remains there, making it clearly visible to the inspector. It calls for visual examination of the part after it has been processed, increasing the visibility of the defect so that it can be detected.

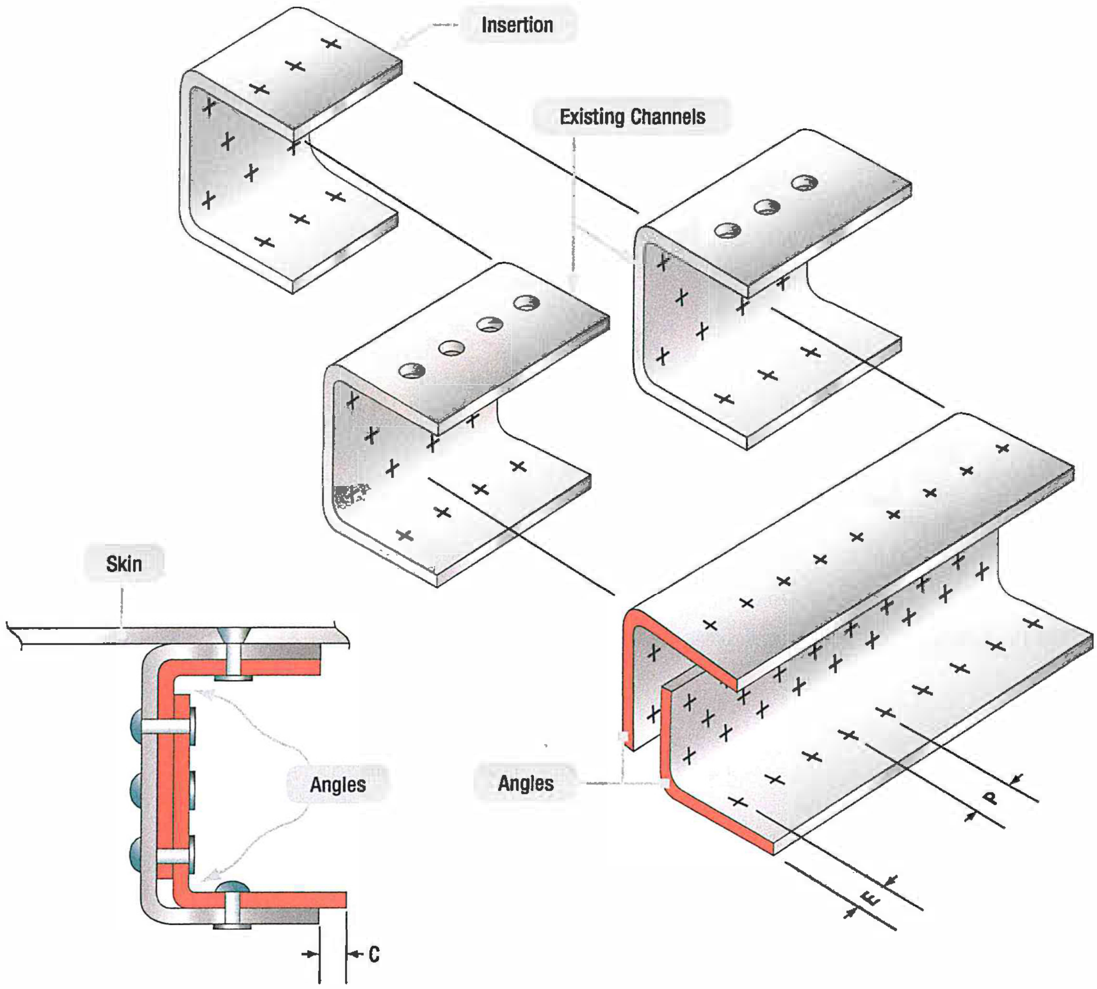


Figure 18-35. C-channel repair.

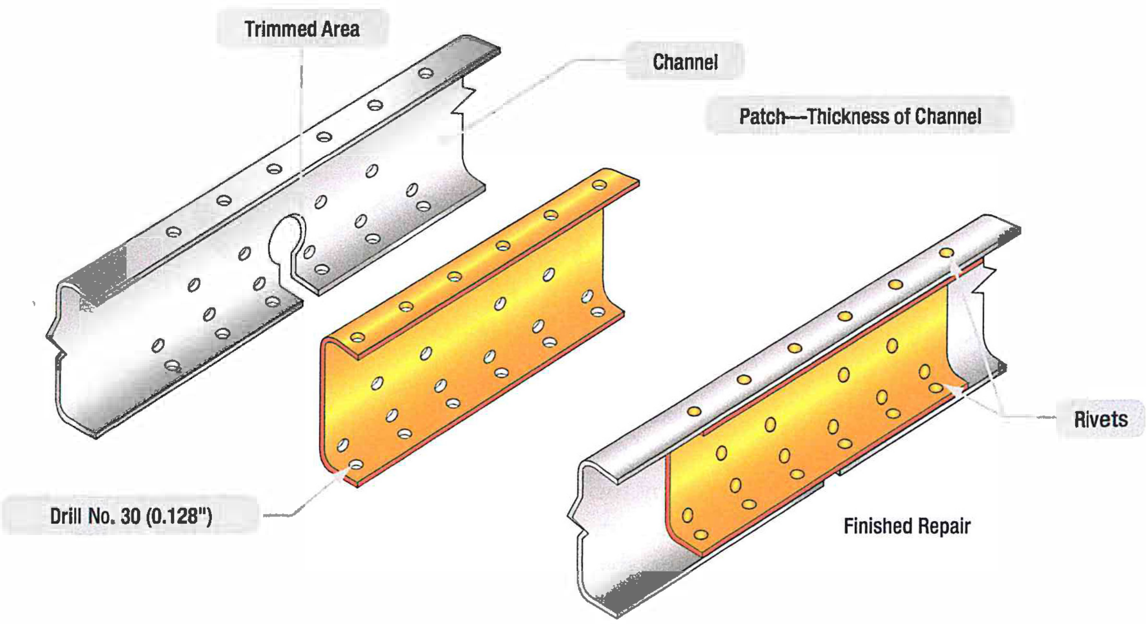


Figure 18-36. Channel repair by patching.

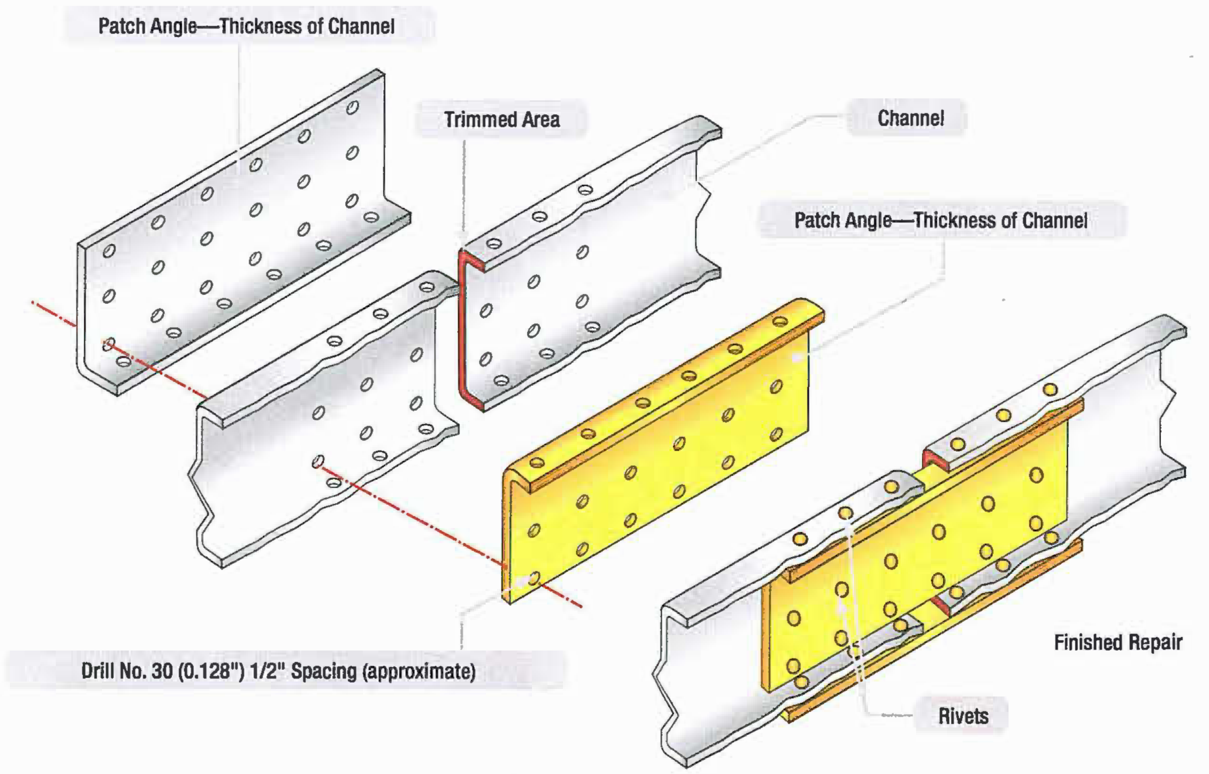


Figure 18-37. Channel repair by insertion.

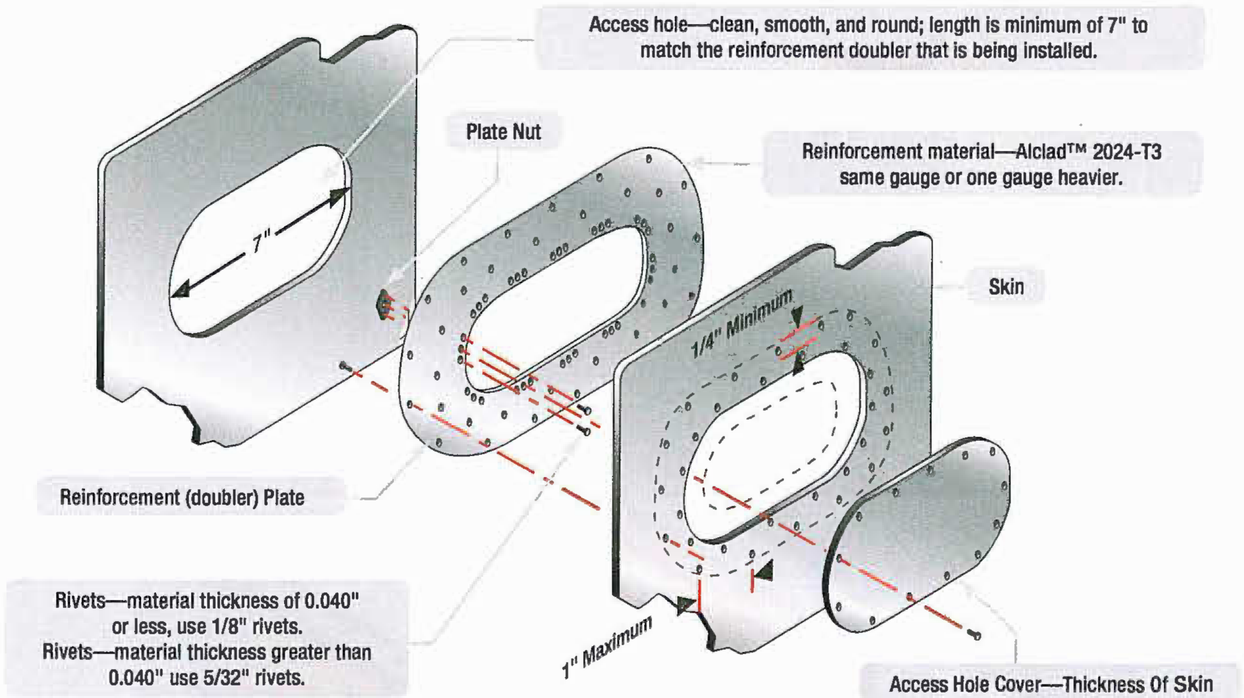


Figure 18-38. Inspection hole.

Visibility of the penetrating material is increased by the addition of one of two types of dye, visible or fluorescent. The visible penetrant kit consists of dye penetrant, dye remover emulsifier, and developer. The fluorescent penetrant inspection kit contains a black light assembly, as well as spray cans of penetrant, cleaner, and developer. The light assembly consists of a power transformer, a flexible power cable, and a hand-held lamp. Due to its size, the lamp may be used in almost any position or location.

Steps for performing a penetrant inspection are:

1. Thorough cleaning of the metal surface.
2. Applying penetrant.
3. Removing penetrant with emulsifier or cleaner.
4. Drying the part.
5. Applying the developer.
6. Inspecting and interpreting results.

INTERPRETATION OF RESULTS

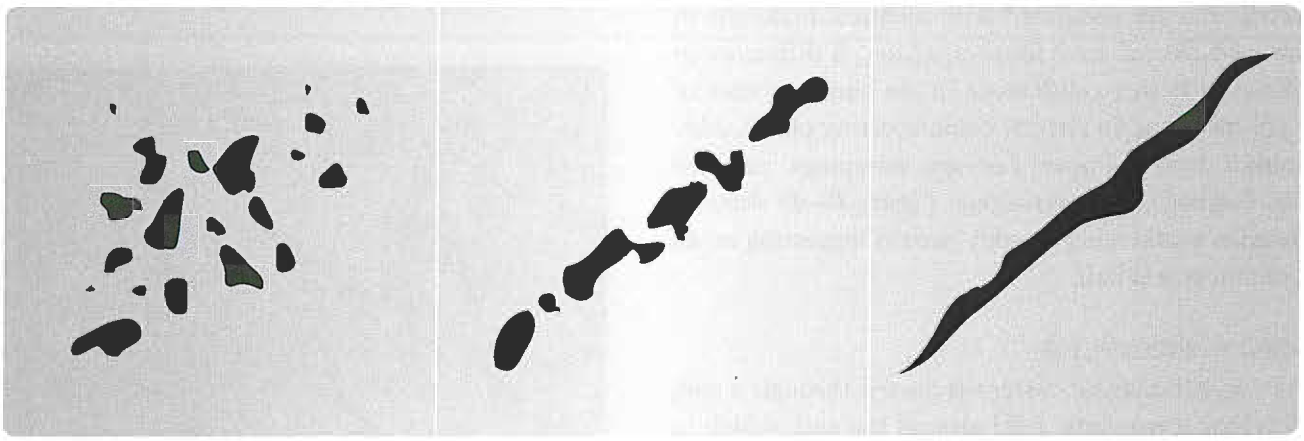
The success and reliability of a penetrant inspection depends upon the thoroughness with which the part was prepared. Basic principles applying to penetrant inspection are:

1. The penetrant must enter the defect in order to form an indication. It is important to allow sufficient time so the penetrant can fill the defect. The defect must be clean and free of contaminating materials so that the penetrant is free to enter.
2. If all penetrant is washed out of a defect, an indication cannot be formed. During the washing or rinsing operation, prior to development, it is possible that the penetrant will be removed from within the defect, as well as from the surface.
3. Clean cracks are usually easy to detect. Surface openings that are uncontaminated, regardless of how fine, are seldom difficult to detect with the penetrant inspection.
4. The smaller the defect, the longer the penetrating time. Fine crack-like apertures require a longer penetrating time than defects such as pores.
5. When the part to be inspected is made of a material susceptible to magnetism, it should be inspected by a magnetic particle inspection method if the equipment is available.
6. Visible penetrant-type developer, when applied to the surface of a part, will dry to a smooth, even, white coating. As the developer dries, bright red indications will appear where there are surface defects. If no red indications appear, there are no surface defects.
7. When conducting the fluorescent penetrant-type inspection, the defects will show up (under black light) as a brilliant yellow-green color and the sound areas will appear deep blue-violet.
8. It is possible to examine an indication of a defect and to determine its cause as well as its extent. Such an appraisal can be made if something is known about the manufacturing processes to which the part has been subjected.

The size of the indication, or accumulation of penetrant, will show the extent of the defect and the brilliance will be a measure of its depth. Deep cracks will hold more penetrant and will be broader and more brilliant. Very fine openings can hold only small amounts of penetrants and will appear as fine lines. ***Figure 18-39*** shows some of the types of defects that can be located using dry penetrant.

FALSE INDICATIONS

With the penetrant inspection, there are no false indications in the sense that they occur in the magnetic particle inspection. There are, however, two conditions which may create accumulations of penetrant that are sometimes confused with true surface cracks and discontinuities.



Pits of Porosity — Tight Crack or Partially Welded Lap — Crack or Similar Opening

Figure 18-39. Types of defects.

The first condition involves indications caused by poor washing. If all the surface penetrant is not removed in the washing or rinsing operation following the penetrant dwell time, the unremoved penetrant will be visible. Evidences of incomplete washing are usually easy to identify since the penetrant is in broad areas rather than in the sharp patterns found with true indications. When accumulations of unwashed penetrant are found on a part, the part should be completely reprocessed. Degreasing is recommended for removal of all traces of the penetrant.

False indications may also be created where parts press fit to each other. If a wheel is press fit onto a shaft, penetrant will show an indication at the fit line. This is perfectly normal since the two parts are not meant to be welded together. Indications of this type are easy to identify since they are regular in form and shape.

EDDY CURRENT INSPECTION

Electromagnetic analysis is a term which describes the broad spectrum of electronic test methods involving the intersection of magnetic fields and circulatory currents. The most widely used technique is the eddy current. Eddy currents are composed of free electrons under the influence of an induced electromagnetic field which are made to "drift" through metal. Eddy current is used in aircraft maintenance to inspect jet engine turbine shafts and vanes, wing skins, wheels, bolt holes, and spark plug bores for cracks, heat or frame damage. Eddy current may also be used in repair of aluminum aircraft damaged by fire or excessive heat.

Different meter readings will be seen when the same metal is in different hardness states. Readings in the affected area are compared with identical materials in known unaffected areas for comparison. A difference in readings indicates a difference in the hardness state of the affected area. In aircraft manufacturing plants, eddy current is used to inspect castings, stampings, machine parts, forgings, and extrusions. ***Figure 18-40*** shows a technician performing an eddy current inspection on an aluminum wheel half.

BASIC PRINCIPLES

When an alternating current is passed through a coil, it develops a magnetic field around the coil, which in turn induces a voltage of opposite polarity in the coil and opposes the flow of original current. If this coil is placed in such a way that the magnetic field passes through an electrically conducting specimen, eddy currents will be induced into the specimen. The eddy currents create their own field which varies the original field's opposition to the flow of original current. The specimen's susceptibility to eddy currents determines the current flow through the coil. (***Figure 18-41***)

The magnitude and phase of this counter field is dependent primarily upon the resistance and permeability of the specimen under consideration, and which enables us to make a qualitative determination of various physical properties of the test material. The interaction of the eddy current field with the original field results in a power change that can be measured by utilizing electronic circuitry similar to a Wheatstone bridge.

The specimen is either placed in or passed through the field of an electromagnetic induction coil, and its effect on the impedance of the coil or on the voltage output of one or more test coils is observed. The process, which involves electric fields made to explore a test piece for various conditions, involves the transmission of energy through the specimen much like the transmission of x-rays, heat, or ultrasound.

Eddy current inspection can frequently be performed without removing the surface coatings such as primer, paint, and anodized films. It can be effective in detecting surface and subsurface corrosion, pits and heat treat condition.

Figure 18-40. Eddy current inspection of wheel half.

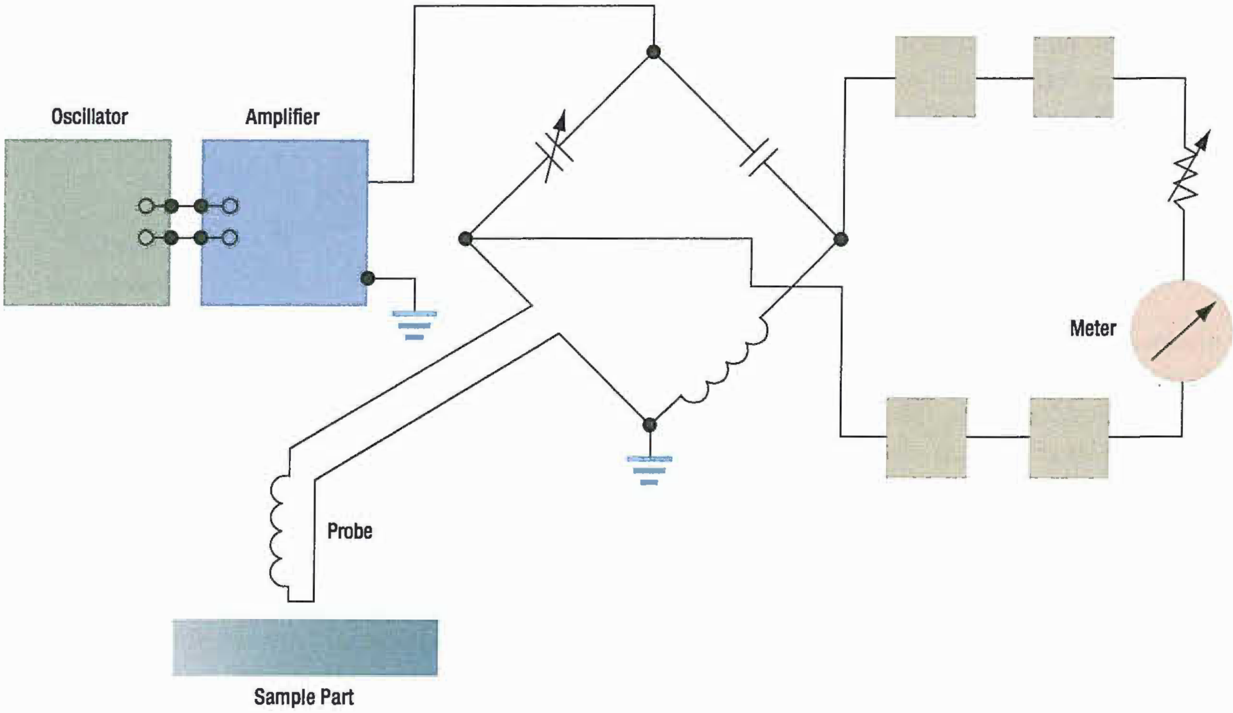


Figure 18-41. Eddy current inspection circuit.

ULTRASONIC INSPECTION

Ultrasonic detection equipment makes it possible to locate defects in all types of materials. Minute cracks, checks, and voids too small to be seen by x-ray can be located by ultrasonic inspection. An ultrasonic test instrument requires access to only one surface of the material to be inspected and can be used with either straight line or angle beam testing techniques.

Two basic methods are used for ultrasonic inspection. The first of these methods is immersion testing. In this method of inspection, the part under examination and the search unit are totally immersed in a liquid couplant, which may be water or any other suitable fluid.

The second method is called contact testing, which is readily adapted to field use and is the method discussed in this chapter. In this method, the part under examination and the search unit are coupled with a viscous material, liquid or a paste, which wets both the face of the search unit and the material under examination. There are three basic ultrasonic inspection methods: (1) pulse echo; (2) through transmission; and (3) resonance.

PULSE ECHO

Flaws are detected by measuring the amplitude of signals reflected and the time required for these signals to travel between specific surfaces and the discontinuity. (*Figure 18-42*)

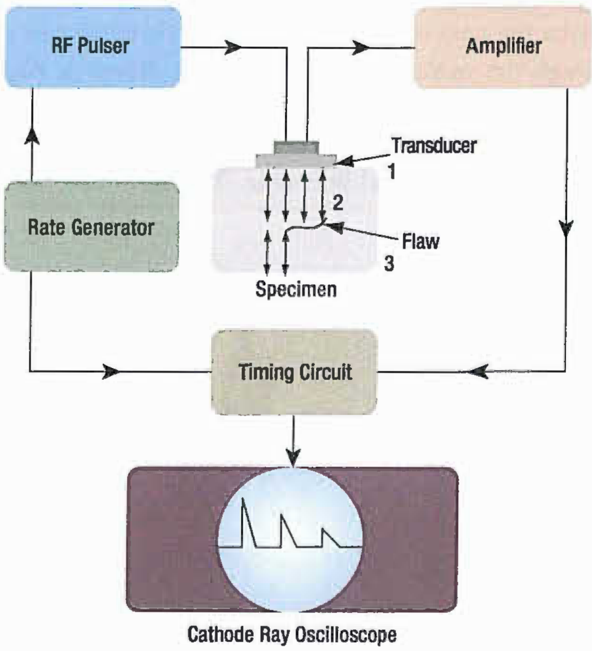


Figure 18-42. Block diagram of basic pulse-echo system.

The time base, which is triggered simultaneously with each transmission pulse, causes a spot to sweep across the screen of the cathode ray tube (CRT). The spot sweeps from left to right across the face of the scope 50 to 5 000 times per second, or higher if required for high speed automated scanning. Due to the speed of the cycle of transmitting and receiving, the picture on the oscilloscope appears to be stationary.

A few microseconds after the sweep is initiated, the rate generator electrically excites the pulser, and the pulser in turn emits an electrical pulse. The transducer converts this pulse into a short train of ultrasonic sound waves. If the interfaces of the transducer and the specimen are properly oriented, the ultrasound will be reflected back to the transducer when it reaches the internal flaw and the opposite surface of the specimen. The time interval between the transmission of the initial impulse and the reception of the signals from within the specimen are measured by the timing circuits. The reflected pulse received by the transducer is amplified, then transmitted to and displayed on the instrument screen. The pulse is displayed in the same relationship to the front and back pulses as the flaw is in relation to the front and back surfaces of the specimen. (***Figure 18-43***)

Pulse-echo instruments may also be used to detect flaws not directly underneath the probe by use of the angle beam testing method.

Angle beam testing differs from straight beam testing only in the manner in which the ultrasonic waves pass through the material being tested. As shown in ***Figure 18-44***, the beam is projected into the material at an acute angle to the surface by means of a crystal cut at an angle and mounted in plastic. The beam or a portion

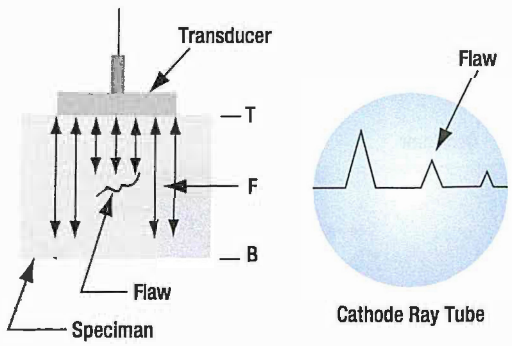


Figure 18-43. Block diagram of basic pulse-echo system.

thereof reflects successively from the surfaces of the material or any other discontinuity, including the edge of the piece. In straight beam testing, the horizontal distance on the screen between the initial pulse and the first back reflection represents the thickness of the piece; while in angle beam testing, this distance represents the width of the material between the searching unit and the opposite edge of the piece.

THROUGH TRANSMISSION

Through transmission inspection uses two transducers, one to generate the pulse and another placed on the opposite surface to receive it. A disruption in the sound path will indicate a flaw and be displayed on the instrument screen. Through transmission is less sensitive to small defects than the pulse-echo method.

RESONANCE

This system differs from the pulse method in that the frequency of transmission may be continuously varied. The resonance method is used principally for thickness measurements when the two sides of the material being tested are smooth and parallel and the backside is inaccessible.

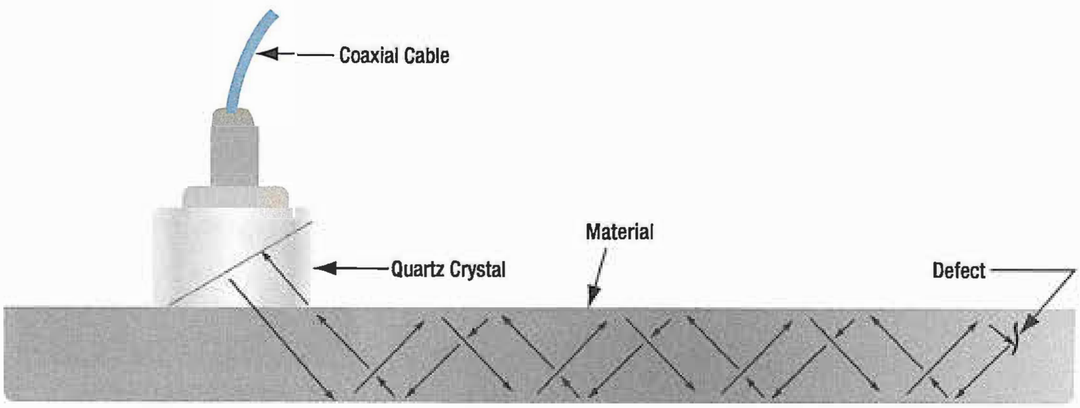


Figure 18-44. Pulse-echo angle beam testing.

The point at which the frequency matches the resonance point of the material being tested is the thickness determining factor.

It is necessary that the frequency of the ultrasonic waves corresponding to a particular dial setting be accurately known. Checks should be made with standard test blocks to guard against possible drift of frequency.

If the frequency of an ultrasonic wave is such that its wavelength is twice the thickness of a specimen (fundamental frequency), then the reflected wave will arrive back at the transducer in the same phase as the original transmission so that strengthening of the signal will occur. This results from constructive interference or a resonance and is shown as a high amplitude value on the indicating screen. If the frequency is increased such that three times the wavelength equals four times the thickness, the reflected signal will return completely out of phase with the transmitted signal and cancellation will occur. Further increase of the frequency causes the wavelength to be equal to the thickness again and gives a reflected signal in phase with the transmitted signal and a resonance once more.

By starting at the fundamental frequency and gradually increasing the frequency, the successive cancellations and resonances can be noted and the readings used to check the fundamental frequency reading. (*Figure 18-45*)

In some instruments, the oscillator circuit contains a motor driven capacitor which changes the frequency of the oscillator. (*Figure 18-46*) In other instruments, the frequency is changed by electronic means. The change in frequency is synchronized with the horizontal sweep of a CRT. The horizontal axis thus represents a frequency range. If the frequency range contains resonances, the circuitry is arranged to present these vertically. Calibrated transparent scales are then placed in front of the tube, and the thickness can be read directly. The instruments normally operate between 0.25 millicycle (mc) and 10 mc in four or five bands.

The resonance thickness instrument can be used to test the thickness of such metals as steel, cast iron, brass, nickel, copper, silver, lead, aluminum, and magnesium. In addition, areas of corrosion or wear on tanks, tubing, airplane wing skins, and other structures or products can be located and evaluated.

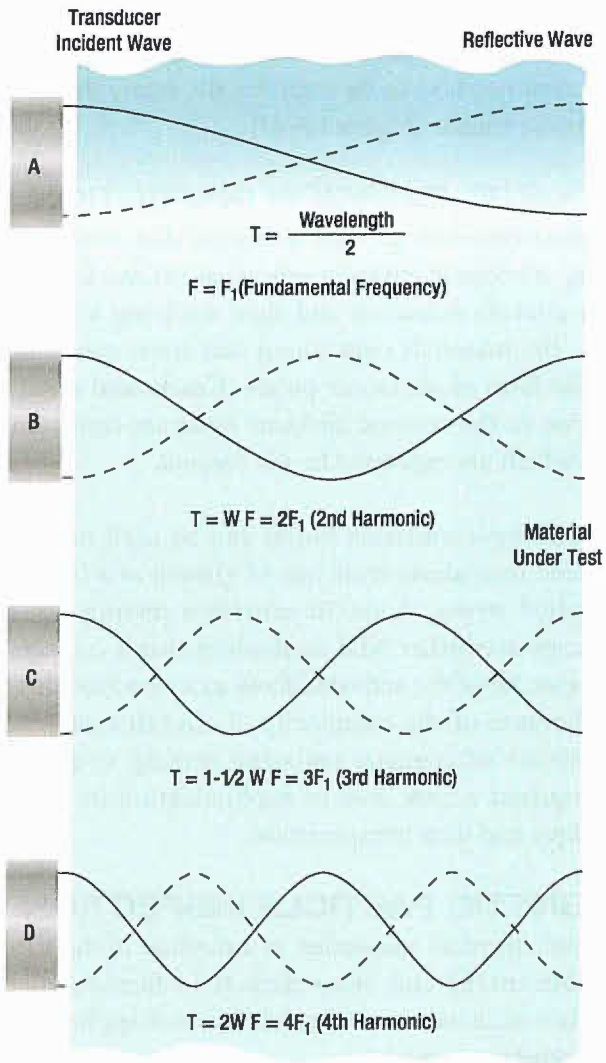


Figure 18-45. Conditions of ultrasonic resonance in a metal plate.

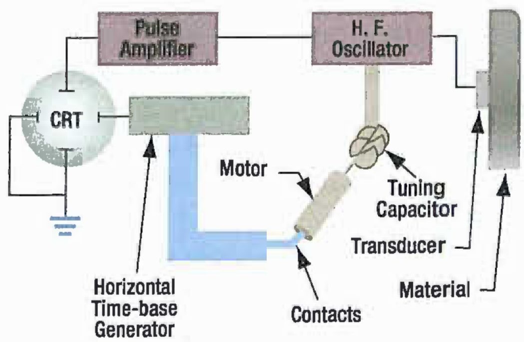


Figure 18-46. Block diagram of resonance thickness measuring system.

Direct reading dial-operated units are available that measure thickness between 0.025 inch and 3 inches with an accuracy of better than ±1 percent.

Ultrasonic inspection requires a skilled operator who is familiar with the equipment being used as well as the inspection method to be used for the many different parts being tested. (***Figure 18-47***)

ACOUSTIC EMISSION INSPECTION

Acoustic emission is an NDI technique that involves the placing of acoustic emission sensors at various locations on an aircraft structure and then applying a load or stress. The materials emit sound and stress waves that take the form of ultrasonic pulses. Cracks and areas of corrosion in the stressed airframe structure emit sound waves which are registered by the sensors.

These acoustic emission bursts can be used to locate flaws and to evaluate their rate of growth as a function of applied stress. Acoustic emission testing has an advantage over other NDI methods in that it can detect and locate all of the activated flaws in a structure in one test. Because of the complexity of aircraft structures, application of acoustic emission testing to aircraft has required a new level of sophistication in testing technique and data interpretation.

MAGNETIC PARTICLE INSPECTION

Magnetic particle inspection is a method of detecting invisible cracks and other defects in ferromagnetic materials such as iron and steel. It is not applicable to nonmagnetic materials.

In rapidly rotating, reciprocating, vibrating, and other highly stressed aircraft parts, small defects often develop to the point that they cause complete failure of the part. Magnetic particle inspection has proven extremely reliable for the rapid detection of such defects located on or near the surface. With this method of inspection, the location of the defect is indicated and the approximate size and shape are outlined.

The inspection process consists of magnetizing the part and then applying ferromagnetic particles to the surface area to be inspected. The ferromagnetic particles (indicating medium) may be held in suspension in a liquid that is flushed over the part; the part may be immersed in the suspension liquid; or the particles, in dry powder form, may be dusted over the surface of the part. The wet process is more commonly used in the inspection of aircraft parts.

Figure 18-47. Block diagram of basic pulse-echo system.

If a discontinuity is present, the magnetic lines of force will be disturbed and opposite poles will exist on either side of the discontinuity. The magnetized particles thus form a pattern in the magnetic field between the opposite poles. This pattern, known as an "indication," assumes the approximate shape of the surface projection of the discontinuity. A discontinuity may be defined as an interruption in the normal physical structure or configuration of a part, such as a crack, forging lap, seam, inclusion, porosity, and the like. A discontinuity may or may not affect the usefulness of a part.

DEVELOPMENT OF INDICATIONS

When a discontinuity in a magnetized material is open to the surface, and a magnetic substance (indicating medium) is available on the surface, the flux leakage at the discontinuity tends to form the indicating medium into a path of higher permeability. (Permeability is a term used to refer to the ease with which a magnetic flux can be established in a given magnetic circuit.) Because of the magnetism in the part and the adherence of the magnetic particles to each other, the indication remains on the surface of the part in the form of an approximate outline of the discontinuity that is immediately below it.

The same action takes place when the discontinuity is not open to the surface, but since the amount of flux leakage is less, fewer particles are held in place and a fainter and less sharply defined indication is obtained.

If the discontinuity is very far below the surface, there may be no flux leakage and no indication on the surface. The flux leakage at a transverse discontinuity is shown in ***Figure 18-48***.

The flux leakage at a longitudinal discontinuity is shown in ***Figure 18-49***.

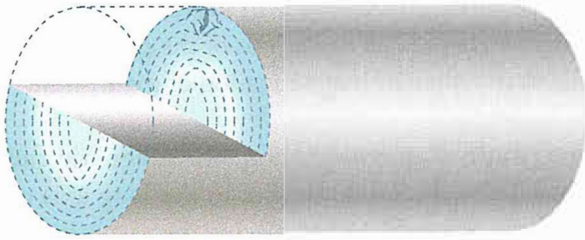


Figure 18-48. Flux leakage at transverse discontinuity.

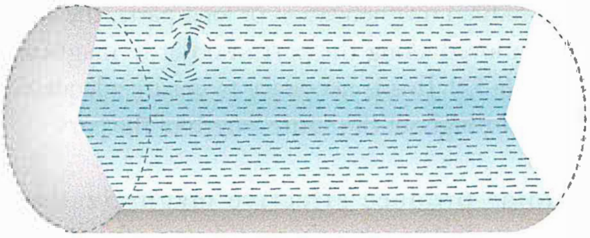


Figure 18-49. Flux leakage at longitudinal discontinuity.

TYPES OF DISCONTINUITIES DISCLOSED

The following types of discontinuities are normally detected by the magnetic particle test: cracks, laps, seams, cold shuts, inclusions, splits, tears, pipes, and voids. All of these may affect the reliability of parts in service.

Cracks, splits, bursts, tears, seams, voids, and pipes are formed by an actual parting or rupture of the solid metal. Cold shuts and laps are folds that have been formed in the metal, interrupting its continuity.

Inclusions are foreign material formed by impurities in the metal during the metal processing stages. They may consist, for example, of bits of furnace lining picked up during the melting of the basic metal or of other foreign constituents. Inclusions interrupt the continuity of the metal because they prevent the joining or welding of adjacent faces of the metal.

PREPARATION OF PARTS FOR TESTING

Grease, oil, and dirt must be cleaned from all parts before they are tested. Cleaning is very important since any grease or other foreign material present can produce non-relevant indications due to magnetic particles adhering to the foreign material as the suspension drains from the part.

Grease or foreign material in sufficient amount over a discontinuity may also prevent the formation of a pattern at the discontinuity. It is not advisable to depend upon the magnetic particle suspension to clean the part. Cleaning by suspension is not thorough and any foreign materials so removed from the part will contaminate the suspension, thereby reducing its effectiveness.

In the dry procedure, thorough cleaning is absolutely necessary. Grease or other foreign material will hold the magnetic powder, resulting in non-relevant indications and making it impossible to distribute the indicating medium evenly over the part's surface.

All small openings and oil holes leading to internal passages or cavities should be plugged with paraffin or other suitable nonabrasive material. Coatings of cadmium, copper, tin, and zinc do not interfere with the satisfactory performance of magnetic particle inspection, unless the coatings are unusually heavy or the discontinuities to be detected are unusually small.

Chromium and nickel plating generally will not interfere with indications of cracks open to the surface of the base metal but will prevent indications of fine discontinuities, such as inclusions. Because it is more strongly magnetic, nickel plating is more effective than chromium plating in preventing the formation of defects.

EFFECT OF FLUX DIRECTION

To locate a defect in a part, it is essential that the magnetic lines of force pass approximately perpendicular to the defect. It is therefore necessary to induce magnetic flux in more than one direction since defects are likely to exist at any angle to the major axis of the part. This requires two separate magnetizing operations, referred to as circular magnetization and longitudinal magnetization. The effect of flux direction is illustrated in ***Figure 18-50***.

Circular magnetization is the induction of a magnetic field consisting of concentric circles of force about and within the part which is achieved by passing electric current through the part.

This type of magnetization will locate defects running approximately parallel to the axis of the part. ***Figure 18-51*** illustrates circular magnetization of a camshaft.

In longitudinal magnetization, the magnetic field is produced in a direction parallel to the long axis of the part. This is accomplished by placing the part in a solenoid excited by electric current. The metal part then becomes the core of an electromagnet and is magnetized by induction from the magnetic field created in the solenoid. In longitudinal magnetization of long parts, the solenoid must be moved along the part in order to magnetize it. (***Figure 18-52***) This is necessary to ensure adequate field strength throughout the entire length of the part.

Solenoids produce effective magnetization for approximately 12 inches from each end of the coil, thus accommodating parts or sections approximately 30 inches in length. Longitudinal magnetization equivalent to that obtained by a solenoid may be accomplished by wrapping a flexible electrical conductor around the part. Although this method is not as convenient, it has an advantage in that the coils conform more closely to the shape of the part, producing a somewhat more uniform magnetization.

The flexible coil method is also useful for large or irregularly shaped parts for which standard solenoids are not available.

EFFECT OF FLUX DENSITY

The effectiveness of the magnetic particle inspection also depends on the flux density or field strength at the surface of the part when the indicating medium is applied. As the flux density in the part is increased, the sensitivity of the test increases because of the greater flux leakages at discontinuities and the resulting improved formation of magnetic particle patterns.

Excessively high flux densities may form non-relevant indications; for example, patterns of the grain flow in the material. These indications will interfere with the detection of patterns resulting from significant discontinuities. It is therefore necessary to use a field strength high enough to reveal all possible harmful discontinuities but not strong enough to produce confusing non-relevant indications.

MAGNETIZING METHODS

When a part is magnetized, the field strength in the part increases to a maximum for the particular magnetizing force and remains at this maximum as long as the magnetizing force is maintained.

Figure 3-50. Foot-operated squaring shear.

Figure 18-51. Circular magnetization of a crankshaft.

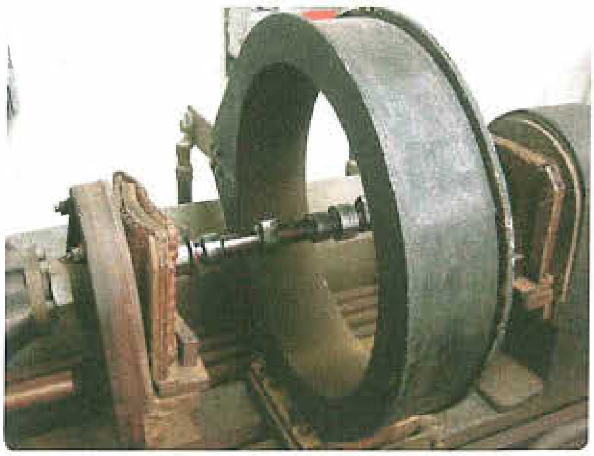


Figure 18-52. Longitudinal magnetization of camshaft (solenoid method).

When the magnetizing force is removed, the field strength decreases to a lower residual value depending on the magnetic properties of the material and the shape of the part. These magnetic characteristics determine whether the continuous or residual method is used in magnetizing the part.

In the continuous inspection method, the part is magnetized and the indicating medium applied while the magnetizing force is maintained. The available flux density in the part is thus at a maximum. The maximum value of flux depends directly upon the magnetizing force and the permeability of the material of which the part is made.

The continuous method may be used in practically all circular and longitudinal magnetization procedures. The continuous procedure provides greater sensitivity than the residual procedure, particularly in locating subsurface discontinuities. The highly critical nature of aircraft parts and assemblies and the necessity for subsurface inspection in many applications have resulted in the continuous method being more widely used. Inasmuch as the continuous procedure will reveal more non-significant discontinuities than the residual procedure, careful and intelligent interpretation and evaluation of discontinuities revealed by this procedure are necessary.

The residual inspection procedure involves magnetization of the part and application of the indicating medium after the magnetizing force has been removed. This procedure relies on the residual or permanent magnetism in the part and is more practical than the continuous procedure when magnetization is accomplished by flexible coils wrapped around the part. In general, the residual procedure is used only with steels which have been heat treated for stressed applications.

IDENTIFICATION OF INDICATIONS

The correct evaluation of the character of indications is extremely important but is sometimes difficult to make from observation of the indications alone. The principal distinguishing features of indications are shape, buildup, width, and sharpness of outline. These characteristics are more valuable in distinguishing between types of discontinuities than in determining their severity. Careful observation of the character of the magnetic particle pattern should always be included in the complete evaluation of the significance of an indicated discontinuity.

The most readily distinguished indications are those produced by cracks open to the surface. These discontinuities include fatigue cracks, heat treat cracks, shrink cracks in welds and castings, and grinding cracks. An example of a fatigue crack is shown in ***Figure 18-53.***

MAGNAGLO INSPECTION

Magnaglo inspection is similar to the preceding method but differs in that a fluorescent particle solution is used and the inspection is made under black light. Efficiency of inspection is increased by the neon-like glow of defects allowing smaller flaw indications to be seen. This is an excellent method for use on gears, threaded parts, and aircraft engine components. The reddish brown liquid spray or bath that is used consists of Magnaglo paste mixed with a light oil at the ratio of 0.10 to 0.25 ounce of paste per gallon of oil. After inspection, the part must be demagnetized and rinsed with a cleaning solvent.

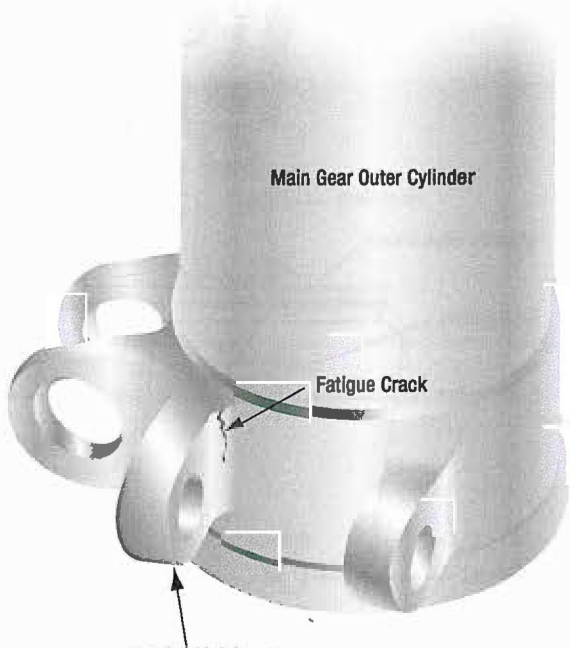


Figure 18-53. Fatigue crack in a landing gear.

MAGNETIZING EQUIPMENT

Fixed (Non-portable) General Purpose Unit

A fixed general purpose unit is shown in ***Figure 18-54.*** This unit provides direct current for wet continuous or residual magnetization procedures. Circular or longitudinal magnetization may be used and it may be powered with rectified alternating current (AC), as well as direct current (DC). The contact heads provide the electrical terminals for circular magnetization. One head is fixed in position with its contact plate mounted on a shaft surrounded by a pressure spring, so that the plate may be moved longitudinally. The plate is maintained in the extended position by the spring until pressure transmitted through the work from the movable head forces it back.

The motor driven movable head slides horizontally in longitudinal guides and is controlled by a switch. The spring allows sufficient overrun of the motor driven head to avoid jamming it and also provides pressure on the ends of the work to ensure good electrical contact.

A plunger operated switch in the fixed head cuts out the forward motion circuit of the movable head motor when the spring has been properly compressed.

In some units the movable head is hand operated, and the contact plate is sometimes arranged for operation by an air ram. Both contact plates are fitted with various fixtures for supporting the work.

The magnetizing circuit is closed by depressing a pushbutton on the front of the unit. It is set to open automatically, usually after about one-half second. The strength of the magnetizing current may be set manually to the desired value by means of the rheostat or increased to the capacity of the unit by the rheostat short circuiting switch. The current utilized is indicated on the ammeter.

Longitudinal magnetization is produced by the solenoid, which moves in the same guide rail as the movable head and is connected in the electrical circuit by means of a switch.

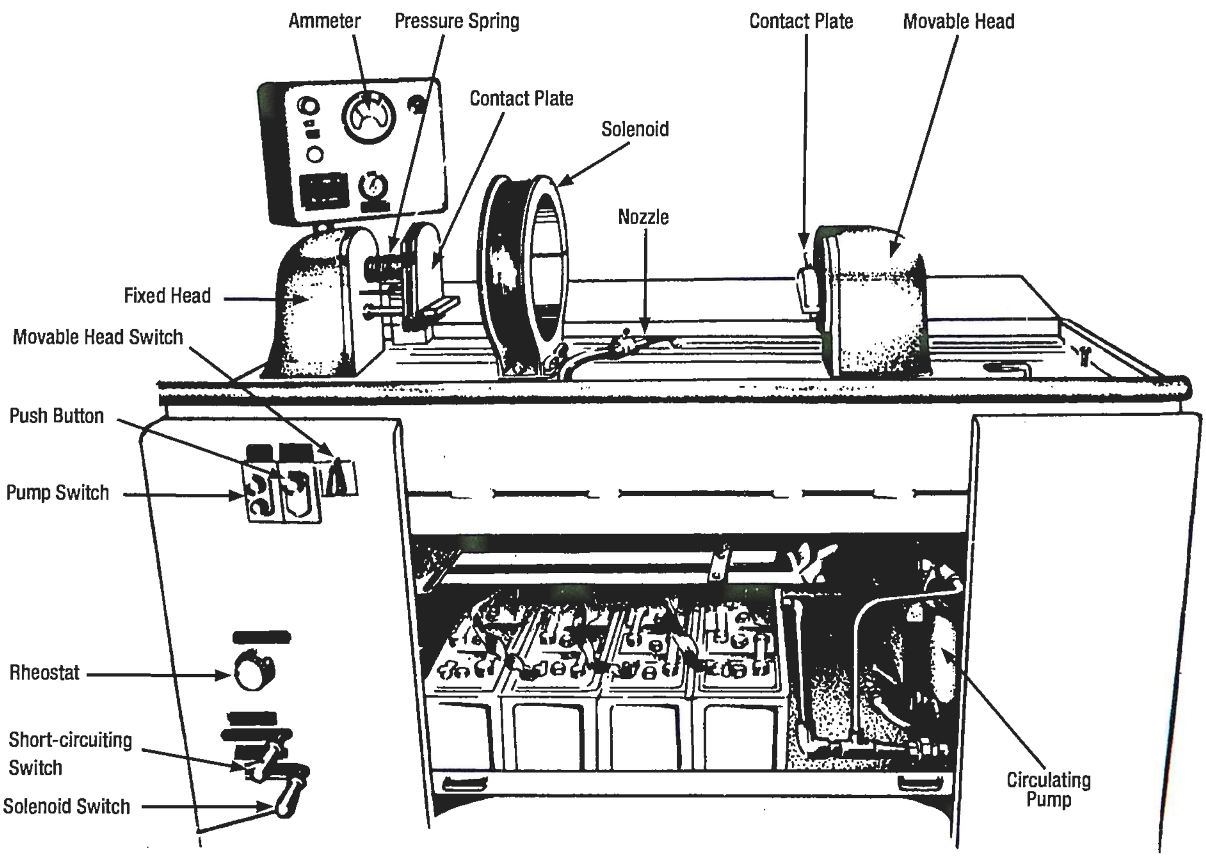


Figure 18-54. Fixed general-purpose magnetizing unit.

The suspension liquid is contained in a sump tank and is agitated and circulated by a pump. The suspension is applied to the work through a nozzle. The suspension drains from the work through a nonmetallic grill into a collecting pan that leads back to the sump. The circulating pump is operated by a pushbutton switch.

Portable General Purpose Unit

It is often necessary to perform the magnetic particle inspection at locations where fixed general purpose equipment is not available or to perform an inspection on members of aircraft structures without removing them from the aircraft.

It is particularly useful for inspecting landing gear and engine mounts suspected of having developed cracks in service. Portable units supply both alternating current and direct current magnetization.

This unit is only a source of magnetizing and demagnetizing current and does not provide a means for supporting the work or applying the suspension. It operates on 200 volt, 60 cycle, alternating current and contains a rectifier for producing direct current when required. (***Figure 18-55***)

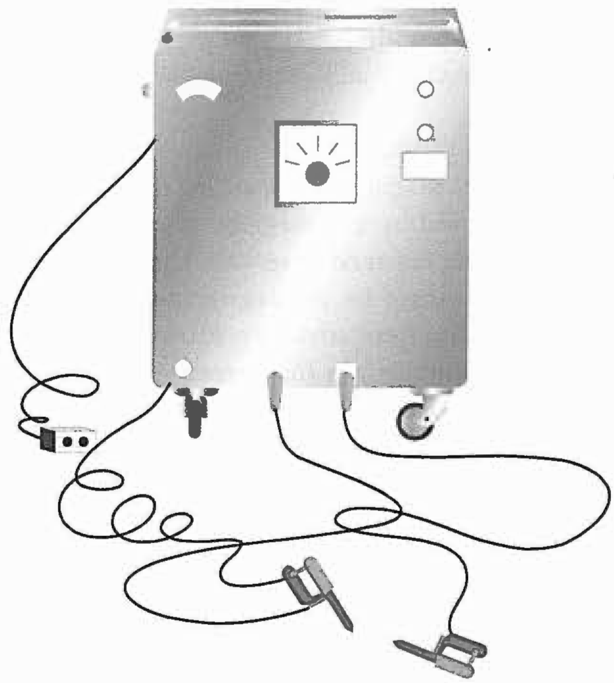


Figure 18-55. Portable general purpose unit.

The magnetizing current is supplied through the flexible cables. The cable terminals may be fitted with prods, as shown in the illustration, or with contact clamps. Circular magnetization may be developed by using either the prods or clamps. Longitudinal magnetization is developed by wrapping the cable around the part.

The strength of the magnetizing current is controlled by an eight point tap switch, and the time duration for which it is applied is regulated by an automatic cutoff similar to that used in the fixed general purpose unit. This portable unit also serves as a demagnetizer and supplies high amperage low voltage alternating current for this purpose. For demagnetization, the alternating current is passed through the part and gradually reduced by means of a current reducer.

In testing large structures with flat surfaces where current must be passed through the part, it is sometimes impossible to use contact clamps. In such cases, contact prods are used. Prods can be used with the fixed general purpose unit as well as the portable unit. The part or assembly being tested may be held or secured above the standard unit and the suspension hosed onto the area; excess suspension drains into the tank. The dry procedure may also be used. Prods should be held firmly against the surface being tested.

There is a tendency for a high amperage current to cause burning at contact areas, but with proper care, such burning is usually slight. For applications where prod magnetization is acceptable, slight burning is normally acceptable.

INDICATING MEDIUMS

The various types of indicating mediums available for magnetic particle inspection may be divided into two general material types: wet and dry. The basic requirement for any indicating medium is that it produce acceptable indications of discontinuities in parts.

The contrast provided by a particular indicating medium on the background or part surface is particularly important. The colors most extensively used are black and red for the wet procedure and black, red, and gray for the dry procedure.

For acceptable operation, the indicating medium must be of high permeability and low retentivity. High permeability ensures that a minimum of magnetic energy will be required to attract the material to flux leakage caused by discontinuities.

Low retentivity ensures that the mobility of the magnetic particles will not be hindered by the particles themselves becoming magnetized and attracting one another.

DEMAGNETIZING

The permanent magnetism remaining after inspection must be removed by a demagnetization operation if the part is to be returned to service. Parts of operating mechanisms must be demagnetized to prevent magnetized parts from attracting filings, grindings, or chips inadvertently left in the system, or steel particles resulting from operational wear. An accumulation of such particles on a magnetized part may cause scoring of bearings or other working parts. Parts of the airframe must be demagnetized so they will not affect instruments.

Demagnetization between successive magnetizing operations is not normally required unless experience indicates that omission of this operation results in decreased effectiveness for a particular application. Demagnetization may be accomplished in a number of different ways. A convenient procedure for aircraft parts involves subjecting the part to a magnetizing force that is continually reversing in direction and, at the same time, gradually decreasing in strength. As the decreasing magnetizing force is applied first in one direction and then the other, the magnetization of the part also decreases.

STANDARD DEMAGNETIZING PRACTICE

The simplest procedure for developing a reversing and gradually decreasing magnetizing force in a part involves the use of a solenoid coil energized by alternating current. As the part is moved away from the alternating field of the solenoid, the magnetism in the part gradually decreases. A demagnetizer whose size approximates that of the work should be used. For maximum effectiveness, small parts should be held as close to the inner wall of the coil as possible.

Parts that do not readily lose their magnetism should be passed slowly in and out of the demagnetizer several times and, at the same time, tumbled or rotated in various directions. Allowing a part to remain in the demagnetizer with the current on accomplishes very little practical demagnetization. The effective operation in the demagnetizing procedure is that of slowly moving the part out of the coil and away from the magnetizing field strength. As the part is withdrawn, it should be kept directly opposite the opening until it is 1 or 2 feet from the demagnetizer.

The demagnetizing current should not be cut off until the part is 1 or 2 feet from the opening as the part may be remagnetized if current is removed too soon. Another procedure used with portable units is to pass alternating current through the part being demagnetized, while gradually reducing the current to zero.

RADIOGRAPHIC

X and gamma radiations, because of their unique ability to penetrate material and disclose discontinuities, have been applied to the radiographic (x-ray) inspection of metal fabrications and nonmetallic products.

The penetrating radiation is projected through the part to be inspected and produces an invisible or latent image in the film. When processed, the film becomes a radiograph or shadow picture of the object. This inspection medium and portable unit provides a fast and reliable means for checking the integrity of airframe structures and engines. (***Figure 18-56***)

RADIOGRAPHIC INSPECTION

Radiographic inspection techniques are used to locate defects or flaws in airframe structures or engines with little or no disassembly. This is in marked contrast to other types of nondestructive testing which usually require removal, disassembly, and stripping of paint from the suspected part before it can be inspected. Due to the radiation risks associated with x-ray, extensive training is required to become a qualified radiographer. Only qualified radiographers are allowed to operate the x-ray units.

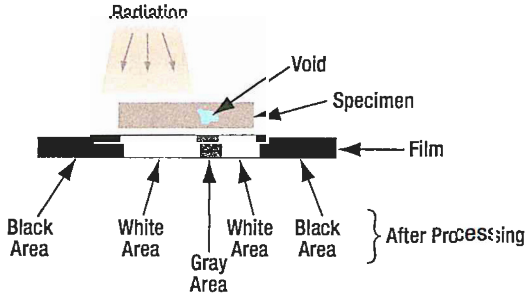


Figure 18-56. Radiograph.

Three major steps in the x-ray process discussed in subsequent paragraphs are: (1) exposure to radiation, including preparation, (2) processing of film, and (3) interpretation of the radiograph.

Preparation and Exposure

The factors of radiographic exposure are so interdependent that it is necessary to consider all factors for any particular radiographic exposure. These factors include but are not limited to the following:

- Material thickness and density
- Shape and size of the object
- Type of defect to be detected
- Characteristics of x-ray machine used
- The exposure distance
- The exposure angle
- Film characteristics
- Types of intensifying screen, if used.

Knowledge of the x-ray unit's capabilities should form a background for the other exposure factors. In addition to the unit rating in kilo-voltage, the size, portability, ease of manipulation, and exposure particulars of the available equipment should be thoroughly understood. Previous experience on similar objects is also very helpful in the determination of the overall exposure techniques. A log or record of previous exposures will provide specific data as a guide for future radiographs.

Film Processing

After exposure to x-rays, the latent image on the film is made permanently visible by processing it successively through a developer chemical solution, an acid bath, and a fixing bath, followed by a clear water wash.

Radiographic Interpretation

From the standpoint of quality assurance, radiographic interpretation is the most important phase of radiography. It is during this phase that an error in judgment can produce disastrous consequences. The efforts of the whole radiographic process are centered in this phase; the part or structure is either accepted or rejected. Conditions of unsoundness or other defects which are overlooked, not understood, or improperly interpreted can destroy the purpose and efforts of radiography and can jeopardize the structural integrity of an entire aircraft. A particular danger is the false sense of security imparted by the acceptance of a part or structure based on improper interpretation.

As a first impression, radiographic interpretation may seem simple, but a closer analysis of the problem soon dispels this impression. The subject of interpretation is so varied and complex that it cannot be covered adequately in this type of document. Instead, this chapter gives only a brief review of basic requirements for radiographic interpretation, including some descriptions of common defects.

Experience has shown that, whenever possible, radiographic interpretation should be conducted close to the radiographic operation. When viewing radiographs, it is helpful to have access to the material being tested. The radiograph can thus be compared directly with the material being tested, and indications due to such things as surface condition or thickness variations can be immediately determined.

The following paragraphs present several factors which must be considered when analyzing a radiograph. There are three basic categories of flaws: voids, inclusions, and dimensional irregularities. The last category, dimensional irregularities, is not pertinent to these discussions because its prime factor is one of degree, and radiography is not exact. Voids and inclusions may appear on the radiograph in a variety of forms ranging from a two-dimensional plane to a three-dimensional sphere. A crack, tear, or cold shut will most nearly resemble a two-dimensional plane, whereas a cavity will look like a three-dimensional sphere. Other types of flaws, such as shrink, oxide inclusions, porosity, and so forth, will fall somewhere between these two extremes of form.

It is important to analyze the geometry of a flaw, especially for items such as the sharpness of terminal points. For example, in a crack-like flaw the terminal points appear much sharper in a sphere-like flaw, such as a gas cavity. Also, material strength may be adversely affected by flaw shape. A flaw having sharp points could establish a source of localized stress concentration. Spherical flaws affect material strength to a far lesser degree than do sharp pointed flaws. Specifications and reference standards usually stipulate that sharp pointed flaws, such as cracks, cold shuts, and so forth, are cause for rejection.

Material strength is also affected by flaw size. A metallic component of a given area is designed to carry a certain load plus a safety factor. Reducing this area by including a large flaw weakens the part and reduces the safety factor. Some flaws are often permitted in components because of these safety factors; in this case, the interpreter must determine the degree of tolerance or imperfection specified by the design engineer. Both flaw size and flaw shape should be considered carefully, since small flaws with sharp points can be just as bad as large flaws with no sharp points.

Another important consideration in flaw analysis is flaw location. Metallic components are subjected to numerous and varied forces during their effective service life. Generally, the distribution of these forces is not equal in the component or part, and certain critical areas may be rather highly stressed. The interpreter must pay special attention to these areas. Another aspect of flaw location is that certain types of discontinuities close to one another may potentially serve as a source of stress concentrations creating a situation that should be closely scrutinized.

An inclusion is a type of flaw which contains entrapped material. Such flaws may be of greater or lesser density than the item being radiographed. The foregoing discussions on flaw shape, size, and location apply equally to inclusions and to voids. In addition, a flaw containing foreign material could become a source of corrosion.

RADIATION HAZARDS

Radiation from x-ray units and radioisotope sources is destructive to living tissue. It is universally recognized that in the use of such equipment, adequate protection must be provided. Personnel must keep outside the primary x-ray beam at all times. Radiation produces changes in all matter through which it passes. This is also true of living tissue. When radiation strikes the molecules of the body, the effect may be no more than to dislodge a few electrons, but an excess of these changes could cause irreparable harm. When a complex organism is exposed to radiation, the degree of damage, if any, depends on which of its body cells have been changed. Vital organs in the center of the body that are penetrated by radiation are likely to be harmed the most. The skin usually absorbs most of the radiation and reacts earliest to radiation.

If the whole body is exposed to a very large dose of radiation, death could result. In general, the type and severity of the pathological effects of radiation depend on the amount of radiation received at one time and the percentage of the total body exposed. Smaller doses of radiation could cause blood and intestinal disorders in a short period of time. The more delayed effects are leukemia and other cancers. Skin damage and loss of hair are also possible results of exposure to radiation.

DISASSEMBLY AND RE-ASSEMBLY TECHNIQUES

Design engineers not only design the components and systems of an aircraft, they design the assembly and re-assembly of the aircraft and components as well. The aircraft, engine and component manufacturer's maintenance manuals contain the approved methods of disassembly and assembly of the aircraft and its components. The instructions in these manuals must be followed at all times. Occasionally, it will be necessary to contact the manufacturer for a procedure when it does not appear in a manual. This is preferred over "winging it". A great amount of damage can be inflicted by disassembling or re-assembling an aircraft assembly in the wrong manner. The cost of such a mistake can be extremely expensive and may even cost one's job or certification. Thus, a first step is to pull the manufacturer's instructions and have them at the job location to be followed step by step.

The controlled protected environment of the hangar or shop is usually preferred for disassembly of aircraft and aircraft component however a great deal of work can be performed on the ramp if needed. Take steps to control the environment around the work area.

Basic aircraft maintenance hangar etiquette should be followed. A clean well defined area for the work is essential. Cordon off the area if required for safety. Placards should be posted as needed in the hangar. Tags should be placed on the flight deck warning other technicians that work is being done on a certain component or system and it should not be operated. These "Do Not Operate" tags are typically placed on the controls and switches of the system being repaired. Circuit breakers related to the system should also be pulled and tagged. These will be some of the first steps in the instructions given for disassembly of a unit given in the maintenance manual.

Before beginning, ensure all of the tooling, parts and servicing fluids are on hand to complete the job. Tools not part of a technician's hand tool kit may be special tools required by the manufacturer. These will be listed in the maintenance manual. Support structures, access stands, attach fitting, safety locks, etc., must all be available and used. Pneumatic and electric power, if required, must also be extended to the work area. Use of the correct tools and support equipment is required in aircraft maintenance.

In airline maintenance operations, it is standard procedure to remove and replace malfunctioning components. The removed components are then sent to a shop or a certified repair organization to be repaired or overhauled. During major maintenance checks, a large amount of the aircraft may be disassembled and parts stored so that inspection and maintenance can be performed on areas of the aircraft usually not accessible. Parts and panels removed must be labeled and stored in a safe place.

Components that are removed and found to be un-airworthy must also be labeled as such. Maintenance operations typically have preprinted label tags that can be filled out and attached to the part. Information such as part number, serial number, location and reason for removal should be noted on the tag.

When disassembling, removing any component, it is vital that all small items such as bolts, screws, nuts, washers and shims are clearly identified. This involves not only identifying the items by part number, but also recording their correct location and which aircraft they have been removed from as, in some hangars, more than one aircraft may be in a state of disassembly at any time.

Some items may simply be attached to the major assembly using many small 'tie on' bags with identification labels. If a number of different sized fasteners are removed from a component such as a windscreen, they can be located in a locally-made holding jig which keeps the different parts in their same relative position to the original item. This should allow all the screws to be returned to their original locations when the screen is reinstalled. Any part which is removed must have its identity and location retained until it is reinstalled.

REPLACEMENT OF MAJOR COMPONENTS/MODULES

This type of operation will normally be completed at a large maintenance base, where all the required equipment is available. An example could be the replacement of a wing that has suffered major damage.

Other types of similar work might be the replacement of damaged wing tips, empennage surfaces and nose cones. If the aircraft is at an 'outstation' when the damage occurs, confirmation should be sought as to whether the aircraft can be flown back to base for repair, or repaired where it is.

DISASSEMBLY AND RE-ASSEMBLY OF MAJOR COMPONENTS

Most of the work done, during this phase of maintenance, is scheduled in with normal aircraft maintenance. The components may not only be removed and reinstalled at different times during the maintenance, but work will also be done on the items whilst they are removed. They may also be removed to allow access to other parts of the airframe during the maintenance. Items such as engines, propellers, landing gears and wheels require some form of maintenance. This may include a simple condition check, or a full overhaul of its component parts, allowing checks on internal component parts for wear, damage and corrosion.

The full procedure for this type of work will be carried out in accordance with the maintenance manuals. This book will give all the operations required to dismantle the component and will advise what to look for whilst the item is undergoing maintenance.
It will also state the re-assembly method, including the fitting of new parts such as seals, gaskets, oil and other consumables that have to be replaced, during overhaul.

DISASSEMBLY AND RE-ASSEMBLY OF MINOR COMPONENTS

A typical passenger aircraft can contain hundreds of small components that work together as parts of a larger system. This can include a wide range of hydraulic and pneumatic components that can be mechanical, electromechanical or electrical in operation.

Other components might include those installed into fuel, air conditioning, pressurization, electrical and electronic systems. These components have their own maintenance manuals to allow maintenance and trouble-shooting to be done. Some components are only removed once they fail (On-Condition), while others receive regular maintenance.

Instruments, electric and electronic components can be dismantled and serviced by the aircraft operator. It normally requires the use of a dedicated overhaul facility, which can provide the correct environmental conditions equipped with special test equipment required to carry out maintenance and repair.

Operators of smaller aircraft, or those who operate only a few aircraft, will usually send components requiring repair or maintenance to a 'third party' maintenance organization. This company will have the special facilities, equipment and personnel, to complete the required work on components from a number of different customers.

BASIC DISASSEMBLY AND RE-ASSEMBLY TECHNIQUES

All of the previously mentioned procedures require the use of the correct techniques over a wide range of working practices. These techniques will ensure that the components are removed, dismantled, re-assembled and re-installed in accordance with both the relevant manuals and using the correct 'standard practices'.

Maintenance manuals dictate the correct type and size of locking wire or split pin to be used during overhaul or maintenance of a component. These publications also stipulate exact detail of items such as the lock wire angle of approach and the correct positioning of a split pin. Maintenance manual chapters 20 and 70 list the standard practices that should be used during overhaul.

Other locking devices include items such as single tab washers, shake-proof washers, circlips and locking rings. Some can only be used once only whilst others are re-used provided they are still serviceable.

The replacement of spring washers is 'advised' during overhaul and repair, especially on engines and pumps. Other devices used for locking or holding fasteners in position, such as multi-tab washers and locking plates can normally be reused.

Stiff nuts with fiber or nylon inserts can be checked to ascertain if a certain degree of stiffness is still available. If the nut can be run along a thread by hand it should be replaced. They should not be used in high temperature areas. In all matters relating to aircraft, the manufacturer has the final say on which fasteners can be reused and which must be replaced.

Because friction is essential to keep the fasteners secure, sometimes it is necessary to do a 'torque check' on the bolt/nut combination, in order to confirm their continuing serviceability. This is especially true of all metal fasteners that can normally be re-used.
The majority of nuts, bolts and set-screws, on an aircraft, are subject to a standard torque value. This depends on their material, finish, lubrication, thread type and size, although the manufacturer's torque value will be the correct one to use.

The correct torque loadings are normally applied using a torque wrench that has been previously calibrated to the correct value. In some special instances, pre-load indicating washers may be specified.

When assembling any component or major airframe part, the manufacturer will specify whether the torque value is 'lubricated' or 'dry'. Lubricated values are measured with the threads and all mating surfaces lightly lubricated with oil, sealant or anti-seize compound as appropriate.

When assembling some components, it may be vital that certain alignments, dimensions or profiles are achieved. During initial production, most of the airframe and many of the components are assembled in a jig.

A jig is device that allows the manufacture, repair or rigging of components to a high dimensional accuracy. This guarantees consistency over a number of components. The jig holds all of the items securely, so that, when assembled, the whole component is exactly the shape that the designer has stipulated.

Jigs are used to build fuselage and wing sections in the factory. They are also used to ensure that small actuators are pre-set to the exact length, to assist in 'rigging' the controls containing the actuator.

DISCARDING OF PARTS

A number of items, when they are removed from their original position, have to be discarded. The 'once only' policy is a combination of the manufacturer's recommendations together with normal engineering practice. Items that are usually discarded at removal are filters, sealing rings, desiccants, fuels and oils of all types. There are many other items that have a given 'life'. This may be counted in flying hours, calendar time or operating cycles, which will mean that items have to be replaced throughout the life of the aircraft.

If aircraft, or major components of them, have been disassembled, it may be policy to replace components with 'zero life' items prior to re-assembly. This will allow the aircraft to fly for considerable time before any parts become due for replacement.

FREEING SEIZED COMPONENTS

When dismantling any part of an aircraft, it is not unusual for the technician to encounter a seized fastener. Depending upon its location, the maintenance manuals may recommend a range of actions to assist in the removal of the item(s).

These actions may involve use of penetrating oil, which works its way down through the seized threads, providing both an anti-corrosion action and lubrication for the threads. Other actions may involve the application of heat or cold to a specific part, so that their relative diameters change, thus lowering the friction between the parts.

ASSEMBLY

Assembly of aircraft parts and components should only be done while following the manufacturer's instruction. Observe all procedures specified including testing. There are different levels of testing of installations which must be followed before the job can be considered complete. Clean-up after a job is complete and returning the hangar to its original condition is also part of the job.

TROUBLE SHOOTING TECHNIQUES

Most aircraft maintenance manuals have troubleshooting sections, which guide the technician through the logical and best faultfinding diagnosis to ascertain what is wrong. Manuals arrange by ATA spec codes will have trouble shooting procedures and diagrams located in the 500 pages of any given chapter and subsection.

Figure 18-57 shows an example trouble shooting diagram from a Boeing 737 maintenance manual for the air conditioning bleed air system. Follow the instructions in the boxes starting from top. Proceed to the next box according to the outcome of the procedure requested in present box.

If no troubleshooting process is available then a logical approach must be adopted, a typical thought process to arrive at best means of finding the defect in the minimum of time and with the minimum of cost, is as follows:

a. Gather all the information available. The more information you have the quicker a solution will be forthcoming. The sources of information could be the aircraft technical log book, results of carrying out a test such as a ground run, fully understanding how the item/system works is also essential. So time gathering this information is time well spent.
b. Having analyzed this information a strategy can be evolved. This information will give you a starting point and quite often point to the most likely cause of the problem.

For example, you have an aircraft that is suffering from nose-wheel shimmy. Now you could start by changing the nose gear leg and this would probably solve the problem, but hardly the most cost effective in time and money.

A more practical way of solving the problem is a follows:

1. Read the aircraft technical logbook and if possible speak to the pilot. He should be able to tell you when this problem occurs and under what conditions.
2. Check the manual for any troubleshooting charts, and if there is one, apply the information you have gathered, to discover a possible cause.
3. If there is not a troubleshooting chart apply a logical approach and inspect the nose strut for an obvious cause, such as badly worn wheel (especially on twin nose-wheel configuration), are there signs of it recently being lubricated, wear in the torque links, is the shimmy damper secure or damaged and so on.
4. If nothing obvious is found, you will have to start with what you believe to be the most obvious or likely cause of the defect in this scenario the tire being worn or out of shape is the most common cause of this defect. Jack the nose up in accordance with the maintenance manual. Spin the wheel

and watch it go round to see if it is out of shape, also take this opportunity to check for wear in the bearings of the torque links, shimmy damper, steering collar etc.. If again there is nothing obvious, replace the wheel(s) or perhaps lubricate the leg and ask for further report from the pilot as there is no way you can prove you have fixed the problem.

5. If the aircraft returns and there is no wheel shimmy then the problem is resolved. If not you have eliminated the most likely cause and further investigation is required.

This process is followed until the problem is resolved; however, changing the strut is most likely the last item you would change, and not the first. All troubleshooting techniques follow a similar logical pattern.

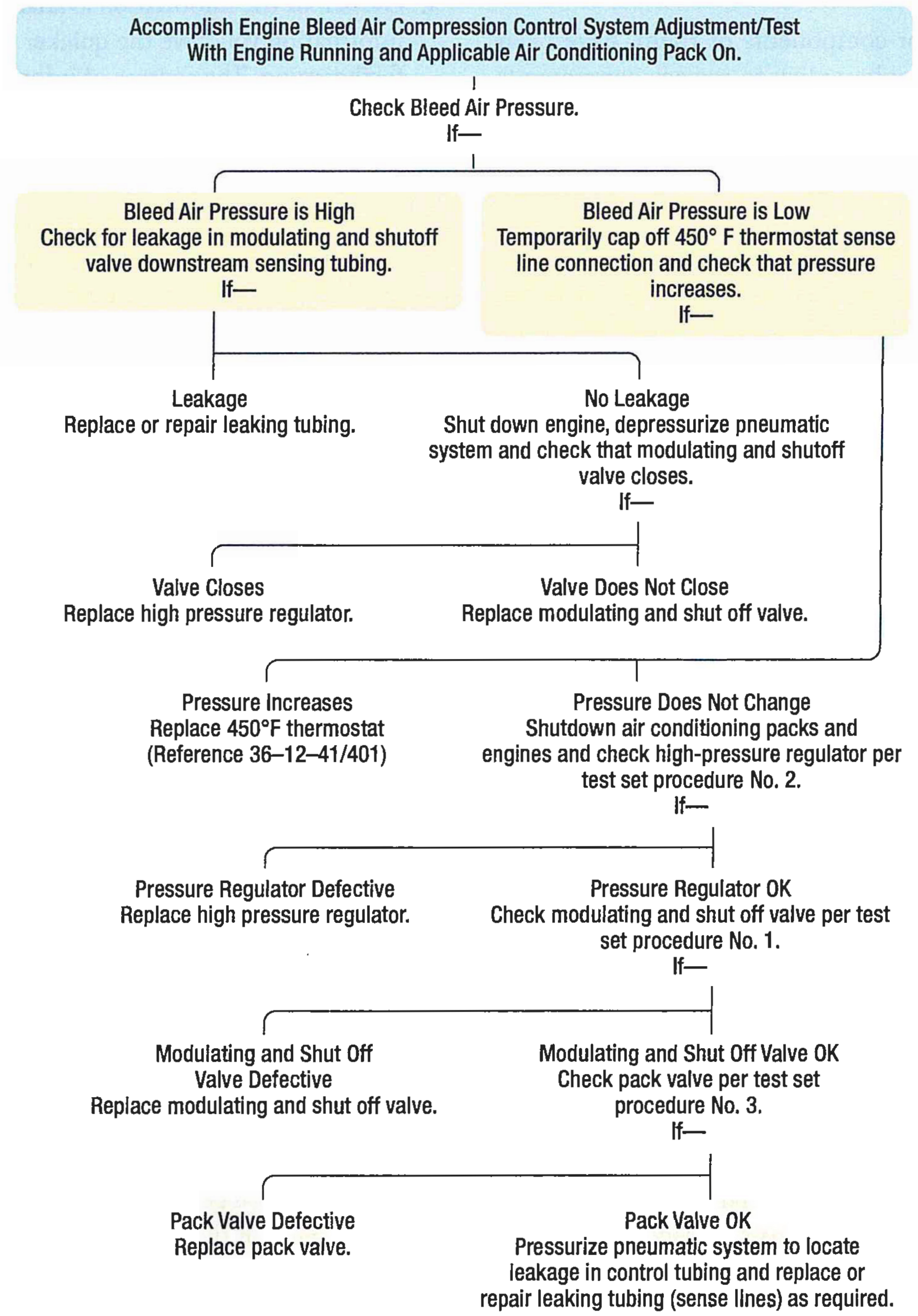


Figure 18-57. A troubleshooting chart for a transport category maintenance manual.

Question: 18-1
Irregular and haphazard inspection will invariably result in ________________ of an aircraft.

Question: 18-2
The manufacturer's ____________________ manual contains complete instructions for maintenance of all systems and components installed in the aircraft.

Question: 18-3
________________ is the slipping of the tire's position on the wheel.

Question: 18-4
The presence of ______________ promotes additional attack by attracting moisture from the air and acting as a catalyst for additional corrosion.

Question: 18-5
Name three forms of aluminum alloy corrosion that are particularly serious.

Question: 18-6
Certain metals are subject to corrosion when placed in contact with other metals. This is commonly referred to as ________________ or ________________ corrosion.

Question: 18-7
________________ is a simple chemical treatment for all aluminum alloys to increase their corrosion resistance and to improve their paint bonding qualities.

Question: 18-8
Four classifications of structural damage are: negligible, damage repairable by patching, damage repairable by insertion and damage necessitating ________________ of parts.

ANSWERS

Answer: 18-1
deterioration.

Answer: 18-2
aircraft.
aircraft maintenance.

Answer: 18-3
Creep.

Answer: 18-4
rust.

Answer: 18-5
Penetrating pit-type corrosion.
Stress corrosion.
Intergranular corrosion.

Answer: 18-6
electrolytic.
dissimilar metals.

Answer: 18-7
Alodizing.

Answer: 18-8
replacement.

Question: 18-9
To prevent severe vibration or __________ of a flight control surface during flight, precautions must be taken to stay within the design balance limitations when performing maintenance or repair.

Question: 18-10
Aircraft skin that is accessible for repair from both sides is called __________ skin.

Question: 18-11
__________________ are cut in rib sections, fuselage frames, and other structural parts to reduce the weight of the part.

Question: 18-12
A __________________ is an oval-shaped members of the fuselage that give form to and maintains the shape of the structure.

Question: 18-13
A __________________ is the main supporting member of the wing.

Question: 18-14
As aircraft age, __________ scrutiny of the structure is required to ensure airworthiness.

Question: 18-15
A __________________ is a device that enables the inspector to see inside areas that could not otherwise be inspected without disassembly.

Question: 18-16
Eddy currents are composed of __________________ under the influence of an induced electromagnetic field which are made to "drift" through metal.

ANSWERS

Answer: 18-9
flutter.

Answer: 18-10
open.

Answer: 18-11
Lightening holes.

Answer: 18-12
bulkhead.

Answer: 18-13
spar.

Answer: 18-14
more.

Answer: 18-15
borescope.

Answer: 18-16
free electrons.

Question: 18-17
Through transmission inspection uses two transducers, one to generate the pulse and another placed on the opposite surface to ________________.

Question: 18-18
Cracks, laps, seams, cold shuts, inclusions, splits, tears, pipes, and voids are discontinuities are normally detected by a ________________ test.

Question: 18-19
A fluorescent particle solution is used and the inspection is made under black light during a ________________ inspection.

Question: 18-20
________________ inspection techniques are used to locate defects or flaws in airframe structures or engines with little or no disassembly.

Question: 18-21
Special tools required by the manufacturer for a particular repair are listed in ________________.

Question: 18-22
Aircraft maintenance manuals arranged by the ATA spec code numbering system have ________________ and diagrams located in the 500 pages of any given chapter and subsection.

ANSWERS

Answer: 18-17
receive it.

Answer: 18-18
magnetic particle.

Answer: 18-19
Magnaglo.

Answer: 18-20
Radiographic.

Answer: 18-21
the maintenance manual.

Answer: 18-22
trouble shooting procedures.

MAINTENANCE PRACTICES

ABNORMAL EVENTS

SUB-MODULE 19

PART-66 SYLLABUS LEVELS

CERTIFICATION CATEGORY →	B1	B2
Sub-Module 19 ABNORMAL EVENTS Knowledge Requirements		
7.19 - Abnormal Events		
(a) Inspections following lightning strikes and HIRF penetration;	2	2
(b) Inspections following abnormal events such as heavy landings and flight through turbulence.	2	-

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
- (a) The applicant should be able to understand the theoretical fundamentals of the subject.
- (b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- (c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
- (d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- (e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

ABNORMAL EVENTS

SPECIAL INSPECTIONS

During the service life of an aircraft, occasions may arise when something out of the ordinary care and use of the aircraft might happen that could possibly affect its airworthiness. When these situations are encountered, special inspection procedures should be followed to determine if damage to the aircraft structure or any other type of damage has occurred. The procedures outlined on the following pages are general in nature and are intended to acquaint the aviation technician with the areas which should be inspected. As such, they are not all inclusive. When performing any abnormal event inspection, always follow the detailed procedures in the aircraft maintenance manual. In situations where the manual does not adequately address the situation, seek advice directly from the manufacturer and from other maintenance technicians who are highly experienced with them.

LIGHTNING STRIKES AND HIRF PENETRATION

Although lightning strikes to aircraft are extremely rare, if a strike has occurred, the aircraft must be carefully inspected to determine the extent of any damage that might have occurred. When lightning strikes an aircraft, the electrical current must be conducted through the structure and be allowed to discharge or dissipate at controlled locations. These controlled locations are primarily the aircraft's static discharge wicks, or on more sophisticated aircraft, null field discharger's.

When surges of high voltage electricity pass through good electrical conductors, such as aluminum or steel, damage is likely to be minimal or nonexistent. When surges of high voltage electricity pass through non-metallic structures, such as a fiberglass radome, engine cowl or fairing, glass or plastic window, or a composite structure that does not have built-in electrical bonding, burning and more serious damage to the structure could occur. Visual inspection of the structure is required. Look for evidence of degradation, burning or erosion of the composite resin at all affected structures, electrical bonding straps, static discharge wicks and null field dischargers. Other non-destructive tests may also be required. Follow maintenance manual instructions for inspection procedures after a lightning strike.

HIGH INTENSITY RADIATED FIELDS (HIRF) PENETRATION

HIRF can interfere with the operation of the aircraft's electrical and electronic systems by coupling electromagnetic energy to the system wiring and components. This can cause problems relating to the control systems, both of the aircraft and its powerplants, the navigation equipment and instrumentation.

Various electrical devices on the ground and in the air radiate high intensity fields which may interfere with avionic equipment and safe flight. Most notable are numerous communications transmitters.

High intensity radiated fields and their effect on the electronics and avionics of an aircraft that flies through them have been of increasing concern in recent decades. The basic concern for better identification and protection from HIRF has arisen for the following reasons:

a. Operation of modern aircraft is increasingly dependent upon electrical/electronic systems, which can be susceptible to electromagnetic interference.
b. The increasing use of non-metallic materials like carbon or glass fibre in the construction of the aircraft reduces their basic shielding capability against the effects of radiation from external emitters.
c. Emitters are increasing in number and in power. They include ground-based systems (military systems, communication, television, radio, radars and satellite uplink transmitters) as well as emitters on ships or other aircraft.

Electronic developments have yielded greater miniaturization and complexity in integrated circuits (IC) and other electronic circuitry and assemblies, increasing the probability of electromagnetic interference. Rapid advances in technology and the increased use of composite materials and higher radio frequency (RF) energy levels, from radar, radio, and television transmitters, have substantially increased the concern for electromagnetic vulnerability of flight critical systems, relative to their exposure to HIRF.

Modern digital systems are highly susceptible to HIRF. In recent decades all newly certified aircraft have been required to be built with protection against HIRF.

Other aircraft have been modified to protect against it. When modifying the aircraft with any RF generating device, the new component must be assessed for its own HIRF protection as well as any effect it may have on existing equipment. Systems required for safe flight must continue to function as designed. There should be no adverse effect (introduced by wiring installation changes for example) on existing system functions as a result of a modification.

Environmental factors such as corrosion, mechanical vibrations, thermal cycling, damage and subsequent repair and modifications can potentially degrade an aircraft's electromagnetic protection. Continued airworthiness of the aircraft requires assurance that the electromagnetic protection is maintained to a high level by a defined maintenance program.

Design philosophies in the area of aircraft bonding for protection against HIRF can employ methods that may not have been encountered previously by maintenance personnel. Because of this, the HIRF protection in the aircraft can be unintentionally compromised during normal maintenance, repair and modification. It is critical that procedures contained in the aircraft maintenance manual and component maintenance manual be followed without omission to prevent incorrect installations that could degrade the HIRF protection features. There are three primary areas to be considered for aircraft operating in HIRF environments:

1. Aircraft Structure (Airframe Skin and Frame).
2. Electrical Wiring Installation Protection (Solid or Braided Shielding Connectors).
3. Equipment Protection (LRU case, Electronics Input Output Protection).

Visual inspection is the first and generally most important step in HIRF maintenance. If errors have been made that do degrade the protection (paint over spray and incorrect assembly of connectors for example), then they should be found during inspections.

Whilst the visual inspection may suffice for observation of the deterioration of the protective features, any time that this method is found to be insufficient or inefficient, then specific testing may be required. These techniques should make use of easy-to-apply, quick-look devices that can be readily integrated into the normal maintenance operations.

SPECIFIC TESTING - HIRF

The milliohmmeter is often used to measure the path resistance of earthing straps (grounding wires) or other bonding. This technique is limited to the indication of only single path resistance values.

The Low-frequency Loop Impedance testing method complements DC bonding testing and can be used together with visual inspection. It can give good confidence in the integrity of the shielding. Loop impedance testing can be used to check that adequate bonding exists between braiding/conduits and the aircraft structure, especially where there are multiple earth paths, when the DC resistance system will not indicate which ground has failed.

The frequency of any maintenance tasks selected for the HIRF protection features should be determined by considering the following criteria:

- Relevant operating experience gained.
- Exposure of the installation to any adverse environment.
- Susceptibility of the installation to damage.
- Criticality of each protective feature, (within the overall protection scheme)
- The reliability of protective devices fitted to equipment.

Cable shielding, aircraft structure shielding and circuit protection devices are designed to protect vital avionics from HIRF. Visual inspection and measurement of shielding and bonding effectiveness are maintenance actions used to check these. HIRF protective devices such as resistors, zener diodes and filters could short or open when exposed to HIRF. Check and repair any circuit protection devices as needed.

The manufacturer will normally protect the aircraft against HIRF. Bonding, shielding and separation of critical components usually achieve this. It is difficult to know when the aircraft has been subjected to HIRF; consequently protection is best achieved by regular checks of:

- Bonding of the aircraft including all bonding terminals correctly torque loaded.
- Correct crimping.
- Screens correctly terminated and grounded.

HARD OR OVERWEIGHT LANDING INSPECTION

The structural stress induced by a landing depends not only upon the gross weight at the time but also upon the severity of impact. However, because of the difficulty in estimating vertical velocity at the time of contact, it is hard to judge whether or not a landing has been sufficiently severe to cause structural damage. For this reason, a special inspection should be performed after a landing is made at a weight known to exceed the design landing weight or after a rough landing, even though the latter may have occurred when the aircraft did not exceed the design landing weight.

Wrinkled wing skin is the most easily detected sign of an excessive load having been imposed during a landing. Another indication which can be detected easily is fuel leakage along riveted seams. Other possible locations of damage are spar webs, bulkheads, nacelle skin and attachments, firewall skin, and wing and fuselage stringers. If none of these areas show adverse effects, it is reasonable to assume that no serious damage has occurred. If damage is detected, a more extensive inspection and alignment check may be necessary.

SEVERE TURBULENCE INSPECTION/OVER "G"

When an aircraft encounters a gust condition, the air load on the wings exceeds the normal wing load supporting the aircraft weight. The gust tends to accelerate the aircraft while its inertia acts to resist this change. If the combination of gust velocity and airspeed is too severe, the induced stress can cause structural damage.

A special inspection should be performed after a flight through severe turbulence. Emphasis should be placed upon inspecting the upper and lower wing surfaces for excessive buckles or wrinkles with permanent set. Where wrinkles have occurred, remove a few rivets and examine the rivet shanks to determine if the rivets have sheared or were highly loaded in shear.

Through the inspection doors and other accessible openings, inspect all spar webs from the fuselage to the tip. Check for buckling, wrinkles, and sheared attachments. Inspect for buckling in the area around the nacelles and in the nacelle skin, particularly at the wing leading edge.

Check for fuel leaks. Any sizable fuel leak is an indication that an area may have received overloads which have broken the sealant and opened the seams.

If the landing gear was lowered during a period of severe turbulence, inspect the surrounding surfaces carefully for loose rivets, cracks, or buckling. The interior of the wheel well may give further indications of excessive gust conditions. Inspect the top and bottom fuselage skin. An excessive bending moment may have left wrinkles of a diagonal nature in these areas.

Inspect the surface of the empennage for wrinkles, buckling, or sheared attachments. Also, inspect the area of attachment of the empennage to the fuselage. The above inspections cover the critical areas. If excessive damage is noted in any of the areas mentioned, the inspection should be continued until all damage is detected.

FIRE DAMAGE

Inspection of aircraft structures that have been subjected to fire or intense heat can be relatively simple if visible damage is present. Visible damage requires repair or replacement. If there is no visible damage, the structural integrity of an aircraft may still have been compromised. Since most structural metallic components of an aircraft have undergone some sort of heat treatment process during manufacture, an exposure to high heat not encountered during normal operations could severely degrade the design strength of the structure. The strength and airworthiness of an aluminum structure that passes a visual inspection but is still suspect can be further determined by use of a conductivity tester. This is a device that uses eddy current and is discussed later in this chapter. Since strength of metals is related to hardness, possible damage to steel structures might be determined by use of a hardness tester such as a Rockwell C hardness tester.

FLOOD DAMAGE

Like aircraft damaged by fire, aircraft damaged by water can range from minor to severe, depending on the level of the flood water, whether it was fresh or salt water and the elapsed time between the flood occurrence and when repairs were initiated. Any parts that were totally submerged should be completely disassembled, thoroughly cleaned, dried and treated with a corrosion inhibitor. Many parts might have to be replaced, particularly interior carpeting, seats, side panels, and instruments. Since water serves as an electrolyte that promotes corrosion, all traces of water and salt must be removed before the aircraft can again be considered airworthy.

SEAPLANES

Because they operate in an environment that accelerates corrosion, seaplanes must be carefully inspected for corrosion and conditions that promote corrosion. Inspect bilge areas for waste hydraulic fluids, water, dirt, drill chips, and other debris. Additionally, since seaplanes often encounter excessive stress from the pounding of rough water at high speeds, inspect for loose rivets and other fasteners; stretched, bent or cracked skins; damage to the float attach fitting; and general wear and tear on the entire structure.

AERIAL APPLICATION AIRCRAFT

Two primary factors that make inspecting these aircraft different from other aircraft are the corrosive nature of some of the chemicals used and the typical flight profile. Damaging effects of corrosion may be detected in a much shorter period of time than normal use aircraft. Chemicals may soften the fabric or loosen the fabric tapes of fabric covered aircraft. Metal aircraft may need to have the paint stripped, cleaned, and repainted and corrosion treated annually. Leading edges of wings and other areas may require protective coatings or tapes. Hardware may require more frequent replacement.

During peak use, these aircraft may fly up to 50 cycles (takeoffs and landings) or more in a day, most likely from an unimproved or grass runway. This can greatly accelerate the failure of normal fatigue items. Landing gear and related items require frequent inspections. Because these aircraft operate almost continuously at very low altitudes, air filters tend to become obstructed more rapidly.

Question: 19-1
What does HIRF stand for?

Question: 19-2
Since most structural metallic components of an aircraft have undergone some sort of heat treatment process during manufacture, an exposure to high heat not encountered during normal operations could severely ________________ the design strength of the structure.

Question: 19-3
Lightening striking a metal aircraft is ________________ likely to cause structural damage than if striking a composite aircraft. (more or less?)

Question: 19-4
________________ is a common cause of damage often experienced by seaplanes and aerial application aircraft.

ANSWERS

Answer: 19-1
High intensity radiated fields.

Answer: 19-2
degrade.

Answer: 19-3
more likely.

Answer: 19-4
Corrosion.

MAINTENANCE PRACTICES

MAINTENANCE PROCEDURES

SUB-MODULE 20

	PART-66 SYLLABUS LEVELS	
CERTIFICATION CATEGORY →	B1	B2
Sub-Module 20 MAINTENANCE PROCEDURES Knowledge Requirements		
7.20 - Maintenance Procedures Maintenance planning; Modification procedures; Stores procedures; Certification/release procedures; Interface with aircraft operation; Maintenance Inspection/Quality Control/Quality Assurance; Additional maintenance procedures; Control of life limited components.	2	2

Level 2
A general knowledge of the theoretical and practical aspects of the subject and an ability to apply that knowledge.

Objectives:
(a) The applicant should be able to understand the theoretical fundamentals of the subject.
(b) The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
(c) The applicant should be able to use mathematical formula in conjunction with physical laws describing the subject.
(d) The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
(e) The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

MAINTENANCE PLANNING

To ensure continued airworthiness, aircraft manufacturers are required to provide operators with a maintenance program approved by the authorities of the country of certification. An aircraft maintenance program is essential to allow for safe and economic operations and it is necessary to obtain a type certificate. The entire program is written and known as the Maintenance Planning Document (MPD). Operators typically customize a maintenance program for their own use based on the manufacturer's program. Each change in the maintenance program of a manufacturer has to be approved by the authorities. From these written and approved programs, planning for all maintenance functions is derived.

Note that MPD's are live documents that are regularly updated with knowledge from the manufacturer and field operators. A global industrial process is used by manufacturers, EASA, FAA, airline operators, and maintenance organizations to modify and ratify changes to the MPD. An Industry Steering Committee (ISC) chaired by a representative of the airlines and co-chaired by the aircraft manufacturer receives and reviews information pertaining to the maintenance of an aircraft. The committee proposes changes to the manufacturer's maintenance program and issues a report. The report, known as the Maintenance Review Board Report (MRBR), is review by regulatory authorities for implementation. Once established, operators may adjust their own maintenance programs according to the details adopted in the report.

It is the aircraft manufacturer's job to process any information from the field operators and design engineers for use by the ISC when considering changes to the manufacturer's maintenance program. A chart of the membership composition of the steering committee is shown in ***Figure 20-1***.

Various maintenance working groups may be established to study details of a specific maintenance function or proposed modification to the maintenance program. The entire process for developing and modifying optimal maintenance programs is run under a process developed over the years by Maintenance Steering Groups (MSG's). The decision logic and analysis procedures are key parts of the process. The current procedures are known as MSG-3R2 (maintenance steering group - Revision 2), as established in 1993.

All modifications to a maintenance operator's own maintenance program must be approved by authorities (NAA and EASA). An operator's program adapts the MPD so that it is easier to implement for the operator's particular situation. Work cards containing the various steps in maintenance tasks to be used by the technician may be the manufacturer's cards or they may be modified by the maintenance operator. A planning department of the maintenance operator prepares and issues the work cards to the technicians as a part of a maintenance package that is accomplished during the scheduled maintenance time when the aircraft will be out of service. All steps on all work cards must be signed off by the technician performing the work.

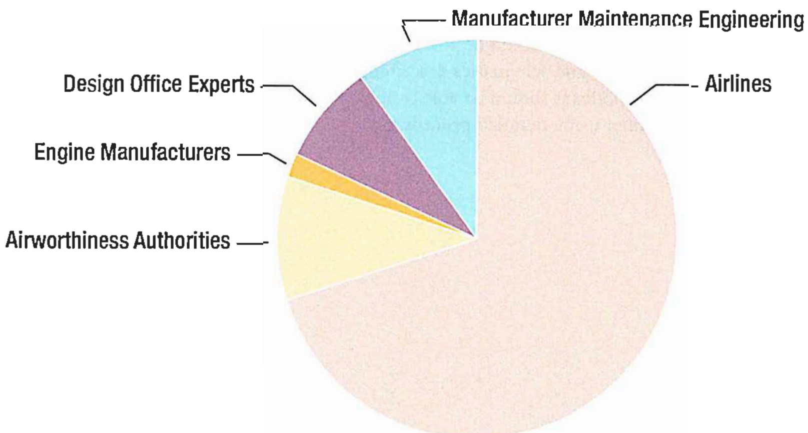


Figure 20-1. Industrial steering committee membership used to propose modifications in a manufacturer's maintenance program for continued airworthiness.

MODIFICATION PROCEDURES

A modification which has no impact on weight, center of gravity, structural strength, reliability, characteristics of usage, or any other characteristic which has an impact on the airworthiness of the systems is known as a minor modification. All other modifications are major modifications.

Manufacturers, operators, vendors and other aviation companies can propose to modify all or part of a system or component on the aircraft. However, the decision to incorporate a modification is up to the operator.

Each modification planned for an aircraft or component on a certified aircraft must be submitted for approval on a modification document and is subject to the same rules used for the establishment of the original technical document on that area of the aircraft. Major modifications are approved directly by the authorities. Minor modifications may be either approved directly by the authorities (or by an organization entitled for approval), or, indirectly though an approved procedure of the authorities granted to an organization holding a design approval.

To be approved indirectly through an approved procedure granted to an organization holding a design approval, the modification must be related to one of the products mentioned in the summary of products associated with the design approval.

The modification must follow the procedure described in the approval specifications, and the holder of the approval must provide the conformity of the modification with the conditions for certification. The requester of the approval for the modification is responsible for that modification and its follow-up.

For approval of a minor modification, the modification document is assigned and approved by the airworthiness authority or by the holder of a designated design certificate. For approval of a major modification, the document is approved by the national airworthiness authority. In doing so, the authority may have technical experts study the modification who may, in turn, request demonstrations, tests and checks to ensure conformity of the modification. The applicant or vendor seeking the approval performs the tests following conformity instructions proposed by the technical experts. The authorities reserve their right to participate in any test for conformity.

Modification can be evaluated on the component level and also on the system level when installed on the aircraft. Tasks typically performed during evaluation of a modification are as follows:

- A review of the installation plan and wiring.
- Verification of the presence of labels.
- Evaluation of the structural installation.
- A safety analysis.
- Evaluation of the conditions equipment/aircraft environment.
- Structural justifications.
- A written evaluation of electrical aspects of repair.
- A statement/analysis of the effect of the modification on weight and balance.

Ground tests and or flight tests may be needed to ensure the modification performs as designed. These are performed by the applicant with or without participation of the authorities. The modifications being discussed are primarily for use in the issuance of a manufacturer's Service Bulletin (SB), an Airworthiness Directive (AD), an Engineering Order (EO) or a Modification.

In most cases, modification of an aircraft or its components is issued as a Service Bulletin and sent to operators. An Alert SB concerns a system or element affecting safety which demands a rapid modification on an essential part. It is often accompanied by an Airworthiness Directive which draws attention to and details the modification and specifies the parameters for incorporating the change. A Recommended SB concerns a system or element affecting the operational conditions of the aircraft. Operators are not required to incorporate it but in most cases this type of SB was demanded by the operators themselves.

A Service Bulletin (SB) concerns minimum modifications which affect neither safety nor the operational status of the aircraft. Often it deals with the improvement of reliability. An Evaluation SB is used for the evaluation of new materials. As with all SB's, it must apply specifically to the aircraft in question and performed within the parameters stated in the SB. Service Letters/

Service Information Letters (SL/SIL) are also issued by manufacturers. These are not subject to approval by the authorities. They pre-warn operators of possible problems and how to cure them or reference changes for spare parts.

Note that the replacement of parts (engine, avionics, landing gears, consumables etc.) do not affect the certificate of airworthiness of the aircraft as long as the parts are specified in the aircraft's Illustrated Parts Catalog (IPC) or in the service bulletin. Standard parts used in an assembly can be supplied by any vendor that manufactures them. Many electronic parts are standard parts.

When a modification is requested by the national authority, manufacturers must create an application document to be used by the operators to document the modification (or explain why the modification was not made if it is not a mandatory modification).

An Airworthiness Directive (AD) is a notification to owners and operators of certified aircraft that a known safety deficiency with a particular model of aircraft, engine, avionics or other system exists and must be corrected. If a certified aircraft has outstanding Airworthiness Directives that have not been complied with, the aircraft is not considered airworthy. Thus, it is mandatory for an aircraft operator to comply with an AD.

ADs usually result from service difficulty reported by operators or from the results of aircraft accident investigations. They are issued either by the national civil aviation authority of the country of aircraft manufacture or of aircraft registration. When ADs are issued by the country of registration they are almost always coordinated with the civil aviation authority of the country of manufacture to ensure that conflicting ADs are not issued. ADs are issued by most civil aviation regulatory authorities.

The purpose of an AD is to notify aircraft owners:

- That the aircraft may have an unsafe condition, or
- That the aircraft may not be in conformity with its basis of certification or of other conditions that affect the aircraft's airworthiness, or
- That there are mandatory actions that must be carried out to ensure continued safe operation, or
- That, in some urgent cases, the aircraft must not be flown until a corrective action plan is designed and carried out.

Therefore, ADs may contain modification(s) to the aircraft or its components that have been approved in the manner stated above in order to bring the aircraft into compliance. An AD may be of an emergency nature and require immediate compliance or it may specified an amount of time within which the AD must be performed in order to stay in compliance.

Most large aircraft operators have their own design engineering departments. When a modification to the certified aircraft in its fleet is deemed desirable or justified, the modification goes through the approval process described above. Then, an EO is issued by the operator's design engineers instructing technicians what the modification is, how to accomplish it and what new parts, if any, need to be utilized. An Engineering Order contains most if not all of the information a service bulletin contains but it is an in-house document typically only used by the operator that originated it.

STORES PROCEDURES

Aircraft maintenance operations have various stocking and storage procedures often depending on the size of the maintenance operation and the number of different aircraft serviced. In general, the job of organization and storage of components and materials is performed not by the technician but by parts storage specialists. The process for requesting a particular part is secured by a part numbering system. A part number is permanently affixed to the component or part and is identified in the manufacturer's illustrated parts manual. Exact part number matching is required. Often, part numbers for similar looking components may be different by only a "dash number" at the end of the part number. Only parts with completely identical part numbers may be substituted for each other.

When materials, parts and components are not installed on aircraft, they need to be kept in accordance with storage instructions defined by their manufacturer. All manufacturers of aircraft parts are required to establish procedures on how to store and transport each of the parts they produce. The documentation concerning storage includes:

- The definition of the item to be stored.
- Identification, differentiation and protection of material in storage including the required environmental conditions under which it should be stored.
- Any periodic checks required and scrapping instructions, especially for materials that deteriorate because of the passage of time.
- Protective measures to be taken to prevent damage of material before usage.
- The definition and establishment of packaging to be used when storing the item.

The correct handling of basic materials is also of great importance. For example, high stress-capable aluminum alloy requires care during loading, unloading and storage to assure that the material does not suffer from damage. Friction, scraping, squeezing, pressing or being bent can seriously affect the mechanical attributes of the alloy. Forged parts, extrusions and heavy frames have to be carried and stocked separately ensuring a stable base to maintain the material in its original shape without load.

Storage locations of spare parts and aircraft elements are important. They must be clean, ventilated and maintained at a constant temperature with a low constant percentage of humidity to reduce to a the effect of condensation. In many cases the manufacturer will indicate the temperature and relative humidity in which the products have to be stored. Thermometers and hygrometers (used to measure relative humidity) are used to ensure the correct conditions are maintained.

Vapor Phase Inhibitors (VPI) are sometimes used when storing ferrous and other metallic materials susceptible to corrosion. The VPI protects the material from corrosion by saturating the environment around the material with a vapor. This displaces oxygen and water vapor which are the cause of corrosion. An enclosed container is required but the advantage of a VPI is that the protective vapor simply disperses when the material container is opened. Paper wrapping of the material sometimes accompanies VPI use and manufacturer approval is required.

Metals susceptible to corrosion while in storage may also be protected from corrosion with oil, fluid or protective compounds. After application, the material is typically wrapped in an impermeable polythene or wax paper, etc. to prevent evaporation of the protective fluid. If stored for a long period of time, the condition of the coating should be checked periodically to ensure it is in acceptable condition to protect the material from corrosion.

Similarly, dehydrating materials are often included inside the packaging of materials and components to remove the moisture that may cause corrosion. Silica gel is one such commonly used material. It changes color as moisture is absorbed. Thus, the condition of the protective dehydrator can be determined by quick visual inspection. Once fully saturated, silica gel can be reactivated by baking in an oven at 135°C for two hours.

Open shelving for parts storage is usually preferred because it allows free circulation of air around components and quick identification. Painted metal is a more appropriate material than wood for shelving material in that it does not absorb moisture.

The container a part or component is stored in is also of concern. Polyethylene, rigid PVC, undulated plastics or card board boxes can be used. Often a form fitted foam liner securely holds the part in the container. Boxes of cast plastics equipped with movable separators allow the separation of small parts and permits better adapted use of space.

Manufacturers of certain aircraft parts impose a shelf life limit after which time the parts must be taken out of storage, verified and inspected according to the manufacturer's instruction.

Many items stored for use on the aircraft have limited shelf lives. Storage methods must be established in a way that the material parts or pieces are distributed in a rotation system so that the oldest stock is distributed before newer stock. This is particularly important for perishable materials, instruments and other components with shelf limit over time.

The serviceability of stocked items can be considerably reduced when proper storage conditions are not met. Storage limited by time assumes these conditions are met.

Flammable materials have unique storage requirements. Safe fire prevention code compliance must be followed. Many flammable materials are stored in a separate building or part of the hangar. Special storage cabinets are often used.

Separation of stocked materials and aircraft parts or components may need to occur. Certain materials have detrimental effects on other materials. For example, acid must not be placed in a shop where escaping vapors can damage raw materials or finished parts. Phenolic plastics must be isolated from steel parts treated with cadmium to prevent corrosion of the steel parts and magnesium alloys must not be stocked close to inflammable materials. Common sense and storage standards are used when storing any material for use on aircraft. Every part, component or material should be handled and stored in a specific manner to preserve it.

The following is a list of just some of the items used in aircraft maintenance that have specific handling and storage methods:

- Ball-bearings and cylindrical bearings
- Aircraft batteries
- Ropes twisted from hard rubber
- Pressurized gas bottles
- Electrical wires
- Forged, cast and profiled parts
- Instruments
- Oil radiators and radiators
- Paint and coating material
- Tubes
- Tires
- Pyrotechnical material
- Parts in hard rubber or containing hard rubber
- Sheet, bars and tubes in metal
- Spark plugs
- Survival equipment
- (Flexible) reservoirs
- (Rigid) reservoirs
- Wood
- Transparent acrylic panels
- Windscreens
- Metallic cables

CERTIFICATION AND RELEASE PROCEDURES

Between scheduled maintenance checks, when maintenance is performed, the aircraft must be released to service before flight. No aircraft can be released to service unless a certificate of release to service is issued. Certifying maintenance personnel issue the certificate when they are satisfied that all required maintenance has been carried out.

Regulations governing release to service are found in the Implementing Rules of EC Regulation 2042/2003, Part M - Continuing Airworthiness. Some of the main highlights of Part M as they relate to release to service follow. Certifying maintenance personnel are:

(a) appropriate certifying staff on behalf of the maintenance organization approved in accordance with Section A, Subpart F of Part M.
(b) certifying staff in compliance with the requirements of Annex III (Part66), (except for complex maintenance tasks listed in Appendix VII of Part M); or
(c) the pilot-owner in compliance with Part M.A.803.

In the case of unforeseen situations, when an aircraft is grounded at a location where no approved Part 145 maintenance organization or certifying staff are available, the owner may authorize any person holding the proper qualifications, with not less than three years of appropriate maintenance experience to perform maintenance according to the standards set out in Part M - Subpart D and release the aircraft to service.

The owner shall in that case:

(a) obtain, and keep in the aircraft records, details of all work carried out.
(b) obtain and keep the qualifications held by that person issuing the certification.
(c) ensure that any such maintenance is rechecked and released by an appropriately authorized person or an organization approved in accordance with Part M Section A, Subpart F or with Annex II (Part-145) approval at the earliest opportunity but within a period not exceeding seven days; and
(d) notify the organization responsible for the continuing airworthiness management of the aircraft when contracted in accordance with Part M.A.201(e), or the competent authority in the absence of such a contract, within seven days of the issuance of such certification authorization.

A certificate of release to service must contain basic details of the maintenance carried out, the date such maintenance was completed and the identity of the organization and/or person issuing the release to service. It should also have the approval reference of the maintenance organization approved in accordance with Part M, Section A, Subpart F and the certifying staff issuing the release certificate.

When M.A.801(b)2 or M.A.801(c) certificate of release to service applies, the identity and license number of the certifying staff issuing the release to service must be recorded. If there are any limitations to airworthiness, they must be stated on the certificate of release to service.

Also, the following statement must be made:
"________________________ certifies that the work specified was carried out in accordance with Part-M and the aircraft is considered ready for release to service".

When extensive maintenance has been carried out, it is acceptable for the certificate of release to service to summarize the maintenance performed. There must be a unique cross-reference to the work-pack (work order) containing full details of maintenance carried out. Any dimensional information should be recorded in the work-pack record.

At the completion of all maintenance, owners, certifying staff, operators and maintenance organizations should all ensure they have a clear, concise, legible record of the work performed.

If a certificate of release to service is issued with incomplete maintenance, a record should be kept stating what action the mechanic, supervisor and certifying staff should take to bring the matter to the attention of the relevant aircraft owner or Part M Subpart G organization so that the issue may be discussed and resolved with the aircraft owner or the Part M Subpart G organization.

Note that a certificate of release to service shall not be issued in the case of any known noncompliance which endangers flight safety.

INTERFACE WITH AIRCRAFT OPERATION

The main interface between aircraft maintenance and aircraft operations is the technical logbook. EASA Part M A 306 establishes that "In the case of commercial air transport, an operator shall use an aircraft technical log system containing the following information for each aircraft:"

1. Information about each flight necessary to ensure continued flight safety.
2. The current aircraft certificate of release to service.
3. The current maintenance statement giving the aircraft maintenance status of what scheduled and out of phase maintenance is next due except that the competent authority may agree to the maintenance statement being kept elsewhere.
4. All outstanding deferred maintenance items that affect the operation of the aircraft; and
5. Any necessary guidance instructions on maintenance support arrangements.

The aircraft technical log system shall be approved by the competent authority which is typically the NAA of the country of registration. An operator shall ensure that the aircraft technical log is retained for 36 months after the date of the last entry. The technical logbook informs the flight crew about the status of the aircraft they are going to fly.

EU OPS 1.875 states: "An operator shall not operate an airplane unless it is maintained and released to service by an organization appropriately approved/accepted in accordance with Part-145 except that pre-flight inspections need not necessarily be carried out by the Part-145 organization."

MAINTENANCE INSPECTION/QUALITY CONTROL/QUALITY ASSURANCE

A maintenance inspection/quality control or quality assurance system must be in place at all maintenance organizations. It should be part of the organizational structure yet independent from the remainder of the maintenance organization to ensure it can carry out the business of quality assurance and conformity for airworthiness without interference. The quality assurance system includes the following capabilities, functions and procedures:

- Delivery, approval or modification of documentation.
- Evaluation, audit and inspection of vendors and subcontractors.
- Verification that products, parts, materials and equipments supplied conform to the defined applicable data. (This is for both used and new parts.)
- Identification and traceability of parts and components as well as maintenance performed.
- Confirmation of conformance of manufacturing processes.
- Inspection and testing during flight tests.
- Calibration of tools, patterns and test material.
- Recording of non-conformities.
- Holding of historical maintenance records.
- Qualification and competency of maintenance staff.
- Delivery of airworthiness approvals.
- Handling, storage and packaging of all spare parts, components and materials.
- Internal quality audits and corrective actions resulting from internal audits.

The quality assurance system/department ensures work is performed satisfactorily when performed at locations other than the maintenance organization's approved installations. In fact, all maintenance on the aircraft operated by an organization and maintained by a maintenance organization is done under the supervision of the quality assurance system/department of the maintenance organization.

ADDITIONAL MAINTENANCE PROCEDURES - UNSCHEDULED MAINTENANCE

Unscheduled maintenance occurs due to failures during operation and from findings during inspections and checks. Typical inspection and check unscheduled maintenance items are:

- Corrosion treatment.
- Adjustment or replacement of components that are not performing to standards.
- Repair of structural cracks and deformations out of tolerances in pressurized areas.

It is rare that an aircraft in operation is totally free of faults. Additional maintenance items must be corrected and performed following the procedures of the AMM (Aircraft Maintenance Manual). All maintenance work is entered into the technical logbook and must be accompanied by a certificate of release to service issued by certifying maintenance staff.

Pre-flight and transit checks can be performed by the flight crew and do not require certifying maintenance staff. However, ETOPS operations (Extended Range Twin-Engine Operational Performance Standards) require that ETOPS approved certifying staff perform these functions before any departure to an ETOPS sector.

All failures found during operation or maintenance are entered into the technical logbook. This is an operational document and not a maintenance document. The person responsible for maintenance operations ensures that following items are entered into logbook:

- Type of work (included P/N and S/N in case of equipment replacement).
- References of the documentation used.
- References in case of deferred work.
- Date and place of work.
- Name of staff responsible for the work performed.

Maintenance on faults and anomalies reported in the logbook is typically performed by the line maintenance staff with follow-up by the quality control department of the maintenance operation. The repetitive character of a particular failure is not always detectable by line maintenance staff due to the passing of time and the geographical distribution of line stations, etc. It is therefore essential that line maintenance staff accurately report these failures in the logbook so that engineering services can analyze with precision the repetitive character of these faults.

A safety analysis of an aircraft is made by the manufacturer and is approved by the authorities. A list of equipment indispensable for flight operation is established. This list is called a MMEL (Master Minimum Equipment List) or "No Go" List. Base on the MMEL, a MEL (Minimum Equipment List) unique to each aircraft permits the aircraft to fly to a base at which a deferred maintenance operation can and must be performed.

The information contained in the MEL document is:

- The minimum number of systems which imperatively have to be in a perfect condition to perform a flight.
- The operational procedures and/or maintenance operations to compensate temporarily for the failure of a system.
- The eventual limits to rectify a fault.

Line maintenance staff regularly consult the list of deferred maintenance items to ensure that no time required for repair has been exceeded. It is also important to note that the addition of a new deferred maintenance item does not combine with an item already deferred to exceed the limits spelled out in the MEL, a CDL (Component Deviation List) or a HIL (Hold Item List). Maintenance operators create a logbook entry confirming accomplishment of corrective action to remove an item from the deferred maintenance list. Note that a deferred maintenance action has to be corrected within 2 weeks after its inscription in the logbook.

CONTROL OF LIFE LIMITED COMPONENTS

Life limited parts or components are parts that are not damage tolerant. That is, inspection would not detect the imminent failure of the unit which could be disastrous. Often, the fatigue life of these parts is less than others on the aircraft or of the remaining parts on the assembly of which it is a component.

A life-limits document is maintained which tracks the hours on all parts and components on the airframe that are considered life limited. A similar document is maintained for engine parts and components. Maintenance personnel must replace life limited units by the latest specified time-in-service hours on the life limits document.

The life-limits document is part of the Airworthiness Limitations section of the Instructions for Continued Airworthiness. Instructions for Continued Airworthiness are required for certification of the aircraft. A list of items and the time before which they need to be replace; known as Safe Life Airworthiness Limitation Items, is approved by the certification directorate of EASA.

Compliance with the requirements contained in this document is mandatory. Failure to comply results in the suspension of the validity of the certificate of airworthiness.

Records must be kept that trace the time in service of all life-limited parts. These should show the installation and service history of an item along with the item serial number, the aircraft identification information upon which the item was installed and any maintenance actions that may have occurred involving the unit. The installation date, part number, part name, and total time on the item and the aircraft must also be recorded. It is the operator's responsibility to maintain accurate time-in-service records for the airframe, engine, and life-limited components.

When a life limited item is removed from service, it should not be mixed with serviceable units so that it might mistakenly be re-installed on an aircraft. Disposal and quarantine action must be taken. Immediate removal/segregation from serviceable component storage areas is required. Mutilation beyond repair limits to prevent rework to appear airworthy may be enacted.

Question: 20-1
A ________________ is developed by manufacturers to allow safe operation of an aircraft and to obtain a type certificate.

Question: 20-2
Aircraft parts and components are identified by unique ________________.

Question: 20-3
No aircraft can be released to service unless a ________________ is issued.

Question: 20-4
The main interface between aircraft maintenance and aircraft operations is the ________________.

ANSWERS

Answer: 20-1
maintenance planning document (MPD).

Answer: 20-2
part numbers.

Answer: 20-3
certificate of release to service.

Answer: 20-4
technical logbook.

TIPS ON ANSWERING ESSAY QUESTIONS

EASA knowledge testing for Module 07, 09 and 10 requires you to answer essay questions.

Module 07 includes two essay questions, and Module 09 and 10 include one essay question each.

The essay portion is given separately from the multiple choice portion with a time limit of 20 minutes per essay question. To pass the entire test, you must pass both the multiple choice and the essay portions.

Essay questions are scored for both technical knowledge and writing style. The knowledge portion is 60% of your grade. It assesses your knowledge of the topic and how well you can share that knowledge with others. The style portion counts for 40% of the grade and tests your ability to communicate your knowledge to others.

In EASA's words:
"The purpose of the essay is to determine if candidates can express themselves in a clear and concise manner in the form of a written response, in a technical report format, using the technical language of the aviation industry."

The following are samples of the types of essay questions that appear on the Module 07, 09, and 10 knowledge tests.

Module 07:
1. You are required to carry out a bonding test on an aircraft. Describe the procedure including all checks and tests to be carried out.
2. Describe the precautions you would take before, during, and after a windscreen replacement.

Module 09:
1. If a skin repair was being carried out and you were the team leader, and the repair was not going to be completed during your shift, how would you do a shift handover for the next shift?
2. Describe "Maintenance Error Decision Air" (MEDA) and how it is utilized for accident prevention.

Module 10:
1. What are the considerations when moving a Private category aircraft into the Commercial Air Transport category?
2. What are the considerations and certifications for release to service when a licensed engineer carries out a component replacement?

Figure 1 on the next page is an example of how your essay question will be graded. When you take the test, you see only the question. You do not see the list of key points you are expected to discuss or the values given to each point. Your knowledge of the topic should be enough to know what those key points are and to discuss each in your answer.

If a key point is partially discussed you will receive a portion of the maximum score for that topic. If a key point is completely missed, you will not receive any score for that point.

To pass the essay portion you must receive a 75% score in both the knowledge section and the style section. You must earn at least 45 of 60 possible points in the knowledge section and 30 of 40 points in the style section.

Below are examples of two essay questions along with successful answers.

EXAMPLE ESSAY QUESTION:
Referring to facility requirements for Part 145 organizations, please explain what requirements shall be met in respect to hangars, workshops, and storage facilities?

KNOWLEDGE SECTION

	Key Points List	Max Points	Earned Points	Remarks
01	Availability of facilities appropriate for planned work.	10		Exact wording not necessary, but understanding should be evident.
02	Protection from the weather elements.	5		
03	Segregation of work areas to prevent work area contamination.	5		Additional 2 points if examples given.
04	Hangars for aircraft base maintenance.	5		
05	Hangar should prevent ingress of rain, hail, ice, snow, wind, dust, etc.	4		
06	In line maintenance, for lengthy work a hangar should be available.	5		May be replaced by an unexpected but relevant answer element.
07	Secure storage shall be provided for components, tools, and material.	6		Additional 2 points if examples given.
08	Separation of serviceable and nonsevicable components.	5		Additional 2 points if examples given.
09	Storage conditions in accordance with manufacturers instructions.	4		
10	Access to storage facilities restricted to authorized personnel.	3		May be replaced by an unexpected but relevant answer element.
11	Storage facilities to be kept clean, dry, and temperature controlled.	5		
12	Components remain packed in protective material to minimize damage.	3		May be replaced by an unexpected but relevant answer element.
	Total Knowledge Points	60		

STYLE SECTION

		Max Points	Earned Points
Structure	Introduction-main-conclusion, logical sequence, technical report style.	20	
Grammar and Language	Communication level, preciseness and clarity, readability, grammar.	10	
Terminology and Tech Language	Occurrences, relevance.	10	
	Total Style Points	40	

TIPS ON ANSWERING ESSAY QUESTIONS

Describe the parts and components in an aircraft bleed system between the engine and airframe duct.

The engine has in general three bleeds that are used for various applications; high pressure, intermediate pressure and fan air bleed. High pressure is connected to a high pressure shut off valve which has its own controller sensing pressure and temperature. This valve opens when intermediate pressure is too low such as in idle. The intermediate air has a non return valve, so that high stage air cannot blow into the engine. Both high and intermediate air are going to a pressure regulating valve, pre-cooler and a pressure regulating and shut off valve (PRSOV) to the aircraft system. At this position air is tapped off for starting and engine anti-icing through their respective valves. The pre-cooler cools the air down and its valve. The fan air valve opens in reference to temperature sensed downstream. The PRSOV controller senses pressure, temperature and reverse flow and can shut the system off.

Describe thrust reversal lockout, how it is archived and how pilot is informed.

Debrief pilot, ensure log entry has been made and check previous log entries. Check Minimum Equipment List (MEL) for dispatch limitations. If dispatch is not acceptable, repair as required. In case dispatch is allowed, lock affected thrust reverser out per maintenance manual. Deactivate engine starting, ignition, air or hydraulic system and thrust reverser by pulling respective circuit breakers and install warning placards. Thrust reverser deactivation is normally accomplished by stowing (if necessary manually), locking in stowed position, e.g. with locking bolts and deactivating the respective drive system, e.g. deactivating pin in a hydraulic valve. Enter MEL deactivation on deferred log page (ADD) and cross reference to tech log page number, enter work done and reactivation details in tech log and sign CRS. Install inoperative placard adjacent to reverser light of deactivated thrust reverser. Pilot is normally informed verbally, by placard in cockpit, ADD page, tech log page and red locking bolts in thrust reverser shells.

Do not fear the essay questions. Instead, consider them as a way to show off your understanding of the topic. Regard them as similar to an oral or practical test with the difference being that your answer is in writing. The following hints and tips from the California Department of Education will help you understand what that good writing style is.

HOW TO WRITE AN ESSAY ANSWER

READ THE QUESTION

This sounds obvious, but many people just begin writing an answer without considering if what they are writing actually answers the question. Read the question several times to make sure you understand what it is asking.

STUDY THE QUESTION

Once you have read the question, you should then study it. Look for key words (the issue to be considered) and topic words (the subject matter) and you can ensure that you actually answer the question. Once you have studied the question, you are ready to write your plan. The simple question "Explain how to install an oversized rivet," should not have an answer including the previous condition of the riveted joint. The question is limited to how to, not when to.

PLANNING

The first step of a successful essay is planning. Do this by first writing an outline or a list of the points you want to discuss. If you do this carefully, you will know exactly what your answer is going to be, in what order you will discuss each point, and that you actually answer each part of the question. This is not something to decide while you are writing the essay! Without a plan it is all too easy to lose focus and write irrelevant nonsense.

WRITING THE ESSAY

Once you have made your plan, you are ready to begin writing. While there is no hard and fast rule, it is always good to make a first impression. It is the first thing anyone will read and if it fails to impress, the rest of the essay will have to be very good to make it up. As you have already identified the key points in the question and your answer, now is the time to use them. Every sentence must refer in some way to those points or it will be irrelevant.

If you are asked to describe a procedure, discuss each point in its proper order. Give examples whenever you can and name each tool, part, component, or regulation with its proper technical term. When possible include "why" a step is done. For example "After drilling, debur each side of the hole ...so that burrs will not interfere with the seating of the new rivet".

Most important is that your discussion should start at the beginning, have a clear and logical process, and then reach a conclusion. The reader should be confident that if you were given that task today, that you would accomplish it in a proper, complete, legal, and safe manner, not just knowing how, but also knowing why each step occurs as it does.

HINTS AND TIPS

1. Do not rewrite the question in the answer. (There are many factors when considering a rivet)
2. Do not make statements that are "fluff". (Choosing a rivet is always a difficult thing to do.)
3. Do not use words that you can't spell or if unsure of the meaning.
4. Don't ramble. Your answer should be clear and precise.
5. Avoid slang or clichés.
6. Write in complete sentences.
7. Do not use contractions or abbreviations. Spell your words out.
8. Do not use double negatives. (ex. "Do not use no oil on the tool.")
9. Describe the procedures in positive form. List what you should do, not what you shouldn't.
10. Use aviation and technical terms whenever they apply.
11. Proof read your answer to be sure you have covered every point in your outline.

AC	/	Alternating Current
ACARS	/	Aircraft Communications Addressing and Reporting System
AD	/	Airworthiness Directive
ADF	/	Automatic Direction Finder
AFM	/	Aircraft Flight Manual
AISI	/	American Iron and Steel Institute
AMM	/	Aircraft Maintenance Manual
AN	/	Army/Navy
ANSI	/	American National Standards Institute
APU	/	Auxiliary Power Unit
ATA	/	Air Transport Association
ATC	/	Air Traffic Control
ATE	/	Automatic Test Equipment
BA	/	Bend Allowance
BITE	/	Built In Test Equipment
BL	/	Buttock Line or Bend Line
BS	/	British Standard
BSI	/	British Standards Institute
CAD	/	Computer Aided Design
CADD	/	Computer Aided Design Drafting
CAE	/	Computer Aided Engineering
CAM	/	Computer Aided Manufacturing
CARC	/	Carcinogenic Materials
CDL	/	Component Deviation List
CDU	/	Control Display Unit
CG	/	Center of Gravity
CMC	/	Central Maintenance Computer
CRT	/	Cathode Ray Tube
DAR	/	Designated Airworthiness Representative (USA)
DC	/	Direct Current
DMM	/	Digital Multimeter
DVM	/	Digital Voltmeter
EASA	/	European Aviation Safety Agency
EC	/	European Community
EMI	/	Electromagnetic Interference
EO	/	Engineering Order
ETOPS	/	Extended Range Twin Engine Operational Performance Standards
EU OPS	/	European Operations
EWIS	/	Electrical Wiring Interconnection System
FAA	/	Federal Aviation Administration
FMS	/	Flight Management System
FOD	/	Foriegn Object Damage
FS	/	Fuselage Station
GMAW	/	Gas Metal Arc Welding
HF	/	Hig Frequency
HIL	/	Hold Item List

ACRONYM INDEX (ACRONYMS USED IN THIS MANUAL)

HIRF	/	High Intensity Radiated Fields
HOT	/	Hold Over Time
HSS	/	High Speed Steel
IFR	/	Instrument Flight Rules
ISO	/	International Standards Organization
IC	/	Integrated Circuits
ID	/	Inside Diameter
IDG	/	Integrated Drive Generator
IPC	/	Illustrated Parts Catalog
IT	/	Internal Tolerances
KVAR	/	Kilovolt-amperes Reactive
LBL	/	Left Buttock Line
LCD	/	Liquid Crystal Display
LEMAC	/	Leading Edge Mean Aerodynamic Chord
LRU	/	Line Replacement Unit
LSK	/	Line Select Key
MAC	/	Mean Aerodynamic Chord
MEL	/	Minimum Equipment List
MIG	/	Metal Inert Gas
ML	/	Mold Line
MMEL	/	Master Minimum Equipment List
MRBR	/	Maintenance Review Board Report
MPD	/	Maintenance Planning Document
MS	/	Military Standard
MSG	/	Maintenance Steering Group
NAA	/	National Aviation Authority
NAS	/	National Aerospace Standard
NAV/COM	/	Navigation/Communication
NDI	/	Non Destructive Inspection
NDT	/	Non Destructive Testing
NFPA	/	National Fire Protection Association
OAT	/	Outside Air Temperature
OEM	/	Original Equipment Manufacturer
P/N	/	Part Number
PAW	/	Plasma Arc Welding
POH	/	Pilots Operating Handbook
PSI	/	Per Square Inch
RBL	/	Right Buttock Line
RF	/	Radio Frequency
RM	/	Multiplier Restistance
RMS	/	Root Mean Square
RT	/	Total Resistance
RPM	/	Revolution per Minute
SAE	/	Society of Automotive Engineers
SB	/	Service Bulletin or Setback
SFM	/	Surface Feet per Minute

SMAW	/	Shielded Metal Arc Welding
S/N	/	Serial Number
SSTDR	/	Spread Spectrum Time Domain Reflectometer
TCDS	/	Type Certificate Data Sheet
TDR	/	Time Domain Reflectometer
TIG	/	Tungsten Inert Gas
TWD	/	Total Developed Width
UL	/	Underwriter's Laboratory
VHF	/	Very High Frequency
VME	/	Versa Model Eurocard
VOM	/	Volt-ohm-milliammeter
VPI	/	Vapor Phase Inhibitor
VXI	/	VME Expansion for Instrumentation
WL	/	Water Line

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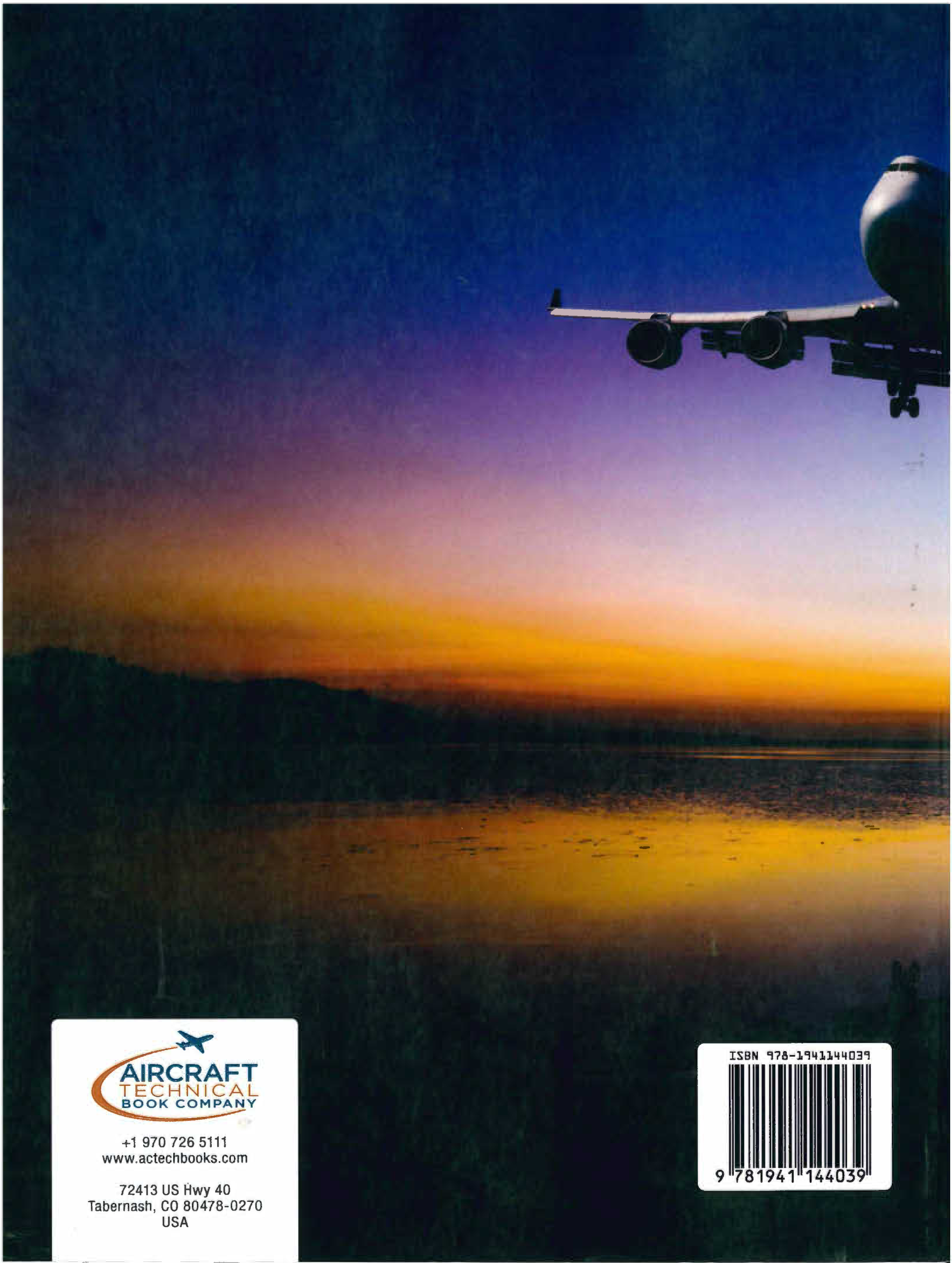

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