SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-1 NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

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SUBJECT NAME: AIRCRAFT SYSTEMS

AIRPLANE CONTROL SYSTEMS

Conventional Systems - Power assisted and fully powered flight controls – Power actuated systems – Engine control systems - Push pull rod system, flexible push pull rod system - Components- Modern control systems - Digital fly by wire systems - Auto pilot system active control Technology,

Introduction to Communication and Navigation systems Instrument, landing systems, VOR - CCV case studies.

CONTROL SYSTEMS

Introduction

The architecture of the flight control system, essential for all flight operations, has significantly changed throughout the years. Soon after the first flights, articulated surfaces were introduced for basic control, operated by the pilot through a system of cables and pulleys. This technique survived for decades and is now still used for small airplanes.

The introduction of larger airplanes and the increase of flight envelopes made the muscular effort of the pilot, in many conditions, not sufficient to contrast the aerodynamic hinge moments consequent to the surface deflection; the first solution to this problem was the introduction of aerodynamic balances and tabs, but further grow of the aircraft sizes and flight enveops brought to the need of powered systems to control the articulated aerodynamic surfaces.

Nowadays two great categories of flight control systems can be found: a full mechanical control on gliders and small general aviation, and a powered, or servo-assisted, control on large or combat aircraft.

One of the great additional effects after the introduction of servomechanisms is the possibility of using active control technology, working directly on the flight control actuators, for a series of benefits:

• compensation for deficiencies in the aerodynamics of the basic airframe;

• stabilisation and control of unstable airplanes, that have commonly higher performances;

• flight at high angles of attack;

• automatic stall and spinning protection;

• gust alleviation.

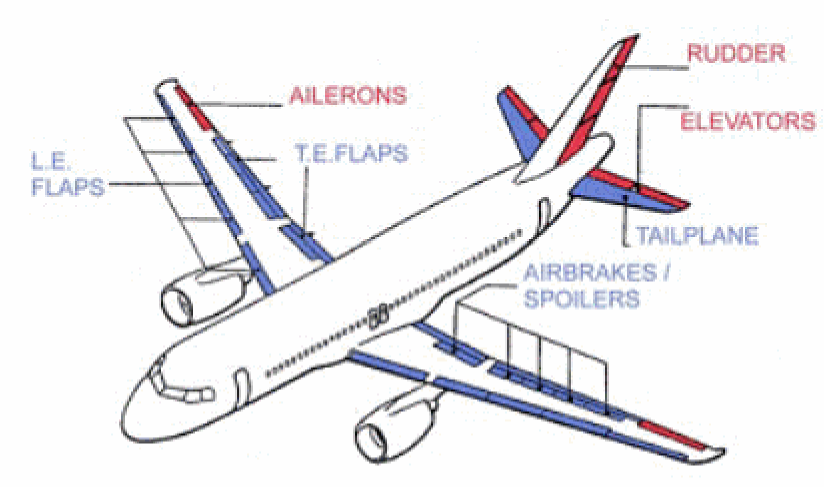


Fig. 1 – Flight control surfaces on airliner

A further evolution of the servo-assisted control is the fly-by-wire technique, based on signal processing of the pilot's demand before conversion into actuator control.

The number and type of aerodynamic surfaces to be controlled changes with aircraft category. Fig. 11 shows the classic layout for a conventional airliner. Aircraft have a number of different control surfaces:

those indicated in red form the primary flight control, i.e. pitch, roll and yaw control, basically obtained by deflection of elevators, ailerons and rudder (and combinations of them); those indicated in blue form the secondary flight control: high-lift and lift-dump devices, airbrakes, tail trimming, etc.

Modern aircraft have often particular configurations, typically as follows:

• elevons on delta wings, for pitch and roll control, if there is no horizontal tail;

• flaperons, or trailing edge flaps-ailerons extended along the entire span:

• tailerons, or stabillisers-ailerons (independently controlled);

• swing wings, with an articulation that allows sweep angle variation;

• canards, with additional pitch control and stabilization

Primary flight control capability is essential for safety, and this aspect is dramatically emphasized in the modern unstable (military) airplanes, which could be not controlled without the continued operation of the primary flight control surfaces. For this reason the actuation system in charge of primary control has a high redundancy and reliability, and is capable of operating close to full performance after one or more failures.

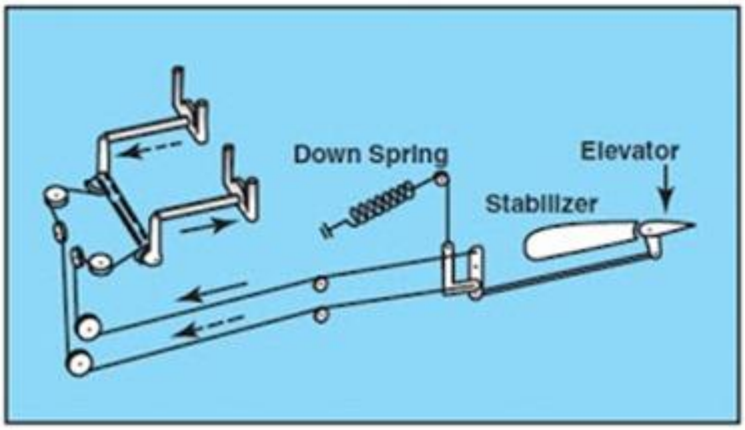
Secondary actuation system failure can only introduce flight restriction, like a flap less landing or reduction in the max angle of attack; therefore it is not necessary to ensure full operation after failures.

<u>FULLY POWERED FLIGHT CONTROLS</u>

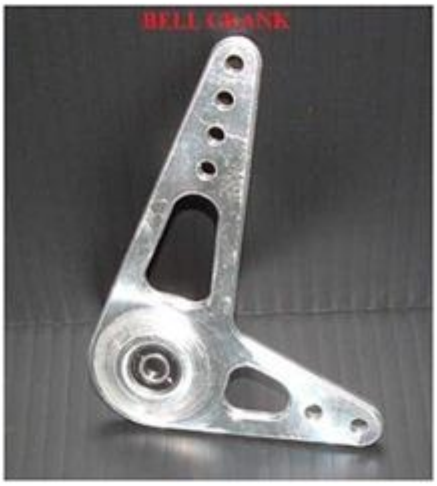
Fully powered Flight Controls

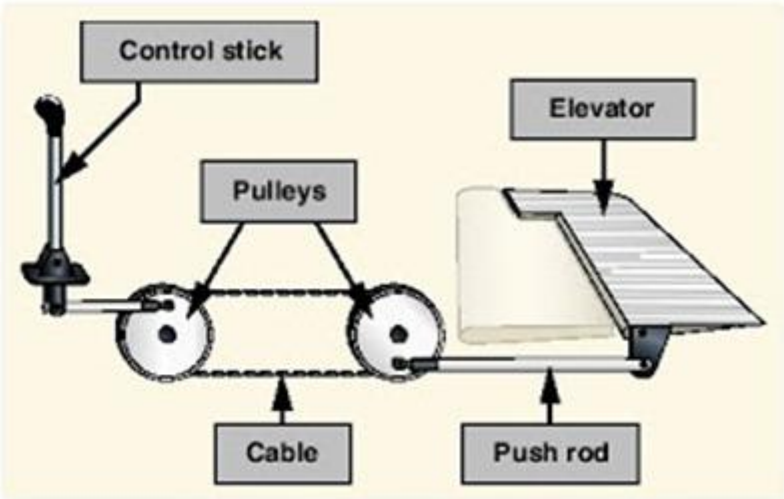
To actuate the control Surface the pilot has to give full effort. This is very tough to actuate the control surfaces through simple mechanical linkages. One can feel the equal toughness when raising the hand perpendicular to the airflow on riding a motorbike.

In this type of flight control system we will have



S.No	Item	Purpose
1	The cable	To transmit the power
2	Cable connector	To connect the cable
3	Turnbuckle	To adjust the Cable length
4	Fairlead	To guide the Cable
5	Pulley	To guide the in radial direction
6	Push pull rod	To go for and aft as per requirement
7	Control stick	To make orders for the remaining circuit





MECHANICAL FLIGHT CONTROL SYSTEM

The most basic flight control system designs are mechanical and date back to early aircraft. They operate with a collection of mechanical parts such as rods, cables, pulleys, and sometimes chains to transmit the forces of the flight deck controls to the control surfaces. Mechanical flight control systems are still used today in small general and sport category aircraft where the aerodynamic forces are not excessive. When the pilot pushes the control stick forward/backward the cable is getting tensed through the linkages and it causes the Control surface to move respectively.

<u>Power actuated systems</u>

Hydraulic control

When the pilot's action is not directly sufficient for a the control, the main option is a powered system that assists the pilot.

A few control surfaces on board are operated by electrical motors: as already discussed in a previous chapter, the hydraulic system has demonstrated to be a more suitable solution for actuation in terms of reliability, safety, weight per unit power and flexibility, with respect to the electrical system, then becoming the common tendency on most modern airplanes: the pilot, via the cabin components, sends a signal, or demand, to a valve that opens ports through which high pressure hydraulic fluid flows and operates one or more actuators.

The valve, that is located near the actuators, can be signalled in two different ways: mechanically or electrically; mechanical signalling is obtained by push-pull rods, or more commonly by cables and pulleys; electrical signalling is a solution of more modern and sophisticated vehicles and will be later on discussed.

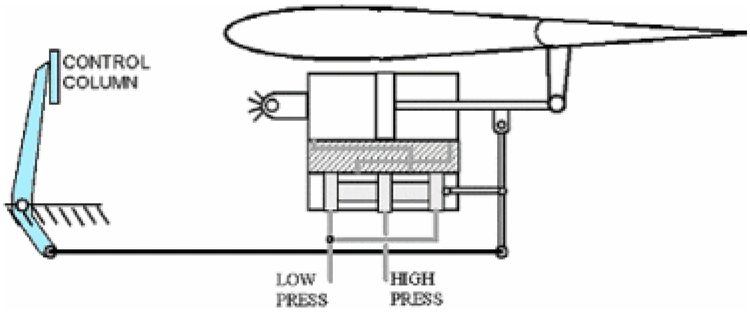
The basic principle of the hydraulic control is simple, but two aspects must be noticed when a powered control is introduced:

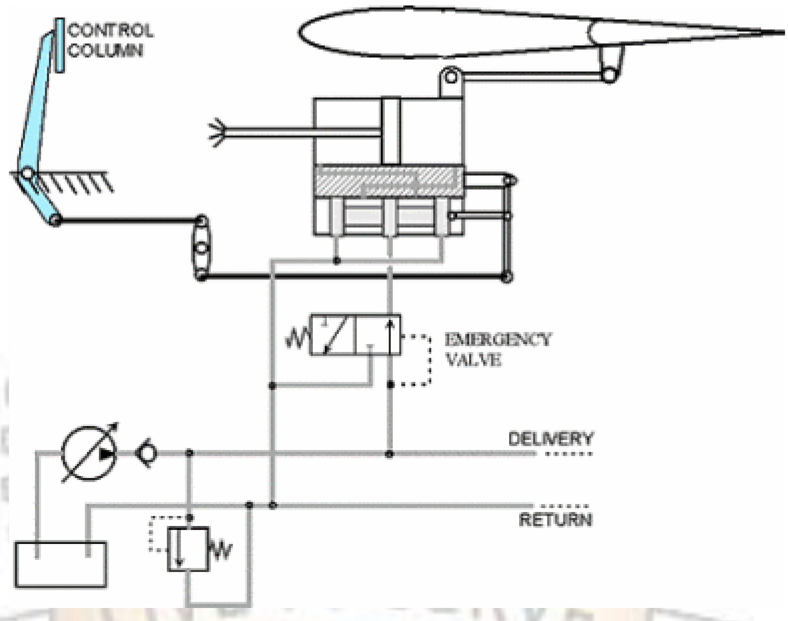
1. the system must control the surface in a proportional way, i.e. the surface response (deflection) must be function to the pilot's demand (stick deflection, for instance);

2. the pilot that with little effort acts on a control valve must have a feedback on the manoeuvre intensity.

The first problem is solved by using (hydraulic) servo-mechanisms, where the components are linked in such a way to introduce an actuator stroke proportional to the pilot's demand; many examples can be made, two of them are sketched, the second one including also the hydraulic circuit necessary for a correct operation.

In both cases the control valve housing is solid with the cylinder and the cabin column





Classic hydraulic servomechanisms

It has a mechanical linkage to drive the valve spool.

In the first case, the cylinder is hinged to the aircraft and, due to valve spool displacement and ports opening, the piston is moved in one direction or the other; the piston rod is also linked to the valve spool stick, in such a way that the piston movement brings the spool back towards its neutral position; when this is reached, the actuator stops, then obtaining a deflection that is proportional to the demand.

In the second case the piston is constrained to the aircraft; the cabin column controls the valve spool stick; this will result in a movement of the cylinder, and this brings the valve housing again towards the valve neutral position, then resulting in a stroke proportional to the pilot's demand. The hydraulic circuit also includes an emergency valve on the delivery segment to the control valve; if the delivery pressure drops, due for instance to a pump or engine failure, the emergency valve switches to the other position and links all the control valve inlets to the tank; this operation hydraulically unlocks the system, allowing the pilot for manual actuation of the cylinder.

It is clear now that the pilot, in normal hydraulic operating conditions, is requested for a very low effort, necessary to contrast the mechanical frictions of the linkage and the movement of the control valve: the pilot is then no more aware of the load condition being imposed to the aircraft.

For this reason an artificial feel is introduced in powered systems, acting directly on the cabin control stick or pedals. The simplest solution is a spring system, then responding to the pilot's demand with a force proportional to the stick deflection; this solution has of course the limit to be not sensitive to the actual flight conditions. A more sophisticated artificial feel is the so-called Q feel. This system receives data from the pitot-static probes, reading the dynamic pressure, or the difference between total (p_t) and static (p_s) pressure, that is proportional to the aircraft speed v through the air density ρ:

$$p_t - p_s = \frac{1}{2}\rho v^2 .$$

This signal is used to modulate a hydraulic cylinder that increases the stiffness in the artificial feel system, in such a way that the pilot is given a contrast force in the pedals or stick that is also proportional to the aircraft speed.

DIGITAL FLY BY WIRE SYSTEMS

Fly-By-Wire

In the 70's the fly-by-wire architecture was developed, starting as an analogue technique and later on, in most cases, transformed into digital. It was first developed for military aviation, where it is now a common solution; the supersonic Concorde can be considered a first and isolated civil aircraft equipped with a (analogue) fly-by-wire system, but in the 80's the digital technique was imported from military into civil aviation by Airbus, first with the A320, then followed by A319, A321, A330, A340, Boeing 777 and A380 (scheduled for 2005).

This architecture is based on computer signal processing and is schematically shown in fig. 6.5: the pilot's demand is first of all transduced into electrical signal in the cabin and sent to a group of independent computers (Airbus architecture substitute the cabin control column with a side stick); the computers sample also data concerning the flight conditions and servo-valves and actuators positions; the pilot's demand is then processed and sent to the actuator, properly tailored to the actual flight status.

The flight data used by the system mainly depend on the aircraft category; in general the following data are sampled and processed:

• pitch, roll, yaw rate and linear accelerations

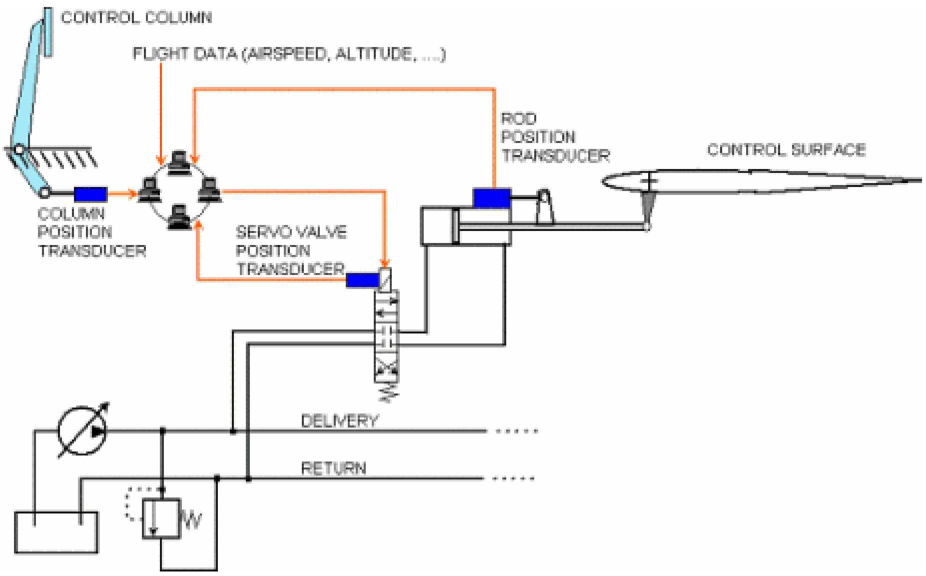
angle of attack and sideslip;

• airspeed/mach number, pressure altitude and radio altimeter indications;

• stick and pedal demands;

• other cabin commands such as landing gear condition, thrust lever position, etc.

The full system has high redundancy to restore the level of reliability of a mechanical or hydraulic system, in the form of multiple (triplex or quadruplex) parallel and independent lanes to generate and transmit the signals, and independent computers that process them; in many cases both hardware and software are different, to make the generation of a common error extremely remote, increase fault tolerance and isolation; in some cases the multiplexing of the digital computing and signal transmission is supported with an analogue or mechanical back-up system, to achieve adequate system reliability.



Fly-by-wire system

Fly-by-wire system between military and civil aircraft; some of the most important benefits are as follows:

• flight envelope protection (the computers will reject and tune pilot's demands that might exceed the airframe load factors);

• increase of stability and handling qualities across the full flight envelope, including the possibility of flying unstable vehicles;

• turbulence suppression and consequent decrease of fatigue loads and increase of passenger comfort;

• use of thrust vectoring to augment or replace lift aerodynamic control, then extending the aircraft flight envelope;

• drag reduction by an optimised trim setting;

• higher stability during release of tanks and weapons;

• easier interfacing to auto-pilot and other automatic flight control systems;

• weight reduction (mechanical linkages are substituted by wirings);

• maintenance reduction;

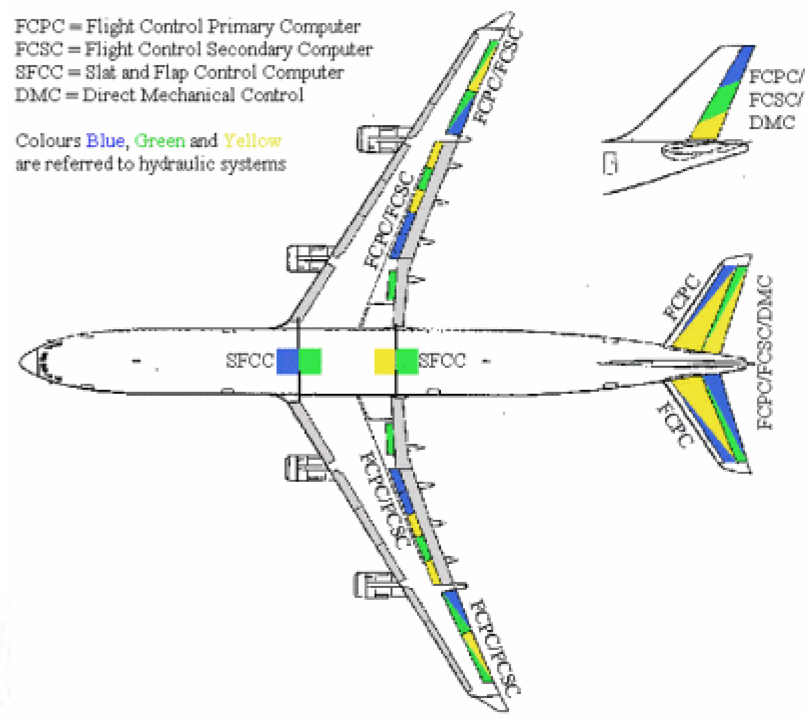
• reduction of airlines' pilot training costs (flight handling becomes very similar in an whole aircraft family).

the flight mode: ground, take-off, flight and flare. Transition between modes is smooth and the pilot is not affected in its ability to control the aircraft: in ground mode the pilot has control on the nose wheel steering as a function of speed, after lift-off the envelope protection is gradually introduced and in flight mode the aircraft is fully protected by exceeding the maximum negative and positive load factors (with and without high lift devices extracted), angle of attack, stall, airspeed/Mach number, pitch attitude, roll rate, bank angle etc; finally, when the aircraft approaches to ground the control is gradually switched to flare mode, where automatic trim is deactivated and modified flight laws are used for pitch control.

The control software is one of the most critical aspects of fly-by-wire. It is developed in accordance to very strict rules, taking into account the flight control laws, and extensive testing is performed to reduce the probability of error. The risk of aircraft loss due to flight control failure is 2×10^{-6} per flight hour for a sophisticated military airplane, that anyway has the ejection seat as ultimate solution; the risk is reduced to 10^{-9} per flight hour for a civil airplane, were occupants cannot evacuate the airplane during flight.

Figure below shows, as example, the fly-by-wire layout for the Airbus 340. Three groups of personal computers are used on board: three for primary control (FCPC), two for secondary control (FCSC) and two for high lift devices control (SFCC). The primary and secondary computers are based on different hardware; computers belonging to the same group have different software.

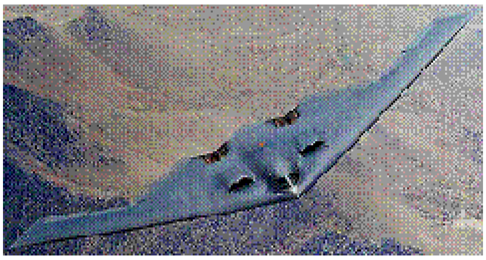
Two additional personal computers are used to store flight data.



A340 fly-by-wire layout, including hydraulic system indications

In the drawing the computer group and hydraulic system that control each surface are indicated (there are three independent hydraulic systems on the A340, commonly indicated as Blue, Yellow and Green). The leading edge flaps are linked together, and so are the trailing edge flaps, and then they are controlled by hydraulic units in the fuselage.

The drawing shows a considerable redundancy of the flight control system: the inboard and outboard ailerons, elevators and rudder are controlled by both the primary and secondary computers and operated by the three hydraulic sub-systems; the high lift devices are controlled by their specific computers and operated by the three hydraulic systems (Blue and Green for the leading edge,Yellow and Green for the trailing edge); the vertical stabiliser, having a secondary role, is controlled only by the secondary computers and operated by two hydraulic sub-systems. Thanks to this layout, first of all, in case of double hydraulic sub-system fault, the aircraft can be basically controlled with one hydraulic sub-system. Moreover, in case of total power black-out, the pilot can control the rudder and elevators by a mechanical back-up system, since the capability of this aircraft to land safely has been demonstrated with only limited pitch and yaw control.

Fly-by-wire architecture is inevitable for some aircraft categories: figure shows a typically unstable aircraft and a tilt rotor aircraft.  **Northrop B-2**	 **Bell-Boeing V-22** Fig – Need of fly-y-wire architecture for unstable (B-2) and thrust vectoring (V-22) airplanes

ENGINE CONTROL SYSTEMS

- It allow the engine to perform at maximum efficiency for a given condition
- Aids the pilot to control and monitor the operation of the aircraft's power plant
- Originally, engine control systems consisted of simple mechanical linkages controlled by the pilot then evolved and became the responsibility of the third pilot-certified crew member, the flight engineer
- By moving throttle levers directly connected to the engine, the pilot or the flight engineer could control fuel flow, power output, and many other engine parameters.
- Following mechanical means of engine control came the introduction of analog electronic engine control.
- Analog electronic control varies an electrical signal to communicate the desired engine settings
- It had its drawbacks including common electronic noise interference and reliability issues
- Full authority analogue control was used in the 1960s.
- It was introduced as a component of the Rolls Royce Olympus 593 engine of the supersonic transport aircraft Concorde. However the more critical inlet control was digital on the production aircraft.
- In the 1970s NASA and Pratt and Whitney experimented with the first experimental FADEC, first flown on an F-111 fitted with a highly modified Pratt & Whitney TF30 left engine.

Rolls Royce Olympus 593 engine

F-111C - Fighter – Bomber

Pratt & Whitney F100 – First Military Engine

Pratt & Whitney PW2000 - First Civil Engine fitted with FADEC

Pratt & Whitney PW4000 - First commercial "dual FADEC" engine.

The Harrier II Pegasus engine by Dowty & Smiths Industries Controls - The first FADEC in service.

Functions

- FADEC works by receiving multiple input variables of the current flight condition including air density, throttle lever position, engine temperatures, engine pressures, and many other parameters
- The inputs are received by the EEC and analyzed up to 70 times per second
- Engine operating parameters such as fuel flow, stator vane position, bleed valve position, and others are computed from this data and applied as appropriate.
- It controls engine starting and restarting.
- Its basic purpose is to provide optimum engine efficiency for a given flight condition.
- It also allows the manufacturer to program engine limitations and receive engine health and maintenance reports. For example, to avoid exceeding a certain engine temperature, the FADEC can be programmed to automatically take the necessary measures without pilot intervention.
- The flight crew first enters flight data such as wind conditions, runway length, or cruise altitude, into the flight management system (FMS). The FMS uses this data to calculate power settings for different phases of the flight.
- At takeoff, the flight crew advances the throttle to a predetermined setting, or opts for an auto-throttle takeoff if available.
- The FADECs now apply the calculated takeoff thrust setting by sending an electronic signal to the engines.
- There is no direct linkage to open fuel flow. This procedure can be repeated for any other phase of flight
- In flight, small changes in operation are constantly made to maintain efficiency.
- Maximum thrust is available for emergency situations if the throttle is advanced to full, but limitations can't be exceeded
- The flight crew has no means of manually overriding the FADEC.
- True full authority digital engine controls have no form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer
- If a total FADEC failure occurs, the engine fails
- If the engine is controlled digitally and electronically but allows for manual override, it is considered solely an EEC or ECU.
- An EEC, though a component of a FADEC, is not by itself FADEC. When standing alone, the EEC makes all of the decisions until the pilot wishes to intervene.

Safety

- With the operation of the engines so heavily relying on automation, safety is a great concern.
- Redundancy is provided in the form of two or more, separate identical digital channels.
- Each channel may provide all engine functions without restriction.
- FADEC also monitors a variety of analog, digital and discrete data coming from the engine subsystems and related aircraft systems, providing for fault tolerant engine control.

Applications

- FADECs are employed by almost all current generation jet engines, and increasingly in piston engines for fixed-wing aircraft and helicopters.
- The system replaces both magnetos in piston-engined aircraft, which makes costly magneto maintenance obsolete and eliminates carburetor heat, mixture controls and engine priming.
- Since, it controls each engine cylinder independently for optimum fuel injection and spark timing, the pilot no longer needs to monitor fuel mixture.
- More precise mixtures create less engine wear, which reduces operating costs and increases engine life for the average aircraft.
- Tests have also shown significant fuel savings

Advantages

- Better fuel efficiency
- Automatic engine protection against out-of-tolerance operations
- Safer as the multiple channel FADEC computer provides redundancy in case of failure
- Care-free engine handling, with guaranteed thrust settings
- Ability to use single engine type for wide thrust requirements by just reprogramming the FADECs**.**
- Provides semi-automatic engine starting
- Better systems integration with engine and aircraft systems
- Can provide engine long-term health monitoring and diagnostics
- Reduces the number of parameters to be monitored by flight crews
- Due to the high number of parameters monitored, the FADEC makes possible "Fault Tolerant Systems" (where a system can operate within required reliability and safety limitation with certain fault configurations)
- Can support automatic aircraft and engine emergency responses (e.g. in case of aircraft stall, engines increase thrust automatically).

Disadvantages

- No form of manual override available, placing full authority over the operating parameters of the engine in the hands of the computer.
- If a total FADEC failure occurs, the engine fails.
- In the event of a total FADEC failure, pilots have no way of manually controlling the engines for a restart, or to otherwise control the engine.
- With any single point of failure, the risk can be mitigated with redundant FADECs
- High system complexity compared to hydro mechanical, analogue or manual control systems
- High system development and validation effort due to the complexity

Auto pilot System

An autopilot is a mechanical, electrical, or hydraulic system used to guide a vehicle without assistance from a human being. An autopilot can refer specifically to aircraft, self-steering gear for boats, or auto guidance of space craft and missiles. The autopilot of an aircraft is sometimes referred to as "George", after one of the key contributors to its development.

Today, autopilots are sophisticated systems that perform the same duties as a highly trained pilot. In fact, for some in-flight routines and procedures, autopilots are even better than a pair of human hands. They don't just make flights smoother -they make them safer and more efficient. We'll look at how autopilots work by examining their main components, how they work together — and what happens if they fail.

Autopilots and Avionics

In the world of aircraft, the autopilot is more accurately described as the automatic flight control system (AFCS). An AFCS is part of an aircraft's avionics – the electronic systems, equipment and devices used to control key systems of the plane and its flight. In addition to flight control systems, avionics include electronics for communications, navigation, collision avoidance and weather. The original use of an AFCS was to provide pilot relief during tedious stages of flight, such as high-altitude cruising. Advanced autopilots can do much more, carrying out even highly precise maneuvers, such as landing an aircraft in conditions of zero visibility.

Although there is great diversity in autopilot systems, most can be classified according to the number of parts, or surfaces, they control. To understand this discussion, it helps to be familiar with the three basic control surfaces that affect an airplane's attitude.

Autopilots can control any or all of these surfaces. A single-axis autopilot manages just one set of controls, usually the ailerons. This simple type of autopilot is known as a "wing leveler" because, by controlling roll, it keeps the aircraft wings on an even keel.

A two-axis autopilot manages elevators and ailerons. Finally, a three-axis autopilot manages all three basic control systems: ailerons, elevators and rudder.

The invention of autopilot

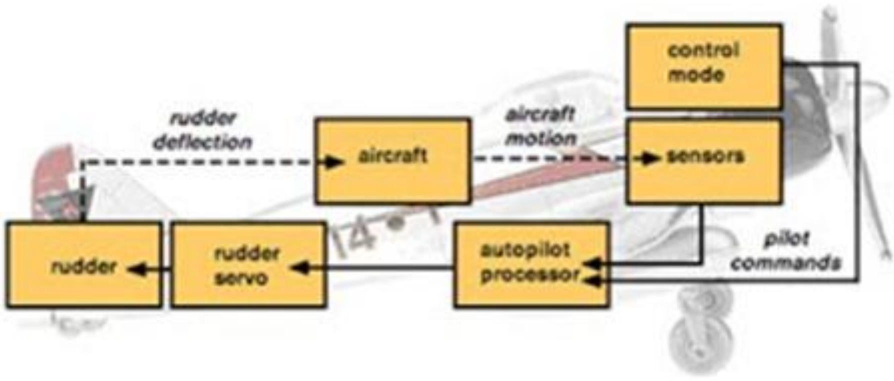
Famous inventor and engineer Elmer Sperry patented the gyrocompass in 1908, but it was his son, Lawrence Burst Sperry, who first flight-tested such a device in an aircraft. The younger Sperry's autopilot used four gyroscopes to stabilize the airplane and led to many flying firsts, including the first night flight in the history of aviation. In 1932, the Sperry Gyroscope Company developed the automatic pilot that Wiley Post would use in his first solo flight around the world.

Autopilot Parts

The heart of a modern automatic flight control system is a computer with several high-speed processors. To gather the intelligence required to control the plane, the processors communicate with sensors located on the major control surfaces. They can also collect data from other airplane systems and equipment, including gyroscopes, accelerometers, altimeters, compasses and airspeed indicators.

The processors in the AFCS then take the input data and, using complex calculations, compare it to a set of control modes. A control mode is a setting entered by the pilot that defines a specific detail of the flight. For example, there is a control mode that defines how an aircraft's altitude will be maintained. There are also control modes that maintain airspeed, heading and flight path.

These calculations determine if the plane is obeying the commands set up in the control modes. The processors then send signals to various servomechanism units. A servomechanism, or servo for short, is a device that provides mechanical control at a distance. One servo exists for each control surface included in the autopilot system. The servos take the computer's instructions and use motors or hydraulics to move the craft's control surfaces, making sure the plane maintains its proper course and attitude.



The above illustration shows how the basic elements of an autopilot system are related. For simplicity, only one control surface — the rudder — is shown, although each control surface would have a similar arrangement. Notice that the basic schematic of an autopilot looks like a loop, with sensors sending data to the autopilot computer, which processes the information and transmits signals to the servo, which moves the control surface, which changes the attitude of the plane, which creates a new data set in the sensors, which starts the whole process again. This type of feedback loop is central to the operation of autopilot systems.

Autopilot Control Systems

An autopilot is an example of a control system. Control systems apply an action based on a measurement and almost always have an impact on the value they are measuring. A classic example of a control system is the negative feedback loop that controls the thermostat in your home. Such a loop works like this:

1. Its summertime and a homeowner set his thermostat to a desired room temperature say 78°F.

2. The thermostat measures the air temperature and compares it to the preset value.

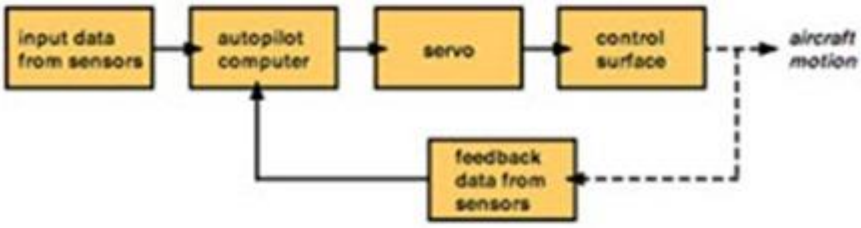
3. Over time, the hot air outside the house will elevate the temperature inside the house. When the temperature inside exceeds 78°F, the thermostat sends a signal to the air conditioning unit.

4. The air conditioning unit clicks on and cools the room.

5. When the temperature in the room returns to 78°F, another signal is sent to the air conditioner, which shuts off.

It’s called a negative feedback loop because the result of a certain action (the air conditioning unit clicking on) inhibits further performance of that action. All negative feedback loops require a receptor, a control center and an effector. In the example above, the receptor is the thermometer that measures air temperature. The control center is the processor inside the thermostat. And the effector is the air conditioning unit.

Automated flight control systems work the same way. Let’s consider the example of a pilot who has activated a single-axis autopilot — the so-called wing leveler we mentioned earlier.



1. The pilot sets a control mode to maintain the wings in a level position.

2. However, even in the smoothest air, a wing will eventually dip.

3. Position sensors on the wing detect this deflection and send a signal to the autopilot computer.

4. The autopilot computer processes the input data and determines that the wings are no longer level.

5. The autopilot computer sends a signal to the servos that control the aircraft's ailerons. The signal is a very specific command telling the servo to make a precise adjustment.

a) Each servo has a small electric motor fitted with a slip clutch that, through a bridle cable, grips the aileron cable. When the cable moves, the control surfaces move accordingly.

b) As the ailerons are adjusted based on the input data, the wings move back toward level.

c) The autopilot computer removes the command when the position sensor on the wing detects that the wings are once again level.

d) The servos cease to apply pressure on the aileron cables.

This loop, shown above in the block diagram, works continuously, many times a second, much more quickly and smoothly than a human pilot could. Two- and three-axis autopilots obey the same principles, employing multiple processors that control multiple surfaces. Some airplanes even have auto thrust computers to control engine thrust. Autopilot and auto thrust systems can work together to perform very complex maneuvers.

Autopilot Failure

Autopilots can and do fail. A common problem is some kind of servo failure, either because of a bad motor or a bad connection. A position sensor can also fail, resulting in a loss of input data to the autopilot computer. Fortunately, autopilots for manned aircraft are designed as a failsafe — that is, no failure in the automatic pilot can prevent effective employment of manual override. To override the autopilot, a crew member simply has to disengage the system, either by flipping a power switch or, if that doesn't work, by pulling the autopilot circuit breaker.

Some airplane crashes have been blamed on situations where pilots have failed to disengage the automatic flight control system. The pilots end up fighting the settings that the autopilot is administering; unable to figure out why the plane won't do what they're asking it to do. This is why flight instruction programs stress practicing for just such a scenario. Pilots must know how to use every feature of an AFCS, but they must also know how to turn it off and fly without it. They also have to adhere to a rigorous maintenance schedule to make sure all sensors and servos are in good working order. Any adjustments or fixes in key systems may require that the autopilot be tweaked. For example, a change made to gyro instruments will require realignment of the settings in the autopilot's computer.

Modern Autopilot Systems

Many modern autopilots can receive data from a Global Positioning System (GPS) receiver installed on the aircraft. A GPS receiver can determine airplane's position in space by calculating its distance from three or more satellites in the GPS network. Armed with such positioning information, an autopilot can do more than keep a plane straight and level — it can execute a flight plan.

Most commercial jets have had such capabilities for a while, but even smaller planes are incorporating sophisticated autopilot systems. New Cessna 182s and 206s are leaving the factory with the Garmin G1000 integrated cockpit, which includes a digital electronic autopilot combined with a flight director. The Garmin G1000 delivers essentially all the capabilities and modes of a jet avionics system, bringing true automatic flight control to a new generation of general aviation planes.Wiley Post could have only dreamed of such technology back in 1933.

Communications

Communications connect the flight deck to the ground, and the flight deck to the passengers. On board communications are provided by public address systems and aircraft intercoms.

The VHF aviation communication system works on the airband of 118.000 MHz to 136.975 MHz. Each channel is spaced from the adjacent by 8.33 kHz. amplitude modulation (AM) is used. The conversation is performed by simplex mode. Aircraft communication can also take place using HF (especially for trans-oceanic flights) or satellite communication.

Navigation

Navigation is the determination of position and direction on or above the surface of the Earth. Avionics can use satellite-based systems (such as GPS and WAAS), ground-based systems (such as VOR or LORAN), or any combination thereof. Older avionics required a pilot or navigator to plot the intersection of signals on a paper map to determine an aircraft's location; modern systems, like the Bendix/King KLN 90B, calculate the position automatically and display it to the flight crew on moving map displays.

Monitoring

Glass cockpits started to come into civilian use with the Gulfstream G-IV private jet in 1985. However, these largely stemmed from the need of military pilots to quickly deal with increasing amounts of flight data while concentrating on the task (dogfight with enemy aircraft, detection of surface targets, etc.) Display systems present sensor data that allows the aircraft to fly safely in a more flexible manner as skipping unnecessary information was not possible with the earlier mechanical (usually dial-type) instruments. Almost all new aircraft include glass cockpits. ARINC 818, titled Avionics Digital Video Bus, is a protocol used by many new glass cockpit displays in both commercial and military aircraft.

Aircraft flight control systems

Airplanes and helicopters have means of automatically controlling flight. They reduce pilot workload at important times (like during landing, or in hover), and they make these actions safer by 'removing' pilot error. The first simple auto-pilots were used to control heading and altitude and had limited authority on things like thrust and flight control surfaces. In helicopters, auto stabilization was used in a similar way. The old systems were electromechanical in nature until very recently.

The advent of fly by wire and electro actuated flight surfaces (rather than the traditional hydraulic) has increased safety. As with displays and instruments, critical devices which were electro-mechanical had a finite life. With safety critical systems, the software is very strictly tested.

Collision-avoidance systems

To supplement air traffic control, most large transport aircraft and many smaller ones use a TCAS (Traffic Alert and Collision Avoidance System), which can detect the location of nearby aircraft, and provide instructions for avoiding a midair collision. Smaller aircraft may use simpler traffic alerting systems such as TPAS, which are passive (they do not actively interrogate the transponders of other aircraft) and do not provide advisories for conflict resolution.

To help avoid collision with terrain, (CFIT) aircraft use systems such as ground-proximity warning systems (GPWS), radar altimeter being the key element in GPWS. A major weakness of (GPWS) is the lack of "look-ahead" information as it only provides altitude above terrain "look-down". To overcome this weakness, modern aircraft use the Terrain Awareness Warning System (TAWS).

Weather systems

Weather systems such as weather radar (typically Arinc 708 on commercial aircraft) and lightning detectors are important for aircraft flying at night or in Instrument meteorological conditions, where it is not possible for pilots to see the weather ahead. Heavy precipitation (as sensed by radar) or severe turbulence (as sensed by lightning activity) are both indications of strong convective activity and severe turbulence, and weather systems allow pilots to deviate around these areas.

Lightning detectors like the Storm scope or Strike finder have become inexpensive enough that they are practical for light aircraft. In addition to radar and lightning detection, observations and extended radar pictures (such as NEXRAD) are now available through satellite data connections, allowing pilots to see weather conditions far beyond the range of their own in-flight systems. Modern displays allow weather information to be integrated with moving maps, terrain, traffic, etc. onto a single screen, greatly simplifying navigation.

Aircraft management systems

There has been a progression towards centralized control of the multiple complex systems fitted to aircraft, including engine monitoring and management. Health and Usage Monitoring Systems (HUMS) are integrated with aircraft management computers to allow maintainers early warnings of parts that will need replacement.

The integrated modular avionics concept proposes an integrated architecture with application software portable across an assembly of common hardware modules. It has been used in Fourth generation jet fighters and the latests generation of airliners.

Mission or tactical avionics

Military aircraft have been designed either to deliver a weapon or to be the eyes and ears of other weapon systems. The vast array of sensors available to the military is used for whatever tactical means required. As with aircraft management, the bigger sensor platforms (like the E-3D, JSTARS, ASTOR, Nimrod MRA4, Merlin HM Mk 1) have mission management computers.

Police and EMS aircraft also carry sophisticated tactical sensors.

Military communications

While aircraft communications provide the backbone for safe flight, the tactical systems are designed to withstand the rigours of the battle field. UHF, VHF Tactical (30-88 MHz) and SatCom systems combined with ECCM methods, and cryptography secure the communications. Data links like Link 11, 16, 22 and BOWMAN, JTRS and even TETRA provide the means of transmitting data (such as images, targeting information etc.).

Radar

Airborne radar was one of the first tactical sensors. The benefit of altitude providing range has meant a significant focus on airborne radar technologies. Radars include airborne early warning (AEW), anti-submarine warfare (ASW), and even weather radar (Arinc 708) and ground tracking/proximity radar.

Besides its primary role as the main sensor for fighters, the military uses radar in fast jets to help pilots fly at low levels. Earlier models were just separate devices often mounted under the primary (e.g. air-to-air) unit and covered with the same randome; modern technologies allow the creation of multi-functional, weapon-controlling radars that additionally perform such terrain-mapping. While the civil market has had weather radar for a while, there are strict rules about using it to navigate the aircraft.

Sonar

Dipping sonar fitted to a range of military helicopters allows the helicopter to protect shipping assets from submarines or surface threats. Maritime support aircraft can drop active and passive sonar devices (Sonobuoys) and these are also used to determine the location of hostile submarines.

Electro-Optics

Electro-optic systems include Forward Looking Infrared (FLIR), and Passive Infrared Devices (PIDS). These are all used to provide imagery to crews. This imagery is used for everything from Search and Rescue through to acquiring better resolution on a target.

ESM/DAS

Electronic support measures and defensive aids are used extensively to gather information about threats or possible threats. They can be used to launch devices (in some cases automatically) to counter direct threats against the aircraft. They are also used to determine the state of a threat and identify it.

Police and air ambulance

Police and EMS aircraft (mostly helicopters) are now a significant market. Military aircraft are often now built with the capability to support response to civil disobedience. Police helicopters are almost always fitted with video/FLIR systems allowing them to track suspects. They can also be equipped with searchlights and loudspeakers.

EMS and police helicopters will be required to fly in unpleasant conditions which may require more aircraft sensors, some of which were until recently considered purely for military aircraft.

LONG RANGE NAVIGATION (LORAN).

The LORAN has been an effective alternative to Rho/Theta R-Nav systems. Hyperbolic systems require waypoint designation in terms of latitude and longitude, unlike original R-Nav (distance navigation) systems, which define waypoints in terms of distance (Rho) and angle (Theta) from established VOR or Tacan facilities. Accuracy is better than the VOR/Tacan system but LORAN is more prone to problems with precipitation static. Proper bonding of aircraft structure and the use of high-quality static wicks will not only produce improved LORAN system performance, but can also benefit the very high frequency 9/27/01 AC 43.13-1B **CHG 1** Par 12-16 Page 12-7 (VHF) navigation and communications systems. This system has an automatic test equipment (ATE).

NOTE: Aircraft must be outside of hangar for LORAN to operate. Normally self test check units, verification of position, and loading of flight plan will verify operation verification of proper flight manual supplements and operating handbooks on board, and proper software status can also be
verified.

GLOBAL POSITIONING SYSTEM (GPS).

The GPS is at the forefront of present generation navigation systems. This space-based navigation system is based on a 4-satellite system and is highly accurate (within 100 meters) for establishing position. The system is unaffected by weather and provides a world-wide common grid reference system. Database updating and antenna maintenance are of primary concern to the GPS user.

NOTE: Aircraft must be outside of hangar for ground test of GPS. 12-18. AUTOPILOT SYSTEMS.

Automatic Flight Control Systems (AFCS)
are the most efficient managers of aircraft performance and control. There are three kinds of autopilot; two axes, three axes, and three axes with coupled approach capability. Attention must be given to the disconnect switch operation, aural and visual alerts of automatic and

intentional autopilot disconnects, override forces and mode annunciation, servo operation, rigging and bridle cable tension, and condition. In all cases the manufacturer's inspection and maintenance instructions must be followed.

FLIGHT DATA RECORDER.

The flight data recorder is housed in a crush-proof container located near the tail section of the aircraft. The tape unit is fire resistant, and contains a radio transmitter to help crash investigators locate the unit under water. Inspection/ Operational checks include:
a. Check special sticker on front of the flight data recorder for the date of the next tape replacement, if applicable.
b. Remove recorder magazine and inspect tape for the following:
(1) broken or torn tape,
(2) proper feed of tape, and
(3) all scribes were recording properly for approximately the last hour of flight.
c. Conditions for tape replacement (as applicable): AC 43.13-1B **CHG 1** 9/27/01 Page 12-10 Par 12-23
(1) There is less than 20 hours remaining in the magazine as read on the *tape remaining* indicator.
(2) Tape has run out.
(3) Broken tape.
(4) After hard landings and severe air turbulence have been encountered as reported by the pilots. After the same tape has been in use 1 year (12 months), it must be replaced.
(5) Ensure that a correlation test has been performed and then recorded in the aircraft records.

d. Refer to the specific equipment manufacturer's manuals and procedures.

a. **The state-of-the art Solid-State Flight Data Recorder (SSFDR)** is a highly flexible model able to support a wide variety of aeronautical radio, incorporated (ARINC) configurations. It has a Built-In Test Equipment (BITE) that establishes and monitors the mission fitness of the hardware. BITE performs verification after storage (read after write) of flight data and status condition of the memory. These recorders have an underwater acoustic beacon mounted on its front panel which must be returned to their respective manufacturer's for battery servicing. For maintenance information refer to the equipment or aircraft manufacture's maintenance instruction manual.

COCKPIT VOICE RECORDERS (CVR).

CVR's are very similar to flight data recorders. They look nearly identical and operate in almost the same way. CVR's monitors the last 30 minutes of flight deck conversations and radio communications. The flight deck conversations are recorded via the microphone monitor panel located on the flight deck. This panel is also used to test the system and erase the tape, if so desired. Before operating the erase CVR mode, consult the operational manual of the manufacturer for the CVR
. **a. Playback is possible** only after the recorder is removed from the aircraft.
b. Refer to the specific equipment manufacturer's manuals and procedures.
c. The Solid State Cockpit Voice Recorder system is composed of three essential components a solid state recorder, a control unit (remote mic amplifier), and an area microphone. Also installed on one end of the recorder is an Under water Locator Beacon (ULB). The recorder accepts four separate

audio inputs: pilot, copilot, public address/ third crew member, and cockpit area microphone and where applicable, rotor speed input and flight data recorder synchronization tone input. For maintenance information refer to the equipment manufacturer's maintenance manual.

WEATHER RADAR.

Ground performance shall include antenna rotation, tilt, indicator brilliance, scan rotation, and indication of received echoes. It must be determined that no objectionable interference from other electrical/electronic equipment appears on the radar indicator, and that the radar system does not interfere with the operation of any of the aircraft's communications or navigation systems.

ALTIMETERS.

Aircraft conducting operations in controlled airspace under instrument flight rule (IFR) are required to have their static system(s) and each altimeter instrument inspected and tested within the previous 24 calendar months. Frequent functional checks of all altimeters and automatic pressure altitude reporting systems are recommended.

a. The tests required must be performed by:
(1) The manufacturer of the aircraft on which the tests and inspection are to be performed.
(2) A certificated repair station properly equipped to perform those functions and holding:

- **(a)** An instrument rating Class I.
- **(b)** A limited instrument rating appropriate to the make and model of appliance to be tested.
- **(c)** A certified/qualified mechanic with an airframe rating(static system tests and inspections only). Any adjustments shall be accomplished only by an instrument shop certified/ qualified person using proper test equipment and adequate reference to the manufacturer's maintenance manuals. The altimeter correlation adjustment shall not be adjusted in the field. Changing this adjustment will nullify the correspondence between the basic test equipment calibration standards and the altimeter. It will also nullify correspondence between the encoding altimeter and its encoding digitizer or the associated blind encoder.

b. Examine the altimeter face for evidence of needle scrapes or other damage. Check smoothness of operation, with particular attention to altimeter performance during decent.
c. Contact an appropriate air traffic facility for the pressure altitude displayed to the controller from your aircraft. Correct the reported altitude as needed, and compare to the AC 43.13-1B **CHG 1** 9/27/01 Page 12-8 Par 12-20 reading on the altimeter instrument. The difference must not exceed 125 feet.

TRANSPONDERS.

There are three modes (types) of transponders that can be used on various aircraft. Mode A provides a (non altitude-reporting) four-digit coded reply; Mode C provides a code reply identical to Mode A with an altitude-reporting signal; and Mode S has the same capabilities as Mode A and Mode C and responds to traffic alert and collision avoidance system (TCAS)-

Equipped Aircraft. **a. Ground ramp equipment** must be used to demonstrate proper operation. Enough codes must be selected so that each switchposition is checked at least once. Low and high sensitivity operation must be checked. Identification operation must be checked. Altitude reporting mode must be demonstrated. Demonstrate that the transponder system does not interfere with other systems aboard the aircraft, and that other equipment does not interfere with transponder operation. Special consideration must be given to other pulse equipment, such as DME and weather radar.

b. All transponders must be tested every 24-calendar months, or during an annual inspection,
if requested by the owner. The test must be conducted by an authorized avionics repair facility.

EMERGENCY LOCATOR TRANS- MITTERS (ELT).

The ELT must be evaluated in accordance with TSO-C91a, TSO-C126 for 406 MHz ELT's, or later TSO's issued for ELT's. ELT installations must be examined for potential operational problems at least once a year (section 91.207(d)). There have been numerous instances of interaction between ELT and other VHF installations. Antenna location should be as far as possible from other antennas to prevent efficiency losses. Check ELT antenna installations in close proximity to other VHF antennas for suspected interference. Antenna patterns of previously installed VHF antennas could be measured after an ELT installation. Tests should be conducted during the first 5 minutes after any hour. If operational tests must be made outside of this time frame, they should be coordinated with the nearest FAA Control Tower or FSS. Tests should be no longer than three audible sweeps.

INSPECTION OF ELT.

An inspection of the following must be accomplished by a properly certified person or repair station within 12-calendar months after the last inspection:

a. Proper Installation.
(1) Remove all interconnections to the ELT unit and ELT antenna. Visually inspect and confirm proper seating of all connector pins. Special attention should be given to coaxial center conductor pins, which are prone to retracting into the connector housing.
(2) Remove the ELT from the mount and inspect the mounting hardware for proper installation and security.
(3) Reinstall the ELT into its mount and verify the proper direction for crash activation. Reconnect all cables. They should have some slack at each end and should be properly secured to the airplane structure for support and protection.
b. Battery Corrosion. Gain access to the ELT battery and inspect. No corrosion should be detectable. Verify the ELT battery is approved and check its expiration date.

b. **Operation of the Controls and Crash Sensor.** Activate the ELT using an applied force. Consult the ELT manufacturer's instructions before activation. The direction for mounting and force activation is indicated on 9/27/01 AC 43.13-1B **CHG 1** Par 12-22 Page 12-9 the ELT. A TSO-C91 ELT can be activated by using a quick rap with the palm. A TSO-C91a ELT can be activated by using a rapid forward (throwing) motion coupled by a rapid reversing action. Verify that the ELT can be activated using a watt meter, the airplane's VHF radio communications receiver tuned to 121.5 MHz, or other means (see NOTE 1). Insure that the "G" switch has been reset if applicable.

c. **For a Sufficient Signal Radiated From its Antenna.** Activate the ELT using the ON or ELT TEST switch. A low-quality AM broadcast radio receiver should be used to determine if energy is being transmitted from the antenna. When the antenna of the AM broadcast radio receiver (tuning dial on any setting) is held about 6 inches from the activated ELT antenna, the ELT aural tone will be heard (see NOTE 2 and 3). **Verify that All Switches are Properly Labeled and Positioned**.

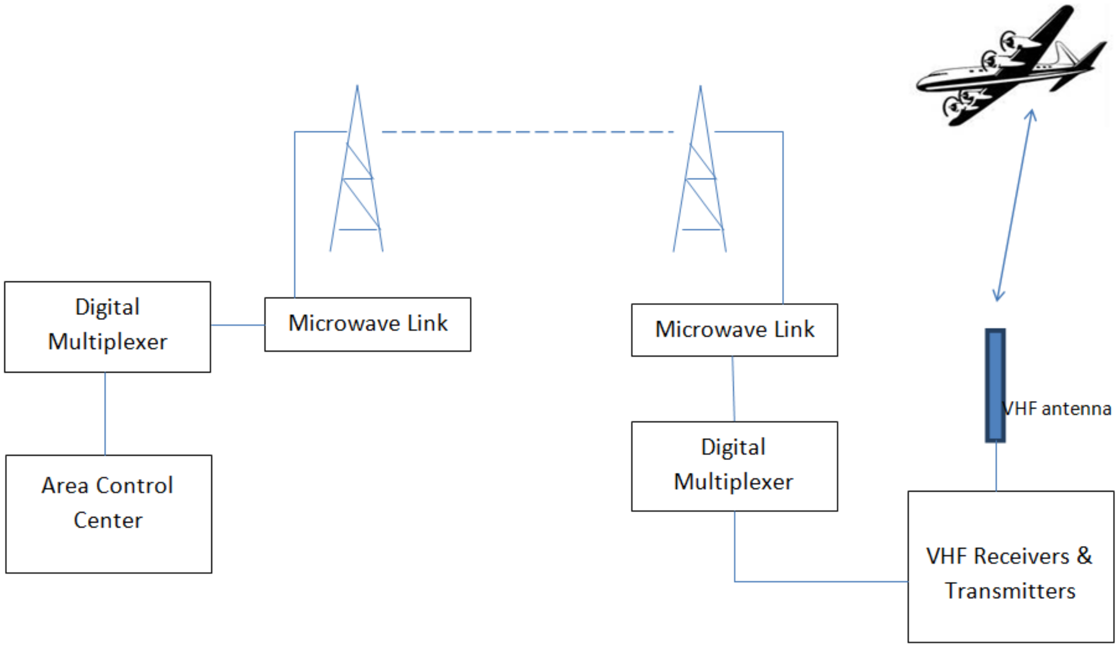
f. Record the Inspection. Record the inspection in the aircraft maintenance records according to 14 CFR part 43, section 43.9. We suggest the following: I inspected the Make/Model ______________
ELT system in this aircraft according to applicable Aircraft and ELT manufacturer's instructions and applicable FAA guidance and found that it meets the requirements of section 91.207(d).

VOR

The Very High-Frequency Omni directional Range (VOR) system is a type of air navigation system. Though older than GPS, VORs are very commonly used and have been a very reliable source of navigation information since the 1960s, and it still serves as a useful navigational aid for many pilots without GPS services.

VOR System Components

- A VOR system is made up of a ground component and aircraft receiver component.
- The VOR ground stations are located both on and off airports to provide guidance information to pilots both en route and during arrival and departure. The VOR system is widely used, and pilots can still use VORs to navigate throughout the country.
- Aircraft equipment includes a VOR antenna, a VOR frequency selector, and a cockpit instrument. The instrument type varies but will consist of one of the following: an Omni-Bearing Indicator (OBI), Horizontal Situation Indicator (HSI) or a Radio Magnetic Indicator (RMI), or a combination of two different kinds.
- Distance Measuring Equipment (DME) is often collocated with a VOR to give pilots a precise indication of the aircraft's distance from the VOR station.
- VORs have AM voice broadcast ability, and each VOR has its own Morse code identifier that it broadcasts to pilots. It ensures that pilots are navigating from the correct VOR station, as there are often many VOR facilities within range of a single aircraft.



Very High-Frequency Omni directional Range (VOR) system Block diagram.

Working principle

- The VOR ground station is aligned with magnetic north, and it emits two signals -- a 360-degree sweeping variable signal and an Omni-directional reference signal. The signals are compared by the aircraft's receiver, and a phase difference between them is measured, giving a precise radial position of the aircraft and displaying it on the OBI, HSI or RMI.
- VORs come with different service volumes and dimensions: High, Low and Terminal. High-altitude VORs can be used up to 60,000 feet and 130 nautical miles wide. Low-altitude VORs service aircraft up to 18,000 feet and up to 40 nautical miles wide. Terminal VORs go up to 12,000 feet and 25 nautical miles. The network of VORs typically provides thorough coverage along published VFR and IFR routes.

VOR Errors

- ➢ As with any system, the VOR comes with some potential problems. While it's more accurate and usable than the old NDB system, the VOR is still a line-of-sight instrument. Pilots flying in low or mountainous terrain may find it difficult to identify a VOR facility successfully.
- ➢ Also, there exists a "cone of confusion" when flying near a VOR. For a brief period when an aircraft flies near or over the top of a VOR station, the aircraft instrument will give erroneous readings.
- ➢ Finally, VOR ground systems require constant maintenance, and they are commonly out of order for short periods of time while maintenance is performed.

Practical Applications of the VOR Navigation System:

- ➢ After tuning in a VOR facility's frequency and identifying that the Morse code is correct, the pilot will be able to determine which radial to or from the VOR station on which the aircraft is located.
- ➢ The OBI, HSI or RMI indicator in the cockpit looks like a compass or a heading indicator, with a superimposed Course Deviation Indicator (CDI) needle on it. The CDI will align itself with the radial that the aircraft is on. Paired with DME, a pilot can determine a precise location from the station.
- ➢ Also, the use of two VOR stations makes determining a precise location even more accurate by using cross-radials, even without DME.

- Pilots fly certain radials to or from VORs as a primary way of navigating. Airways are often designed to and from VOR facilities for ease of use.
- In its more basic form, a VOR facility can be used to go directly to an airport. A large number of VOR facilities are located on airport property, allowing even student pilots to fly directly to a VOR to find the airport easily.
- The VOR system is at risk of being decommissioned by the FAA due to the popularity of new technology such as GPS, WAAS, and ADS-B. For the time being, pilots will continue to use VORs as a primary navigational aid, but in the distant future, as more and more aircraft are equipped with GPS receivers, VORs will most likely be retired from use.

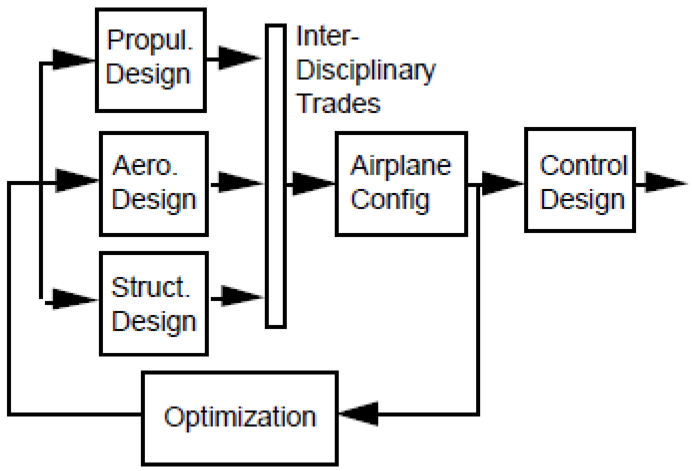
Introduction CCV

In the mid 1970s, flight control research was focused on the concept of a Control Configured Vehicle (CCV). The goal of CCV design was to improve aircraft performance through the use of active control.CCV concepts under study at the time included: improved handling qualities, flight envelope limiting, relaxed static stability, gust alleviation, maneuver load control, and active structural mode control. Many of the concepts were flight tested and, in some cases, the CCV design concept allowed for modifications of existing aircraft. For example, CCV concepts were used on the L-1011 aircraft to increase the gross take-off weight while minimizing wing structural changes. A design methodology is needed to find the optimum combination of control system development cost and total aircraft system performance and cost. Kehrer, for example, describes how use of stability augmentation methods during preliminary design led to a 150 inch reduction in fuselage length for the Boeing 2707-300 Supersonic Transport (SST).

The shortened fuselage also led to reduced vertical tail size and gear length, with a weight savings of 6,000 lbs and range increase of 225 nautical miles. The weight savings reported by the Boeing study came at the expense of an increase in control system development cost, however. The total cost of the Boeing SST flight and avionics systems were estimated to be double that of the Boeing 747. As a result, there was an assumption that the increased flight control system design complexity and cost (risk) was balanced by the performance improvements in the new design.

The first CCV aircraft was the YB-49 flying wing. The YB-49 was actually flight demonstrated at a 10% unstable static margin, using an automatic control system. The X-29 forward-swept wing aircraft represents one of the more recent aircraft where in the ability to use active control had a significant impact on the airframe configuration. To achieve the performance benefits of the forward swept wing-canard configuration, the X-29 airplane was required to have a 35% unstable static margin. Even more recently, the F-117 and B-2 aircraft undoubtedly have poor bare-airframe stability characteristics but have reached production status because of active control.

Each of these aircraft configurations would not be feasible had the impact of active control not been considered at the conceptual design stage. The CCV concept fostered research on the impact of active control on aircraft configurations. During this early development period, the realization that aircraft performance gains were achievable using active control was an important motivation for multivariable control research. Today, the use of a multivariable flight control system is accepted and even expected. However, to a large extent, a quantifiable impact of active control on the aircraft configuration design and layout has not been exploited. Design rules are certainly being used within airframe companies to include the benefit of active control on the configuration design. However, there appears to be no current systematic method through which the configuration can be optimized within the constraints of control system structure and control power.



(A) Traditional Aircraft Design Process

Figure (A) illustrates the traditional and CCV design processes as described. The "traditional" design process includes flight control design on the outside of the primary configuration selection and optimization loop. This process is represented by Figure (A). Basically, the airplane configuration is established through optimization amongst the aerodynamic, propulsion, and structures disciplines. The flight control design is not conducted until after the final aircraft configuration has been selected. Therefore, the design of the flight control system has no impact on the airplane configuration.

The CCV design process is illustrated by Figure (B). The CCV design concept includes active control system design in parallel with the other disciplines for configuration selection and optimization. Thus, flight control design directly affects configuration selection. However, the implication is that a complete control system design is carried out for each configuration iteration. One of the primary drawbacks of this approach, and others like it, is that a complete control system is designed at each iteration step.

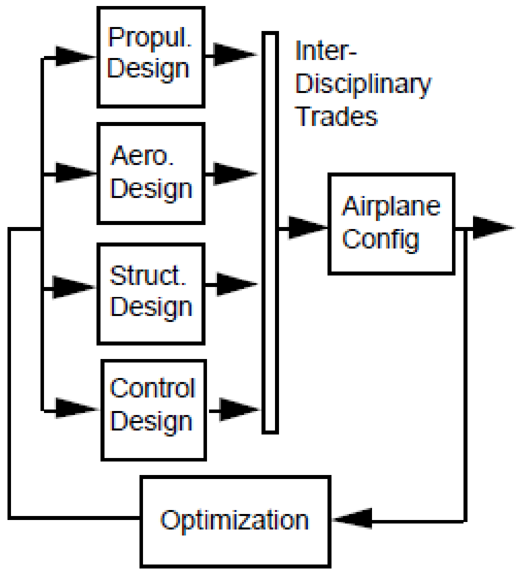


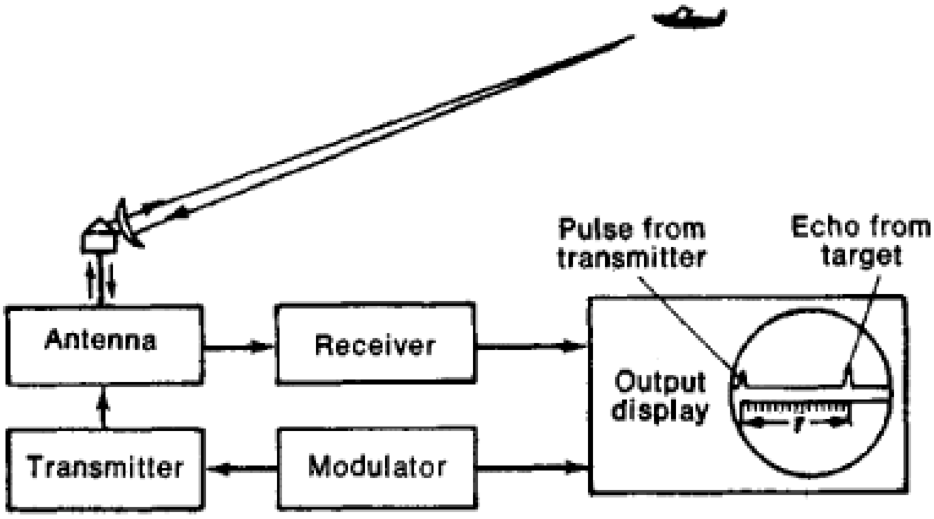
Figure (B) Control-Configured-Vehicle Design Process

If the flying qualities of the bare airframe are optimized, then it is reasoned that the control system of the aircraft will be inexpensive to develop and build. However, this approach ignores the benefits of active control completely and is contrary to the objectives of CCV design. This approach attempts to eliminate the control system rather than benefit from it. As a result, statically unstable aircraft such as the F-16 and X-29 would not emerge from this approach.

The natural extension of CCV design is to link flight control considerations and configuration design such that the best configuration can be obtained through numerical optimization. This type of cross-disciplinary optimization is the basis for Multidisciplinary Design Optimization (MDO). An aircraft configuration MDO problem generally consists of separate modules which come from different traditional aeronautical disciplines such as structures, aerodynamics, and controls. The interaction between the structures and aerodynamics disciplines are at least clear conceptually - changes in geometric contours lead to lead changes in both fuel (drag) and structural weights.

ILS (Introduction)

The guidance of an aircraft towards an airport is called homing. In busy airports, large numbers of aircrafts are scheduled to arrive simultaneously; the pilot of each aircraft must know its own bearing in flying, with precision otherwise such a simultaneous approach to an airport by no of aircrafts may lead to collision between adjacent aircrafts.



Instrument Landing System (ILS)

Instrument Landing System (ILS)

- When the aircraft approaching closely to the airport the landing of an aircraft is often aided by radio aids called ILS.
- It is useful during poor visibility conditions and during night.
- Radio aids for landing of an aircraft to the airport are called Instrument Landing Aids.
- The Radio aids may be incorporated within the aircraft operated and controlled by the pilot. These are called Instrument Landing Systems.
- GCA (Ground Control Approach): Alternatively, it may be systems controlled from the ground when the pilot is to landing following instructions from the ground control operator obtained from the Ground Control Approach systems
- I.L. Systems enables blind landing of an aircraft under poor visibility conditions.
- The I.L. Systems guides the aircraft both in elevation and azimuth supported by an aid called Radio Altimeter.
- Elevation guidance using radiation pattern
- Elevation guidance using lobe switching
- I.L.Systems is also called as the guides lope system in airports (UHF339.3-335MHz)

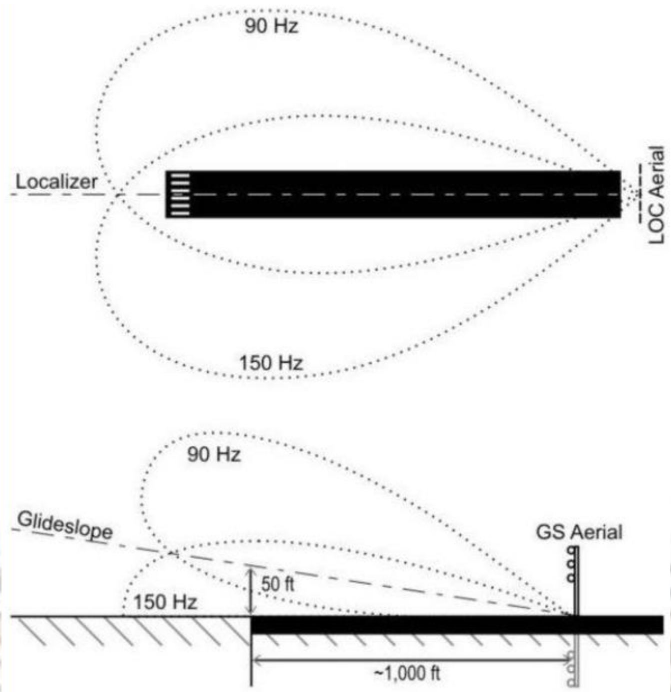
Radio altimeter

- A Radio altimeter is designed to the altitude indication of an aircraft while it is landing phase is based on FM-CW radar
- Due to the modulation the transmitted frequency will allow the modulation
- Fig c the transmitted frequency at the instant 0, when the modulation wave from passes through a zero, with the carrier frequency FC.
- This transmission will be received back the reflection at the ground after delay

$$\Delta t = \frac{2h}{c}$$

➢ During the delta t the transmitted frequency is changed to a new value FC differing from FC by during the delta t the transmitted frequency is changed to a new value FC differing from FC by

$$f_b = f'_c - f_c$$



Localizers

- Localizers operate in the VHF range and provide horizontal course guidance to runway center line.
- Transmitters are located on the center line at the opposite end of the runway from the approach threshold.
- The signal transmitted consists of two fan shaped patterns that overlap at the centre. The overlap area provides the on-track signal.
- The angular width of the beam is between 3°and 6°. Normally width is 5°, resulting in full scale deflection at 2.5°.
- The width of the beam is adjusted to be 700 feet wide at runway threshold.
- Beginning with X, aligned localizer identifiers begin with I.
- The localizer may be offset from runway centerline by up to 3°. Localizers offset more than 3°will have an identifier
- A cautionary note will be published in the CAP whenever localizer is offset more than 3°.
- Normal reliable coverage of localizers is 18nm within 10°of either side of course centreline and 10nm within 35°.
- Localizer installations provide back course information, and non-precision localizer back course approaches may be published.

- Caution: a localizer signal is transmitted differently than a VOR radial. Aircraft receivers are not supplied with azimuth information relative to magnetic or true north. It is simply a beam aligned with the runway center line.

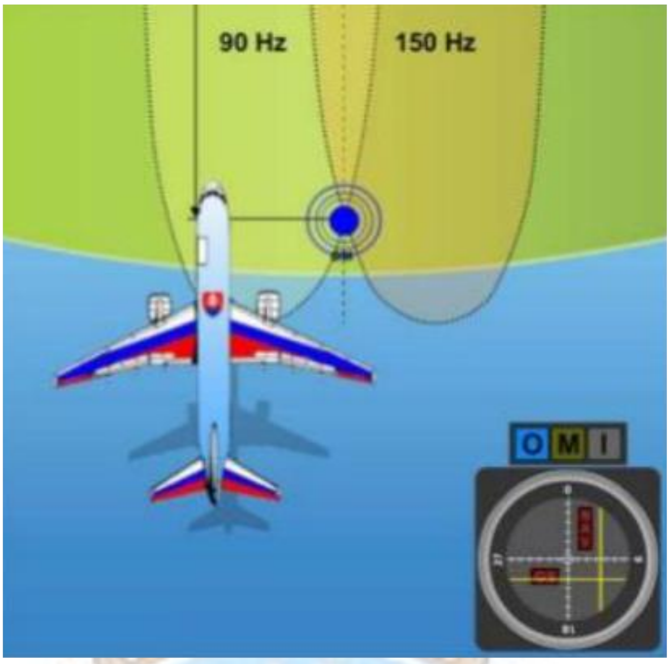
Glide Path

- Glide path information is paired with the associated localizer frequency.
- The glide path is normally adjusted to an angle of 3°(may be adjusted 2°to 4.5°) and a beam width of 1.4°(0.7°for full scale deflection).
- The antenna array is located approx. 1000ft from the approach end of the runway and offset approx. 400ft. (if glide path is followed to the pavement touchdown point will be at the 1000ft markers)
- In installations with an ILS serving both ends of a runway the systems are interlocked so only one can operate at a time.

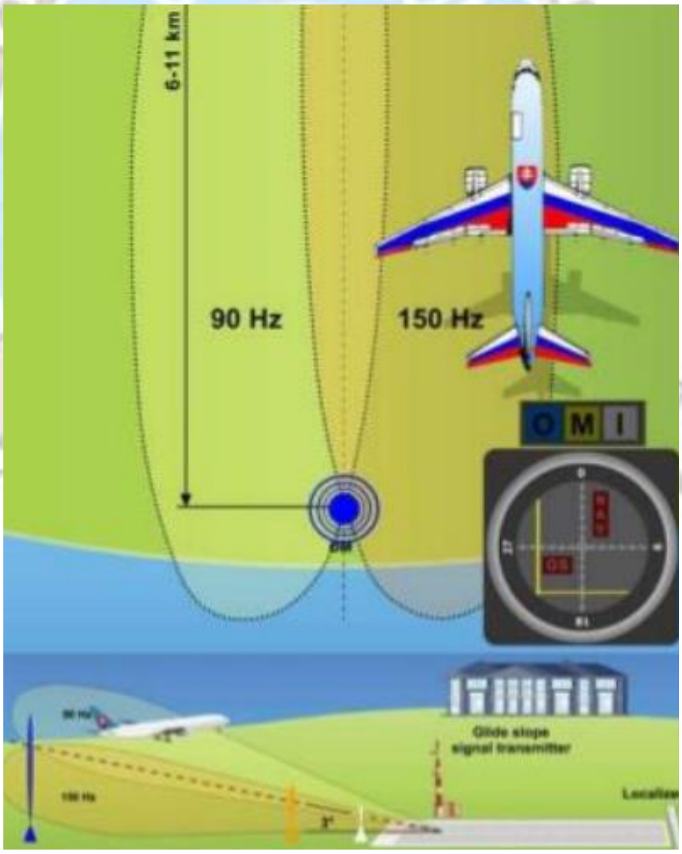
RUNWAY LIGHTING AND TRANSMISSOMETERS

The following must be fully serviceable to meet CAT II/III standards:

- ***Airport lighting:***
    - Approach lights
    - Run way threshold lights
    - Touchdown zone lights
    - Centre line lights
    - Run way edge lights
    - Run way end lights
    - All stop bars and lead-on lights
    - Essential taxiway lights
- ***ILS components:***
    - Localizer
    - Glide path
- ***RVR equipment:***
    - CAT II-two transmissometers-approach end, mid-field
    - CAT III-three transmissometers-approach end, mid-field, departure end
- ***Power source:***
    - Airport emergency power as primary power source for all essential system elements.
    - Commercial power available within one second as a backup.


90 Hz
150 Hz
O M I

ILS


6-11 km
90 Hz
150 Hz
O M I
Glide slope
signal transmitter

ILS

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-II NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 5AN3 **SEMESTER: V**

SUBJECT NAME: AIRCRAFT SYSTEMS

AIRCRAFT SYSTEMS

Hydraulic systems - Study of typical workable system - components – Hydraulic system controllers - Modes of operation - Pneumatic systems - Advantages -Working principles - Typical Air pressure system – Brake system – Typical Pneumatic power system - Components,

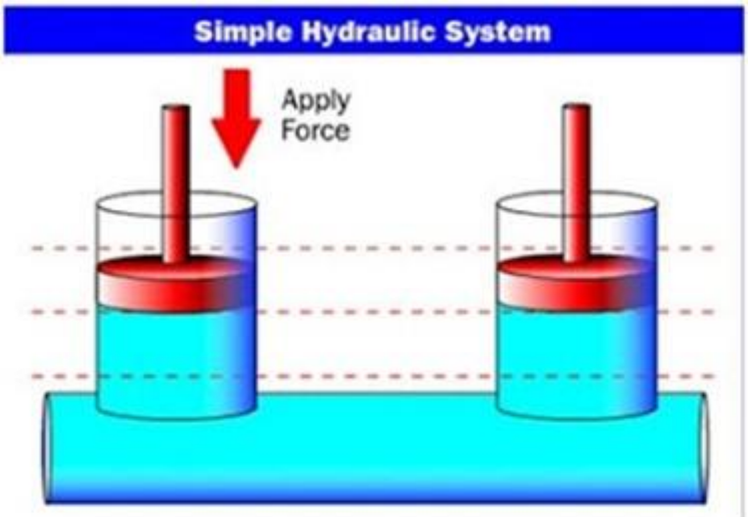
Landing Gear systems - Classification – Shock absorbers - Retractive mechanism. Anti skid system, wheels and brake, steering systems, indications.

INTRODUCTION

In the industry we use three methods for transmitting power from one point to another. Mechanical transmission is through shafts, gears, chains, belts, etc. Electrical transmission is through wires, transformers, etc. Fluid power is through liquids or gas in a confined space. In this chapter, we shall discuss a structure of hydraulic systems and pneumatic systems. We will also discuss the advantages and disadvantages and compare hydraulic, pneumatic, electrical and mechanical systems.

Hydraulic system

The word hydraulics is based on the Greek word for water, and originally meant the study of water at rest and in motion. Today the meaning has been expanded to include the physical behavior of all liquids, including hydraulic fluid. With the use of incompressible phenomenon of liquid we can easily make a hydraulic system.



As per Pascal's law "Pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other parts" .The basic idea behind any hydraulic system is very simple: **Force that is applied at one point is transmitted to another point using an incompressible fluid.** The fluid is almost always an oil of some sort. The force is almost always multiplied in the process.

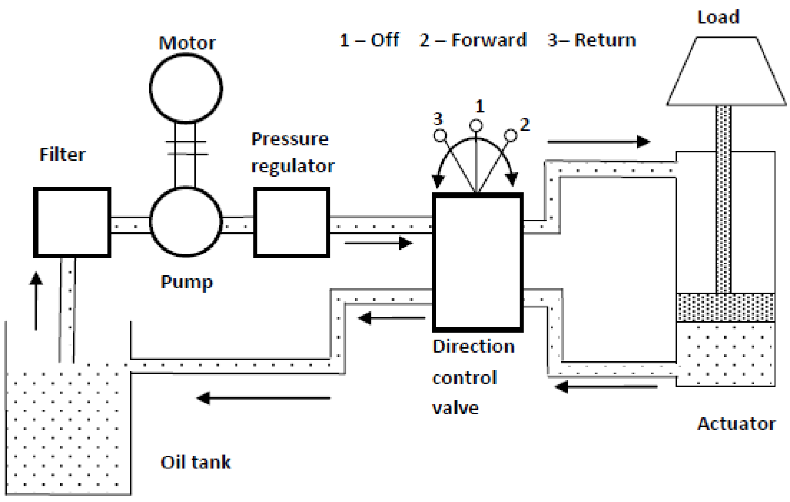
In this drawing, two pistons (red) fit into two glass cylinders filled with oil (light blue) and connected to one another with an oil-filled pipe. If you apply a downward force to one piston (the left one in this drawing), then the force is transmitted to the second piston through the oil in the pipe. Since oil is in-compressible, the efficiency is very good — almost all of the applied force appears at the second piston. The great thing about hydraulic systems is that the pipe connecting the two cylinders can be any length and shape, allowing it to snake through all sorts of things separating the two pistons. The pipe can also fork, so that one **master cylinder** can drive more than one slave cylinder if desired.

Hydraulic system in airplanes

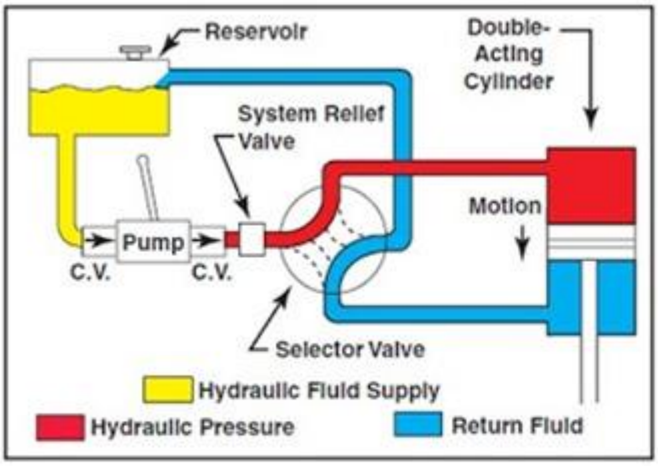
There are multiple applications for hydraulic use in airplanes, depending on the complexity of the airplane. For example, hydraulics is often used on small airplanes to operate wheel brakes, retractable landing gear, and some constant speed propellers. On large airplanes, hydraulics is used for flight control surfaces, wing flaps, spoilers, and other systems.

A basic hydraulic system

Hydraulic systems are power-transmitting assemblies employing pressurized liquid as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work.



A basic hydraulic system schematic diagram



A basic hydraulic system

A basic hydraulic system consists

- Reservoirs
- Pumps
- Selector Valves
- Check Valves
- Hydraulic Fuses
- Accumulators
- Actuators

Functions of the components are as follows:

1. The hydraulic actuator is a device used to convert the fluid power into mechanical power to do useful work. The actuator may be of the linear type (e.g., hydraulic cylinder) or rotary type (e.g., hydraulic motor) to provide linear or rotary motion, respectively. Actuators can be either single-acting or double-acting servos based on the needs of the system. This means that the fluid can be applied to one or both sides of the actuators, depending on the actuators type, and therefore provides power in one direction with a single-acting actuator/servo. A servo is a cylinder with a piston inside that turns fluid power into work and creates the power needed to move an aircraft system or flight control. The selector valve allows the fluid direction to be controlled. This is necessary for operations like the extension and retraction of landing gear where the fluid must work in two different directions.

2. The hydraulic pump is used to force the fluid from the reservoir to rest of the hydraulic circuit by converting mechanical energy into hydraulic energy.

3. Valves are used to control the direction, pressure and flow rate of a fluid flowing through the circuit.

4. External power supply (motor) is required to drive the pump.

5. Reservoir is used to hold the hydraulic liquid, usually hydraulic oil.

6. Piping system carries the hydraulic oil from one place to another.

7. Filters are used to remove any foreign particles so as keep the fluid system clean and efficient, as well as avoid damage to the actuator and valves.

8. Pressure regulator regulates (i.e., maintains) the required level of pressure in the hydraulic fluid.

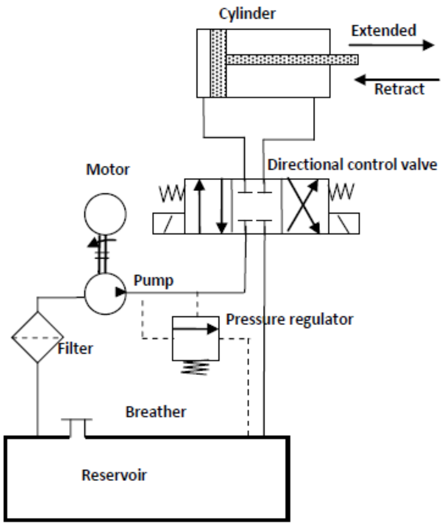
The piping shown in Figure is of closed-loop type with fluid transferred from the storage tank to one side of the piston and returned back from the other side of the piston to the tank. Fluid is drawn from the tank by a pump that produces fluid flow at the required level of pressure. If the fluid pressure exceeds the required level, then the excess fluid returns back to the reservoir and remains there until the pressure acquires the required level.

Cylinder movement is controlled by a three-position change over a control valve.

1. When the piston of the valve is changed to upper position, the pipe pressure line is connected to port A and thus the load is raised.

2. When the position of the valve is changed to lower position, the pipe pressure line is connected to port B and thus the load is lowered.

3. When the valve is at center position, it locks the fluid into the cylinder (thereby holding it in position) and dead-ends the fluid line (causing all the pump output fluid to return to tank via the pressure relief).



A hydraulic systems circuit diagram

In industry, a machine designer conveys the design of hydraulic systems using a circuit diagram. Above Figure shows the components of the hydraulic system using symbols. The working fluid, which is the hydraulic oil, is stored in a reservoir. When the electric motor is switched ON, it runs a positive displacement pump that draws hydraulic oil through a filter and delivers at high pressure. The pressurized oil passes through the regulating valve and does work on actuator. Oil from the other end of the actuator goes back to the tank via return line. To and fro motion of the cylinder is controlled using directional control valve.

HYDRAULIC FLUID

The fluid used in aircraft hydraulic systems is one of the system’s most important parts.

- The fluid must flow with a minimum of opposition.
- Must be incompressible
- Good lubricating properties
- Inhibit corrosion and not attack seals
- Must not foam in operation

Some characteristics that must be considered.

- Viscosity
- Chemical Stability
- Flash Point
- Fire Point

Viscosity

Viscosity is the internal resistance to flow.

- Gasoline flows easily (has a low viscosity)
- Tar flows slowly (has a high viscosity)

A satisfactory liquid for a hydraulic system must have enough body t give a good seal at pumps, valves and pistons; but it must not be so thick that it offers excessive resistance to flow.

The average hydraulic liquid has a low viscosity.

Fire Point

Fire Point is the temperature at which a substance gives off vapor in sufficient quantity to ignite and continue to burn when exposed to a spark or flame.

High fire point is required of desirable hydraulic fluids.

Flash Point

Flash Point is the temperature at which a liquid gives off vapor in sufficient quantity to ignite momentarily when a flame is applied.

High flash point is desirable for hydraulic fluids.

Types of Hydraulic Fluid

Vegetable-base

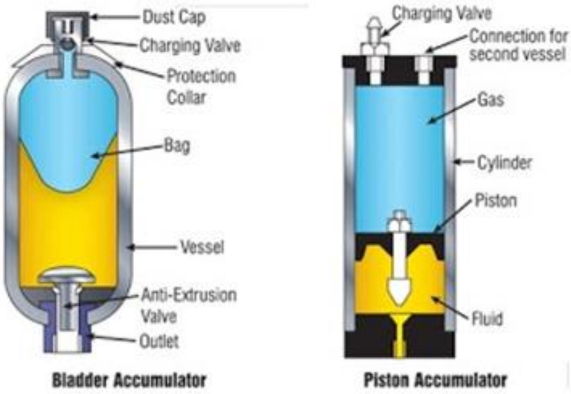
Mineral-base

Synthetic Fluid

A mineral-based fluid is the most widely used type for small airplanes. This type of hydraulic fluid, which is a kerosene-like petroleum product, has good lubricating Properties, as well as additives to inhibit foaming and prevent the formation of corrosion. It is quite stable chemically, has very little viscosity change with temperature, and is dyed for identification. Since several types of hydraulic fluids are commonly used, make sure your airplane is serviced with the type specified by the manufacturer.

The three types of gas-charged accumulators you'll encounter on hydraulic systems are bladder, piston and diaphragm. Accumulators are used to store the fluid under given pressure.

The most popular of these is the bladder type. Bladder accumulators feature fast response (less than 25 milliseconds), a maximum gas compression ratio of around 4:1 and a maximum flow rate of 15 liters (4 gallons) per second, although "high-flow" versions up to 38 liters (10 gallons) per second are available. Bladder accumulators also have good dirt tolerance; they are mostly unaffected by particle contamination in the hydraulic fluid.



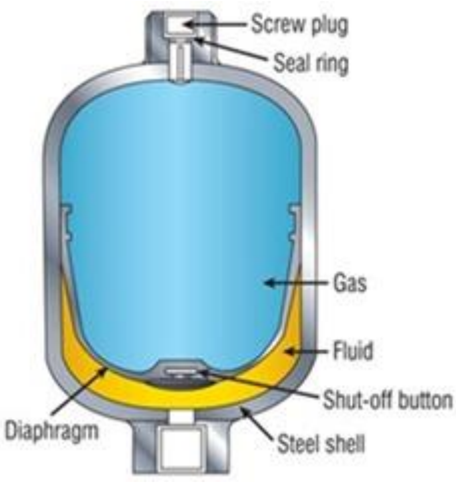
Piston accumulators, on the other hand, can handle much higher gas compression ratios (up to 10:1) and flow rates as high as 215 liters (57 gallons) per second. Unlike bladder accumulators, who's preferred mounting position is vertical to prevent the possibility of fluid getting trapped between the bladder and the shell, piston accumulators can be mounted in any position.

But, piston accumulators also require a higher level of fluid cleanliness than bladder units, have slower response times (greater than 25 milliseconds) – especially at lower pressures – and exhibit hysteresis. This is explained by the static friction of the piston seal which has to be overcome, and the necessary acceleration and deceleration of the piston mass.

Diaphragm accumulators have most of the advantages of bladder-type units but can handle gas compression ratios up to 8:1. They are limited to smaller volumes, and their performance can sometimes be affected by gas permeation across the diaphragm.

Maintenance Considerations

When charging the gas end of a bladder or diaphragm accumulator, the nitrogen gas should always be admitted very slowly. If the high-pressure nitrogen is allowed to expand rapidly as it enters the bladder, it can chill the bladder's polymeric material to the point where immediate brittle failure occurs. Rapid pre-charging can also force the bladder underneath the poppet at the oil-end, causing it to be cut. If pre-charge pressure is too high or minimum system pressure is reduced without a corresponding reduction in pre-charge pressure, the operation of the accumulator will be affected and damage may also result. Excessive pre-charge of a bladder accumulator can drive the bladder into the poppet assembly during discharge, causing damage to the poppet assembly and/or the bladder. This is a common cause of bladder failure.



Accumulator

Low or no pre-charge also can have drastic consequences for bladder accumulators. It can result in the bladder being crushed into the top of the shell by system pressure. This can cause the bladder to extrude into or be punctured by the gas valve. In this scenario, only one such cycle is required to destroy the bladder.

Similarly, excessively high or low pre-charge of a piston accumulator can cause the piston to bottom out at the end of its stroke, resulting in damage to the piston and its seal. The good news is that, if this happens, an audible warning will result. Even though piston accumulators can be damaged by improper charging, they are much more tolerant of it than bladder accumulators.

Artificial feel devices

With purely mechanical flight control systems, the aerodynamic forces on the control surfaces are transmitted through the mechanisms and are felt directly by the pilot, allowing tactile feedback of airspeed. With hydro mechanical flight control systems, however, the load on the surfaces cannot be felt and there is a risk of overstressing the aircraft through excessive control surface movement. To overcome this problem, artificial feel systems can be used.

For example, for the controls of the RAF's Avro Vulcan jet bomber and the RCAF's Avro Canada CF-105 Arrow supersonic interceptor (both 1950s-era designs), the required force feedback was achieved by a spring device. The fulcrum of this device was moved in proportion to the square of the air speed (for the elevators) to give increased resistance at higher speeds. For the controls of the American Vought F-8 Crusader and the LTV A-7 Corsair II warplanes, a 'bob-weight' was used in the pitch axis of the control stick, giving force feedback that was proportional to the airplane's normal acceleration.

Stick shaker

A stick shaker is a device (available in some hydraulic aircraft) that is fitted into the control column, which shakes the control column when the aircraft is about to stall. Also in some aircraft like the McDonnell Douglas DC-10 there is/was a back-up electrical power supply that the pilot can turn on to re-activates the stick shaker in case the hydraulic connection to the stick shaker is lost.

Boeing 737 Next Generation Hydraulic System

The Boeing 737 Next Generation has three 3,000 psi hydraulic systems: system A, system B, and standby. The standby system is used if system A and/or B pressure is lost.

The hydraulic systems power the following aircraft systems:

• Flight controls

• Leading edge flaps and slats

• Trailing edge flaps

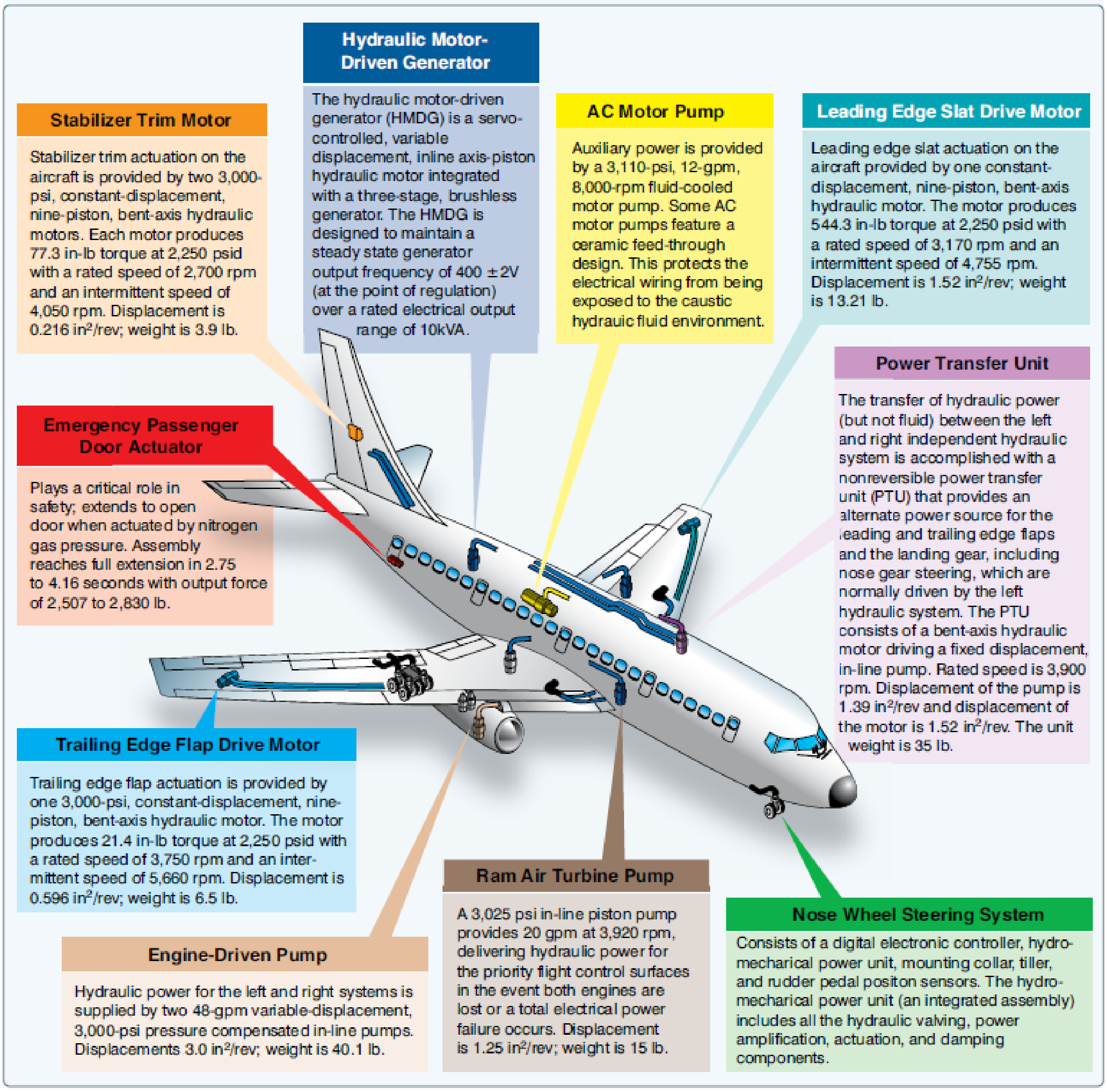
• Landing gear

• Wheel brakes

• Nose wheel steering

• Thrust reversers

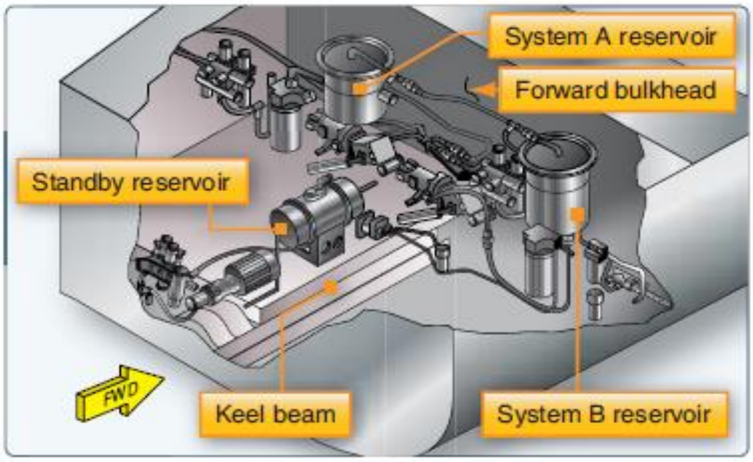
• Autopilots



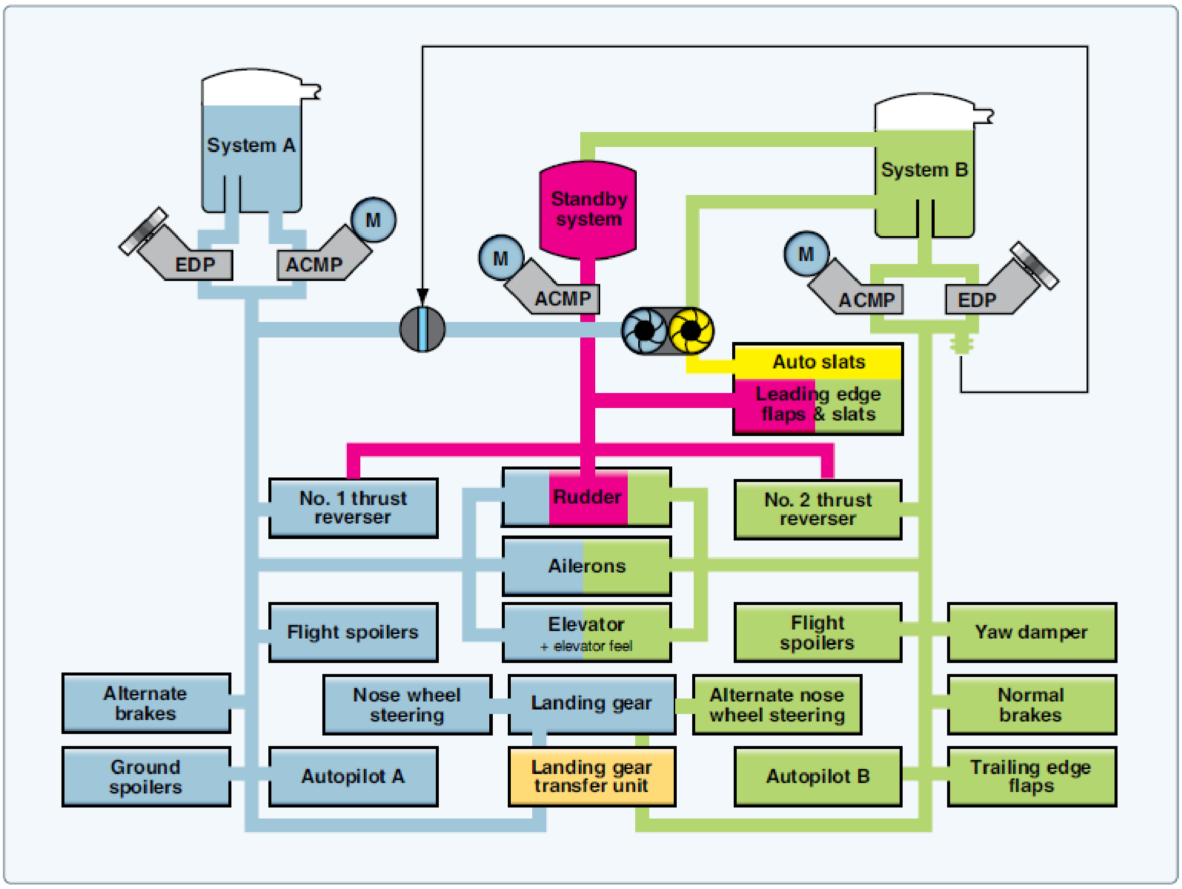
Large aircraft hydraulic systems

Reservoirs

The system A, B, and standby reservoirs are located in the wheel well area. The reservoirs are pressurized by bleed air through a pressurization module. The standby reservoir is connected to the system B reservoir for pressurization and servicing. The positive pressure in the reservoir ensures a positive flow of fluid to the pumps. The reservoirs have a standpipe that prevents the loss of all hydraulic fluid if a leak develops in the engine-driven pump or its related lines. The engine-driven pump draws fluid through a standpipe in the reservoir and the AC motor pump draws fluid from the bottom of the reservoir.



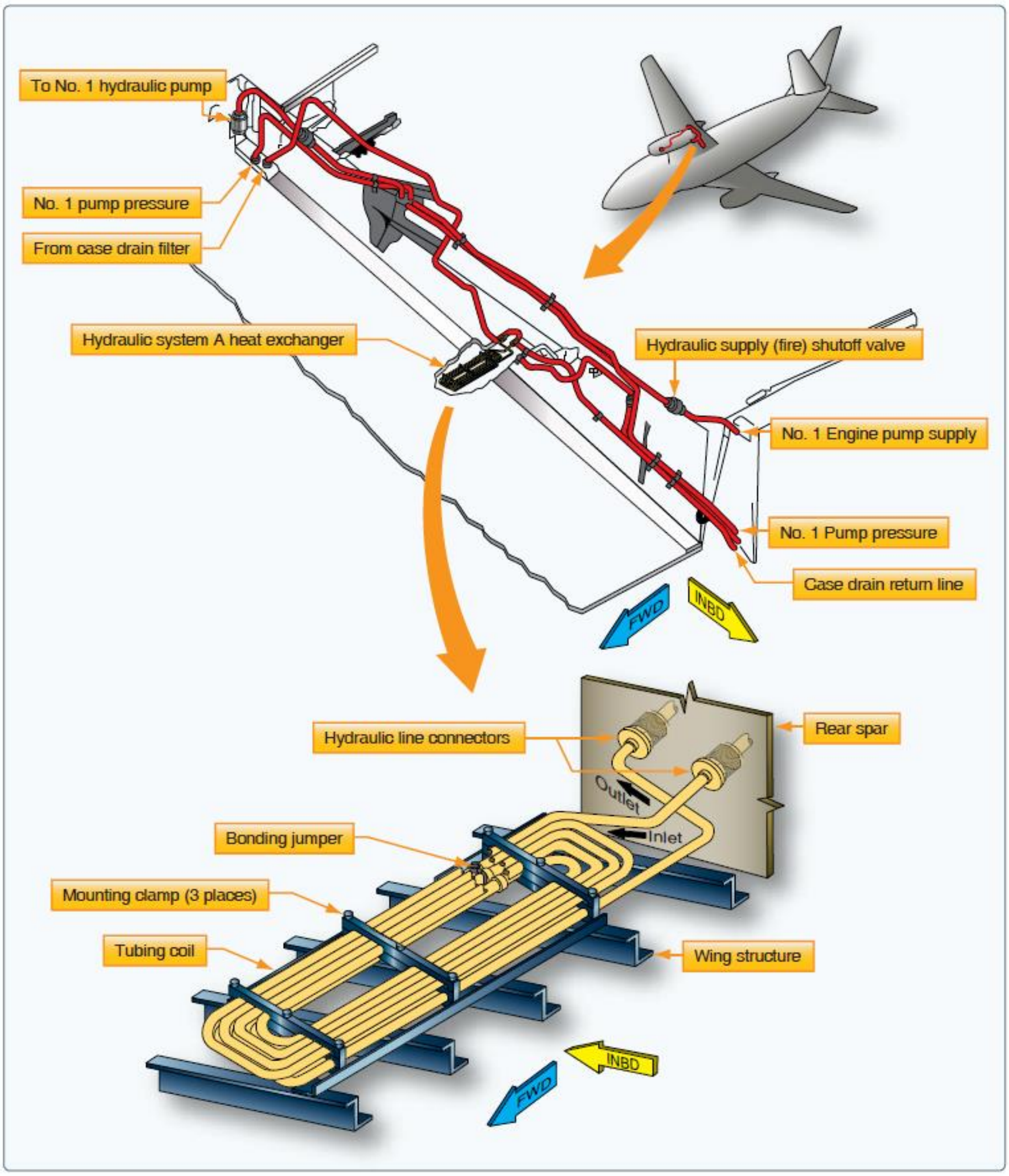
Hydraulic reservoirs on a Boeing 737.



Boeing 737 hydraulic system (simplified).

Pumps

Refer to above *Figure* for the following description. Both A and B hydraulic systems have an engine-driven pump (EDP) and an ACMP. The system A engine-driven pump is installed on the number 1 engine and the system B engine-driven pump is installed on the number 2 engine. The AC pumps are controlled by a switch on the flight deck. The hydraulic case drain fluid that lubricates and cools the pumps return to the reservoir through a heat exchanger.



Boeing 737 hydraulic case drain fluid heat exchanger installed in the fuel tank.

The heat exchanger for the A system is installed in the main fuel tank No. 1, and the heat exchanger for the B system is installed in the main fuel tank No. 2. Minimum fuel for ground operation of electric motor-driven pumps is 1,675 pounds in the related main tank. Pressure switches, located in the EDP and ACMP pump output lines, send signals to illuminate the related LOW PRESSURE light if pump output pressure is low. The related system pressure transmitter sends the combined pressure of the EDP and ACMP to the related hydraulic system pressure indicator.

Filter Units

Filter modules are installed in the pressure, case drain, and return lines to clean the hydraulic fluid. Filters have a differential pressure indicator that pops out when the filter is dirty and needs to be replaced.

Power Transfer Unit (PTU)

The purpose of the PTU is to supply the additional volume of hydraulic fluid needed to operate the auto slats and leading edge flaps and slats at the normal rate when system B EDP malfunctions. The PTU unit consists of a hydraulic motor and hydraulic pump that are connected through a shaft. The PTU uses system A pressure to drive a hydraulic motor. The hydraulic motor of the PTU unit is connected through a shaft with a hydraulic pump that can draw fluid from the system B reservoir. The PTU can only transfer power and cannot transfer fluid. The PTU operates automatically when all of the following conditions are met:

• System B EDP pressure drops below limits.

• Aircraft airborne.

• Flaps are less than 15° but not up.

Landing Gear Transfer Unit

The purpose of the landing gear transfer unit is to supply the volume of hydraulic fluid needed to raise the landing gear at the normal rate when system A EDP is lost. The system B EDP supplies the volume of hydraulic fluid needed to operate the landing gear transfer unit when all of the following conditions are met:

• Aircraft airborne.

• No. 1 engine rpm drops below a limit value.

• Landing gear lever is up.

• Either or both main landing gear not up and locked.

Standby Hydraulic System

The standby hydraulic system is provided as a backup if system A and/or B pressure is lost. The standby system can be activated manually or automatically and uses a single electric ACMP to power:

• Thrust reversers

• Rudder

• Leading edge flaps and slats (extend only)

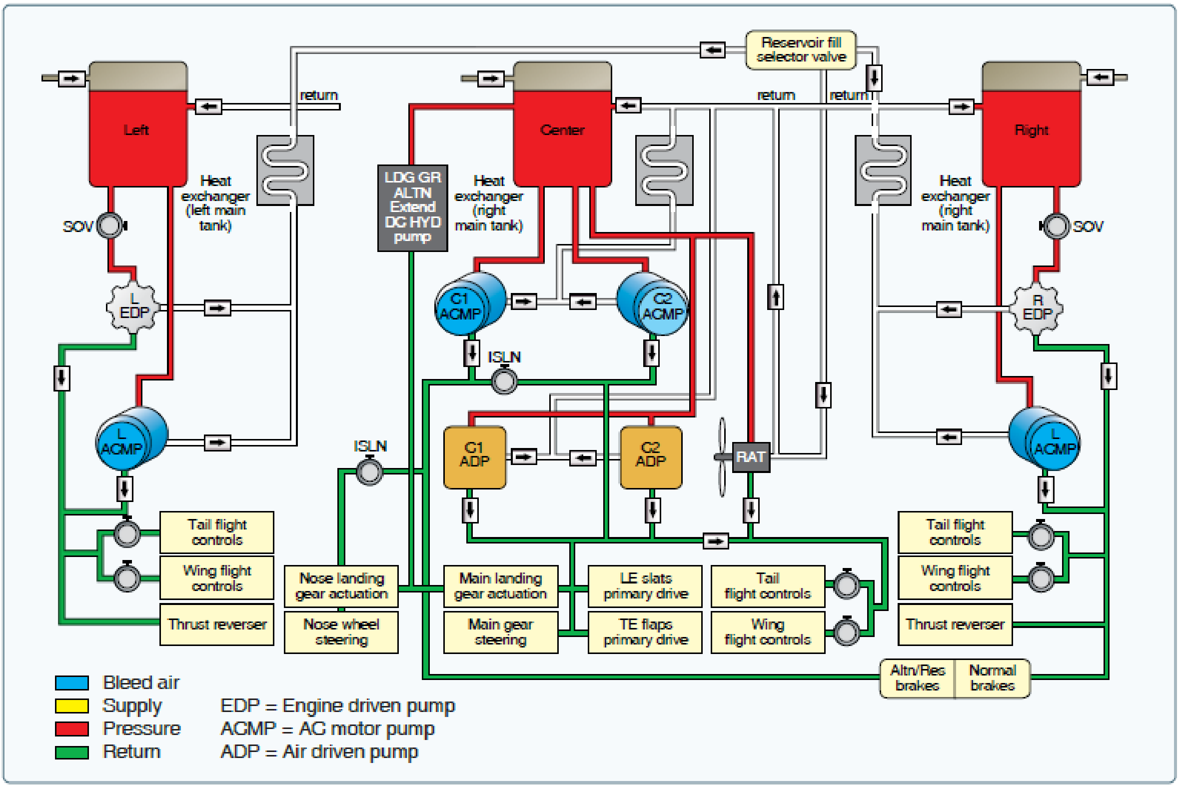
• Standby yaw damper

Indications

A master caution light illuminates if an overheat or low pressure is detected in the hydraulic system. An overheat light on the flight deck illuminates if an overheat is detected in either system A or B and a low-pressure light illuminates if a low pressure is detected in system A and B.

Boeing 777 Hydraulic System

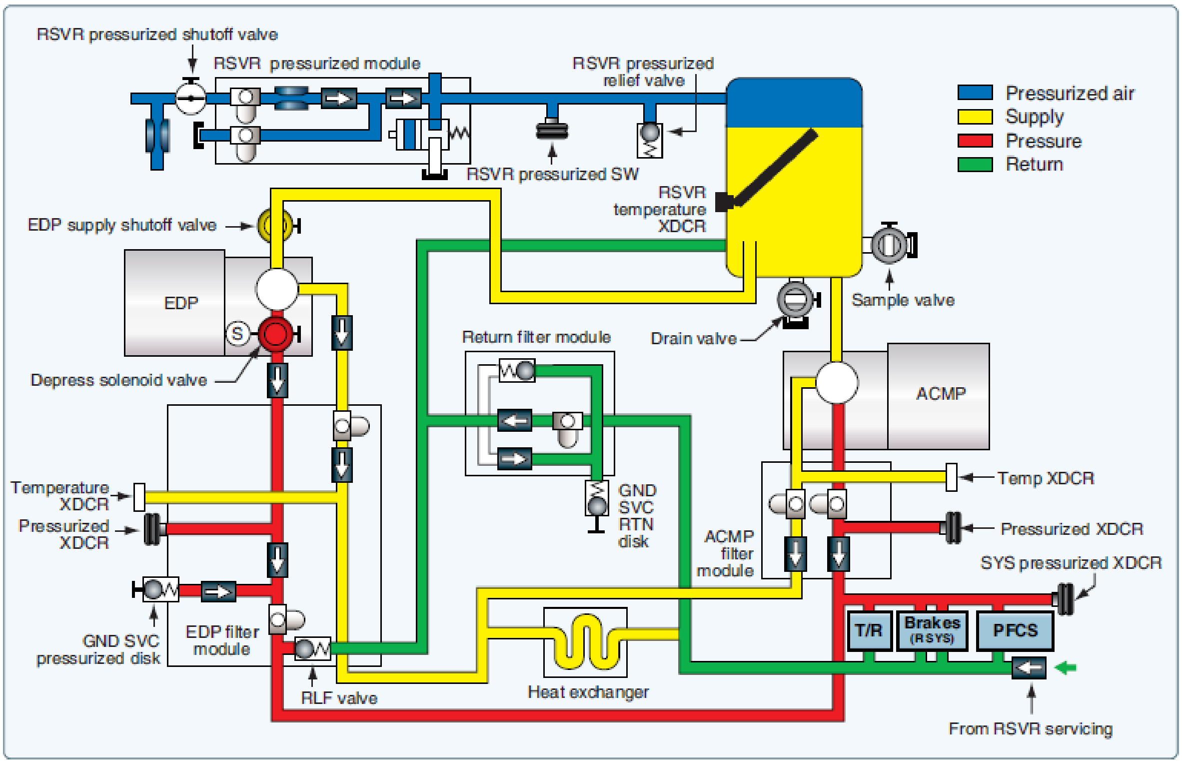
The Boeing 777 is equipped with three hydraulic systems. The left, center, and right systems deliver hydraulic fluid at a rated pressure of 3,000 psi (207 bar) to operate flight controls, flap systems, actuators, landing gear, and brakes. Primary hydraulic power for the left and right systems is provided by two EDPs and supplemented by two on-demand ACMPs. Primary hydraulic power for the center system is provided by two electric motor pumps (ACMP) and supplemented by two on-demand air turbine-driven pumps (ADP). The center system provides hydraulic power for the engine thrust reversers, primary flight controls, landing gear, and flaps/slats. Under emergency conditions, hydraulic power is generated by the ram air turbine (RAT), which is deployed automatically and drives a variable displacement inline pump. The RAT pump provides flow to the center system flight controls.



A Boeing 777 hydraulic system.

Left and Right System Description

The left and right hydraulic systems are functionally the same. The left hydraulic system supplies pressurized hydraulic fluid to operate the left thrust reverser and the flight control systems. The right hydraulic system supplies pressurized hydraulic fluid to operate the right thrust reverser, flight control systems, and the normal brake system.



Right hydraulic system of a Boeing 777. A left system is similar.

Reservoir

The hydraulic system reservoirs of the left and right system contain the hydraulic fluid supply for the hydraulic pumps. The reservoir is pressurized by bleed air through a reservoir pressurization module. The EDP draws fluid through a standpipe. The ACMP draws fluid from the bottom of the reservoir. If the fluid level in the reservoir gets below the standpipe, the EDP cannot draw any fluid any longer, and the ACMP is the only source of hydraulic power. The reservoir can be serviced through a center servicing point in the fuselage of the aircraft. The reservoir has a sample valve for contamination testing purposes, a temperature transmitter for temperature indication on the flight deck, a pressure transducer for reservoir pressure, and a drain valve for reservoir draining.

Pumps

The EDPs are the primary pumps for the left and right hydraulic systems. The EDPs get reservoir fluid through the EDP supply shutoff valves. The EDPs operates whenever the engines operate. A solenoid valve in each EDP controls the pressurization and depressurization of the pump. The pumps are variable displacement inline piston pumps consisting of a first stage impeller pump and a second stage piston pump.

The impeller pump delivers fluid under pressure to the piston pump. The ACMPs are the demand pumps for the left and right hydraulic systems. The ACMPs normally operate only when there is high hydraulic system demand.

Filter Module

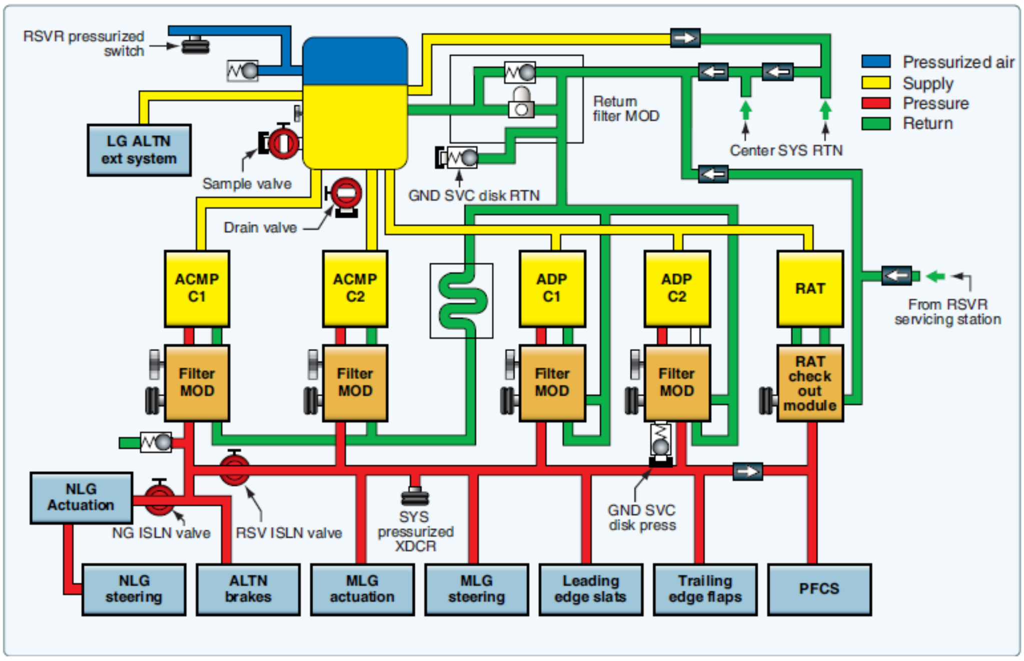
Pressure and case drain filter modules clean the pressure flows and the case drain flows of the hydraulic pumps. A return filter module cleans the return flow of hydraulic fluid from the user systems. The module can be bypassed if the filter clogs, and a visible indicator pops to indicate a clogged filter. The heat exchanger, which is installed in the wing fuel tanks, cools the hydraulic fluid from ACMP and EDP case drain lines before the fluid goes back to the reservoir.

Indication

The hydraulic system sensors send pressure, temperature, and quantity signals to the flight deck. A reservoir quantity transmitter and temperature transducer are installed on each of the reservoirs, and a hydraulic reservoir pressure switch is located on the pneumatic line between the reservoir pressurization module and the reservoir. The ACMP and EDP filter modules each have a pressure transducer to measure pump output pressure. A temperature transducer is installed in the case drain line of each filter module and measures pump case drain fluid temperature. A system pressure transducer measures hydraulic system pressure. A pressure relief valve on the EDP filter module protects the system against over pressurization. (above figure)

Center Hydraulic System

The center hydraulic system supplies pressurized hydraulic fluid to operate these systems:



Center hydraulic system.

• Nose landing gear actuation

• Nose landing gear steering

• Alternate brakes

• Main landing gear actuation

• Main landing gear steering

• Trailing edge flaps

• Leading edge slat

• Flight controls

Reservoir

The hydraulic system reservoir of the center system contains the hydraulic fluid supply for the hydraulic pumps. The reservoir is pressurized by bleed air through a reservoir pressurization module. The reservoir supplies fluid to the ADPs, the RAT, and one of the ACMPs through a standpipe. The other ACMP gets fluid from the bottom of the reservoir. The reservoir also supplies hydraulic fluid to the landing gear alternate extension system.

The ACMPs are the primary pumps in the center hydraulic system and are normally turned on. The ADPs are the demand pumps in the center system. They normally operate only when the center system needs more hydraulic flow capacity. The RAT system supplies an emergency source of hydraulic power to the center hydraulic system flight controls. A reservoir quantity transmitter and temperature transducer are installed on the reservoir. A hydraulic reservoir pressure switch is installed on the pneumatic line between the reservoir and the reservoir pressurization module.

Filter

Filter modules clean the pressure and case drain output of the hydraulic pumps. A return filter module cleans the return flow of hydraulic fluid from the user systems. The module can be bypassed. The heat exchanger cools the hydraulic fluid from the ACMP case drains before the fluid goes back to the reservoir. ADP case drain fluid does not go through the heat exchangers. The ACMP and ADP filter modules each have a pressure transducer to measure pump output pressure. A temperature transducer in each filter module measures the pump case drain temperature. A system pressure transducer measures hydraulic system pressure.

Pressure relief valves in each ADP filter module prevent system overpressurization. A pressure relief valve near ACMP C1 supplies overpressure protection for the center hydraulic isolation system (CHIS).

Center Hydraulic Isolation System (CHIS)

The CHIS supplies engine burst protection and a reserve brakes and steering function. CHIS operation is fully automatic. Relays control the electric motors in the reserve and nose gear isolation valves. When the CHIS system is operational, it prevents hydraulic operation of the leading edge slats.

ACMP C1 gets hydraulic fluid from the bottom of the center system reservoir. All other hydraulic pumps in the center system get fluid through a standpipe in the reservoir. This gives ACMP C1 a 1.2 gallon (4.5 liter) reserve supply of hydraulic fluid. The reserve and nose gear isolation valves are normally open. Both valves close if the quantity in the center system reservoir is low (less than 0.40) and the airspeed is more than 60 knots for more than one second. When CHIS is active, this divides the center hydraulic system into different parts.

The NLG actuation and steering and the leading edge slat hydraulic lines are isolated from center system pressure. The output of ACMP C1 goes only to the alternate brake system. The output of the other center hydraulic system pumps goes to the trailing edge flaps, the MLG actuation and steering, and the flight controls. If there is a leak in the NLG actuation and steering or LE slat lines, there is no further loss of hydraulic fluid. The alternate brakes, the trailing edge flaps, the MLG actuation and steering, and the PFCS continue to operate normally If there is a leak in the trailing edge flaps, the MLG actuation and steering, or the flight control lines, the reservoir loses fluid down to the standpipe level (0.00 indication). This causes a loss of these systems but the alternate brake system continues to get hydraulic power from ACMP C1. If there is a leak in the lines between ACMP C1 and the alternate brake system, all center hydraulic system fluid is lost.

Nose Gear Isolation Valve

The nose gear isolation valve opens for any of these conditions:

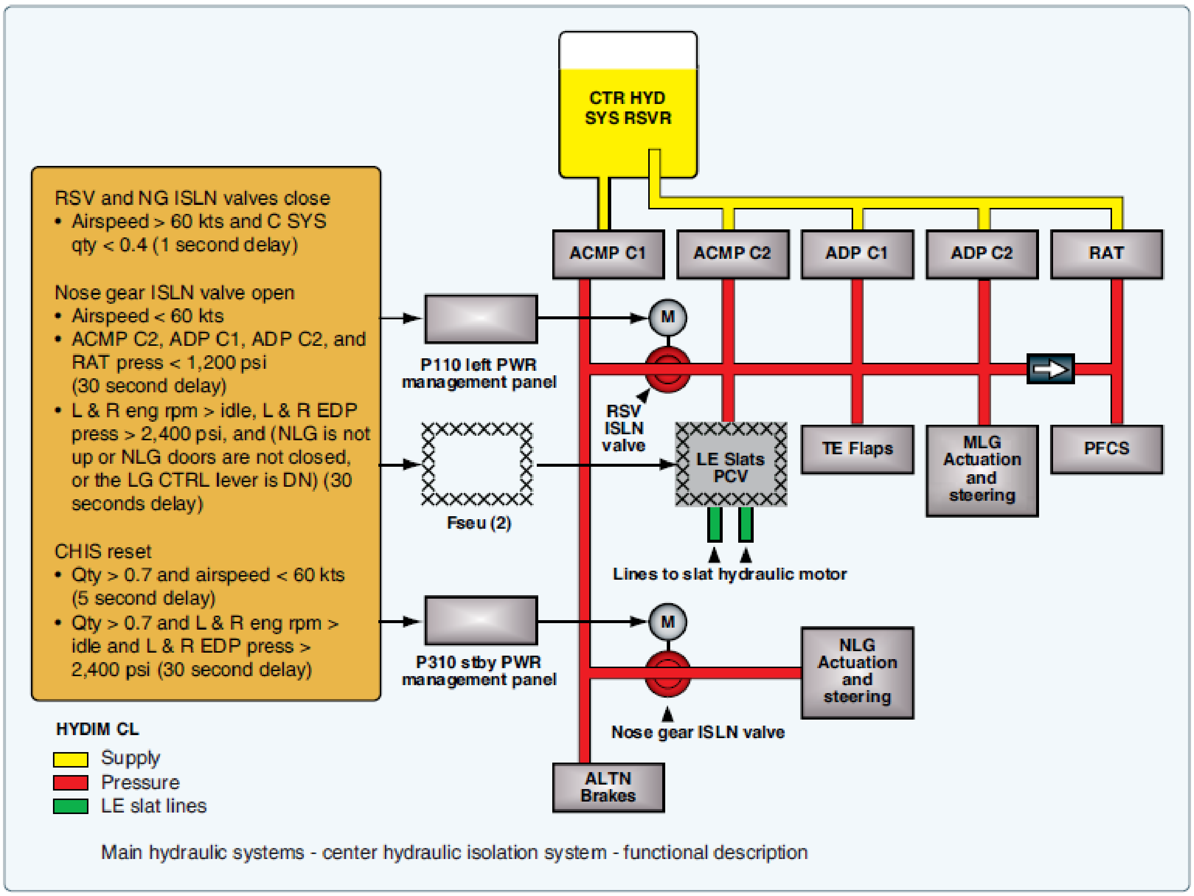
• Airspeed is less than 60 knots.

• Pump pressures for ACMP C2, ADP C1, ADP C2

Left and right engine rpm is above idle, left and right EDP pressure is more than 2,400 psi, and the NLG is not up, the NLG doors are not closed, or the landing gear lever is not up for 30 seconds. The first condition permits the flight crew to operate the LG steering when airspeed is less than 60 knots (decreased rudder control authority during taxi). The second condition permits operation of the NLG actuation and steering if the hydraulic leak is in the part of the center hydraulic system isolated by the reserve isolation valve. The third condition permits operation of the NLG actuation and steering if there has not been an engine burst and the other hydraulic systems are pressurized. The nose gear isolation valve opens when pressure is necessary at the NLG. If the NLG is not fully retracted or the NLG doors are not closed, the nose gear isolation valve opens to let the NLG complete the retraction. When the landing gear lever is moved to the down position, the nose gear isolation valve opens to let the NLG extend with center system pressure.

Central Hydraulic System Reset

Both valves open again automatically when the center system quantity is more than 0.70 and airspeed is less than 60 knots for 5 seconds. Both valves also reset when the center system quantity is more than 0.70 and both engines and both engine-driven pumps operate normally for 30 seconds.



Center hydraulic isolation system.

Advantages of Hydraulic system

1. Large load capacity with almost high accuracy and precision.

2. Smooth movement.

3. Automatic lubricating provision to reduce to wear.

4. Division and distribution of hydraulic force are easily performed.

5. Limiting and balancing of hydraulic forces are easily performed.

Disadvantages of Hydraulic system

1. A hydraulic element needs to be machined to a high degree of precision.

2. Leakage of hydraulic oil poses a problem to hydraulic operators.

3. Special treatment is needed to protect them from rust, corrosion, dirt etc.,

4. Hydraulic oil may pose problems if it disintegrates due to aging and chemical deterioration.

5. Hydraulic oils are messy and almost highly flammable.

Merits and Demerits

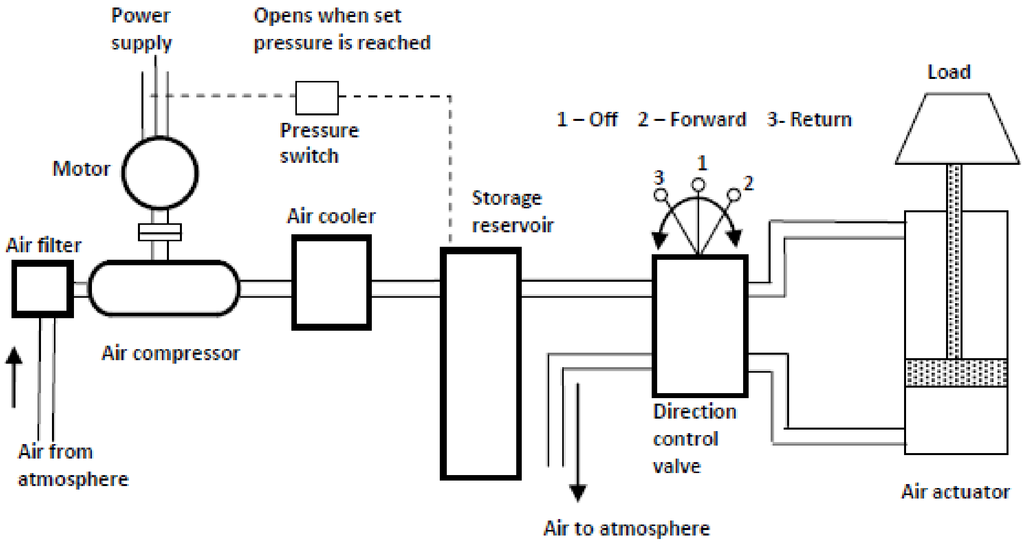
- Ease and accuracy of control: By the use of simple levers and push buttons, the operator of a hydraulic system can easily start, stop, speed up and slow down.
- Multiplication of force: A fluid power system (without using cumbersome gears, pulleys and levers) can multiply forces simply and efficiently from a fraction of a pound, to several hundred tons of output.
- Constant force and torque: Only fluid power systems are capable of providing a constant torque or force regardless of speed changes.
- Simple, safe and economical: In general, hydraulic systems use fewer moving parts in comparison with mechanical and electrical systems. Thus they become simpler and easier to maintain.

In spite of possessing all these highly desirable features, hydraulic systems also have certain drawbacks, some of which are:

- Handling of hydraulic oils which can be quite messy. It is also very difficult to completely eliminate leakage in a hydraulic system.
- Hydraulic lines can burst causing serious human injuries.
- Most hydraulic fluids have a tendency to catch fire in the event of leakage, especially in hot regions.

PNEUMATIC SYSTEM

A pneumatic system carries power by employing compressed gas, generally air, as a fluid for transmitting energy from an energy-generating source to an energy-using point to accomplish useful work.



Basic Pneumatic System Components

Pneumatic System Components

- Pneumatic actuator
- Compressor
- reservoir
- Valves
- Air filter
- Air cooler
- External power supply (Motor)

The functions of various components shown in Figure are as follows:

1. The pneumatic actuator converts the fluid power into mechanical power to perform useful work.

2. The compressor is used to compress the fresh air drawn from the atmosphere.

3. The storage reservoir is used to store a given volume of compressed air.

4. The valves are used to control the direction, flow rate and pressure of compressed air.

5. External power supply (motor) is used to drive the compressor.

6. The piping system carries the pressurized air from one location to another.

Air is drawn from the atmosphere through air filter and raised to required pressure by an air compressor. As the pressure rises, the temperature also rises and hence air cooler is provided to cool the air with some preliminary treatment to remove the moisture.

Then the treatment pressurized air needs to get stored to maintain the pressure. With the storage reservoir, a pressure switch is fitted to start and stop the electric motor when pressure falls and reached the required level, respectively.

The cylinder movement is controlled by pneumatic valve. One side of the pneumatic valve is connected to the compressed air and silencers for the exhaust air and the other side of the valve is connected to port A and Port B of the cylinder.

Position of the valve is as follows

1. **Raise:** To lift the weight, the compressed air supply is connected to port A and the port B is connected to the exhaust line, by moving the valve position to the "Raise"

2. **Lower:** To bring the weight down, the compressed air line is connected to port B and port A is connected to exhaust air line, by moving the valve position to the "lower"

3**. Off:** The weight can be stopped at a particular position by moving the valve to position to "Off" position. This disconnects the port A and port B from the pressurized line and the retrieval line, which locks the air in the cylinder.

AIRCRAFT PNEUMATIC SYSTEMS

Some aircraft manufacturers have equipped their aircraft with a high pressure pneumatic system (3,000 psi) in the past. The last aircraft to utilize this type of system was the Fokker F27. Such systems operate a great deal like hydraulic systems, except they employ air instead of a liquid for transmitting power. Pneumatic systems are sometimes used for:

• Brakes

• Opening and closing doors

• Driving hydraulic pumps, alternators, starters, water injection pumps, etc.

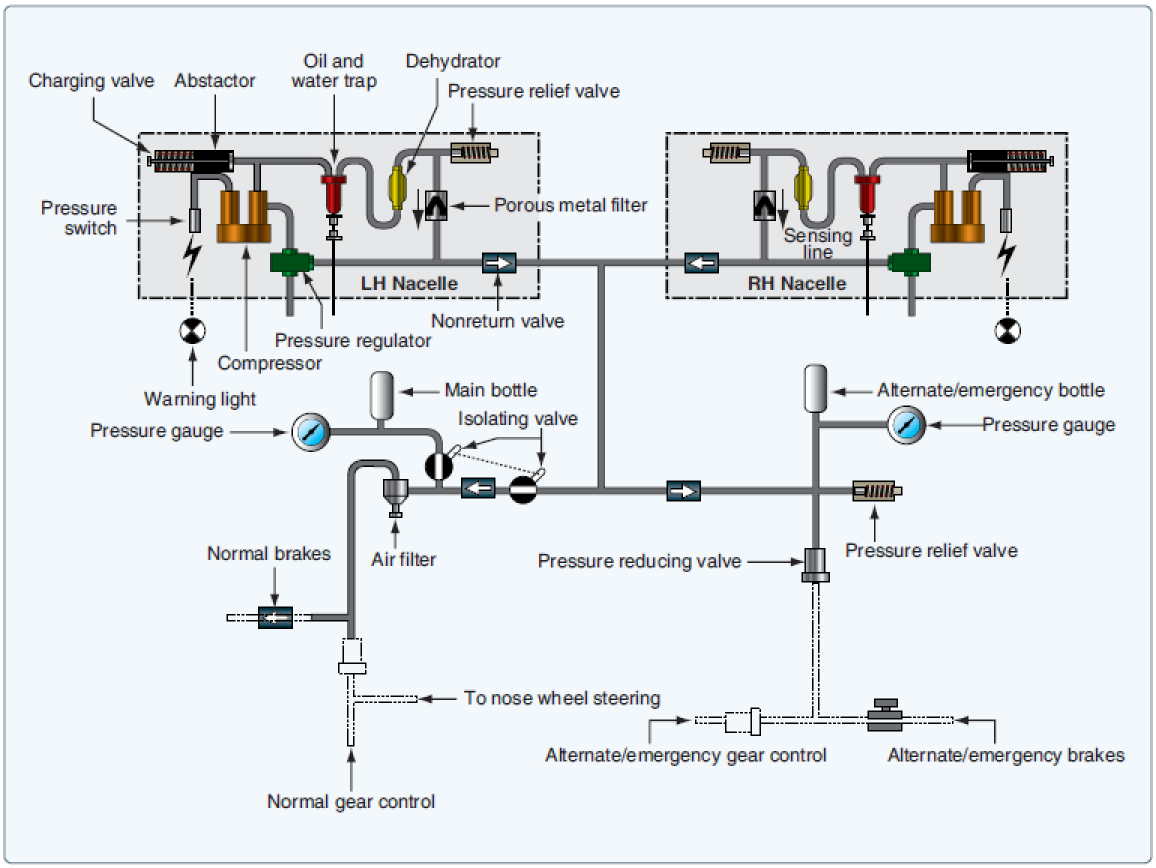
• Operating emergency devices

Both pneumatic and hydraulic systems are similar units and use confined fluids. The word confined means trapped or completely enclosed. The word fluid implies such liquids as water, oil, or anything that flows. Since both liquids and gases flow, they are considered as fluids; however, there is a great deal of difference in the characteristics of the two.

Liquids are practically incompressible; a quart of water still occupies about a quart of space regardless of how hard it is compressed. But gases are highly compressible; a quart of air can be compressed into a thimbleful of space. In spite of this difference, gases and liquids are both fluids and can be confined and made to transmit power. The type of unit used to provide pressurized air for pneumatic systems is determined by the system's air pressure requirements.

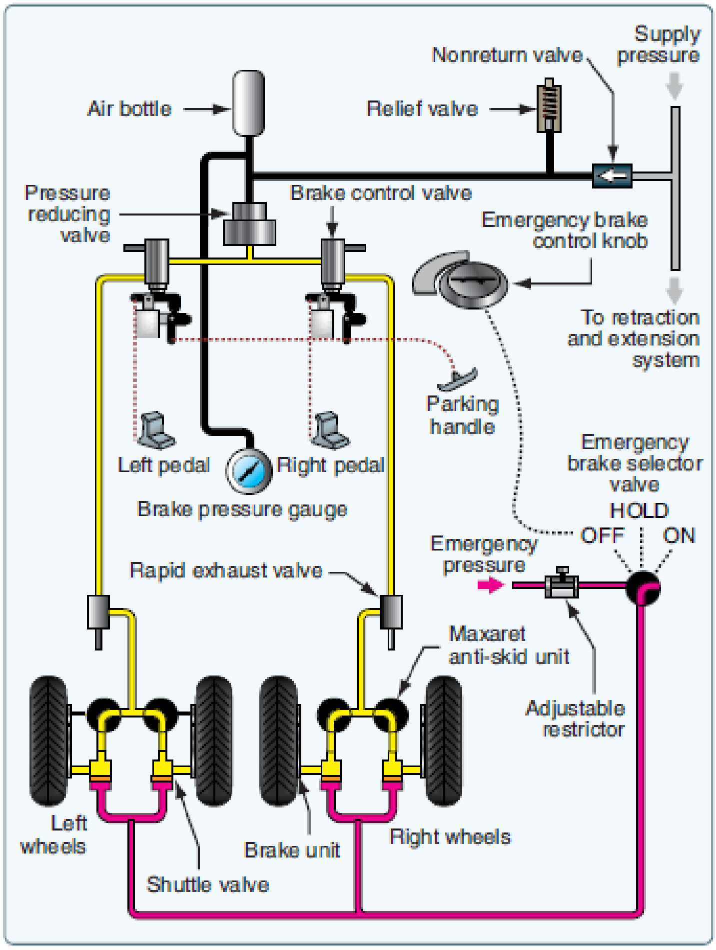
High-Pressure Systems

For high-pressure systems, air is usually stored in metal bottles at pressures ranging from 1,000 to 3,000 psi, depending on the particular system. This type of air bottle has two valves, one of which is a charging valve. A ground-operated compressor can be connected to this valve to add air to the bottle.



High-pressure pneumatic system.

The other valve is a control valve. It acts as a shutoff valve, keeping air trapped inside the bottle until the system is operated. Although the high-pressure storage cylinder is light in weight, it has a definite disadvantage. Since the system cannot be recharged during flight, operation is limited by the small supply of bottled air. Such an arrangement cannot be used for the continuous operation of a system. Instead, the supply of bottled air is reserved for emergency operation of such systems as the landing gear or brakes. The usefulness of this type of system is increased, however, if other air-pressurizing units are added to the aircraft.



Pneumatic brake system.

Pneumatic System Components

Pneumatic systems are often compared to hydraulic systems, but such comparisons can only hold true in general terms. Pneumatic systems do not utilize reservoirs, hand pumps, accumulators, regulators, or engine-driven or electrically driven power pumps for building normal pressure. But similarities do exist in some components.

Air Compressors

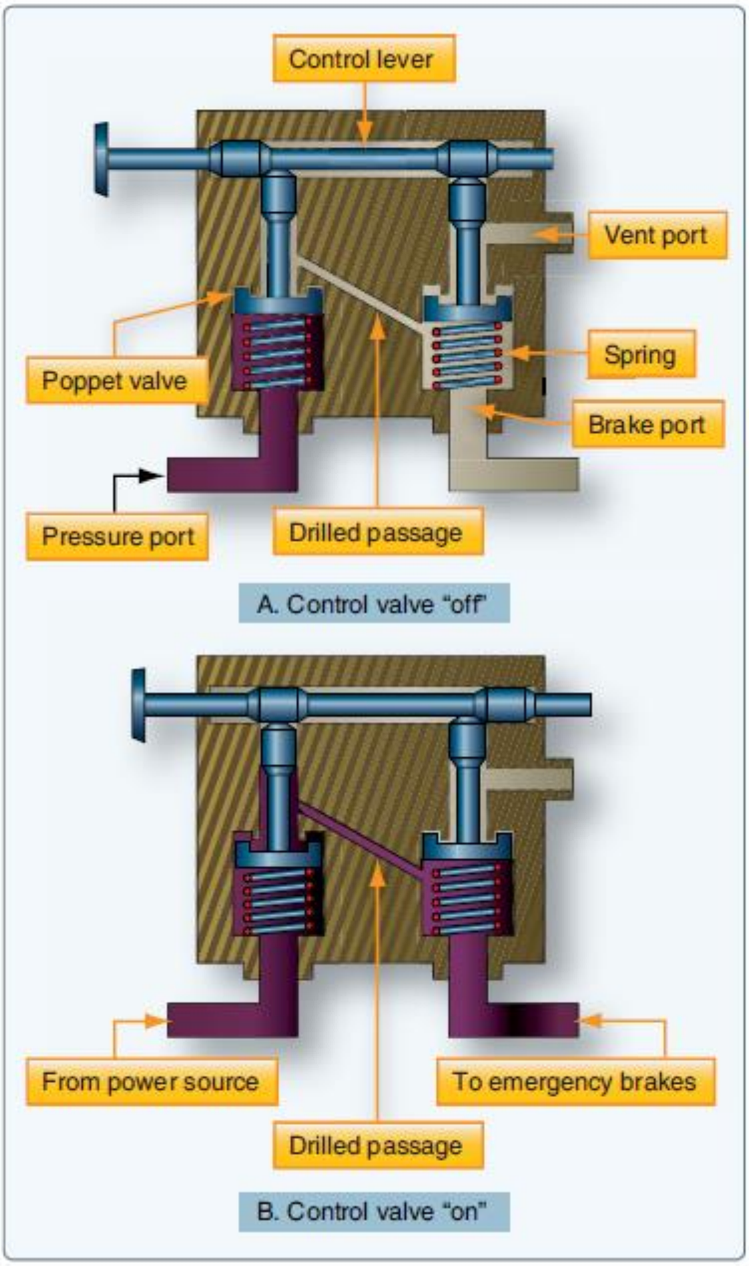
On some aircraft, permanently installed air compressors have been added to recharge air bottles whenever pressure is used for operating a unit. Several types of compressors are used for this purpose. Some have two stages of compression, while others have three, depending on the maximum desired operating pressure.

Relief Valves

Relief valves are used in pneumatic systems to prevent damage. They act as pressure limiting units and prevent excessive pressures from bursting lines and blowing out seals.

Control Valves

Control valves are also a necessary part of a typical pneumatic system.



Pneumatic control valve.

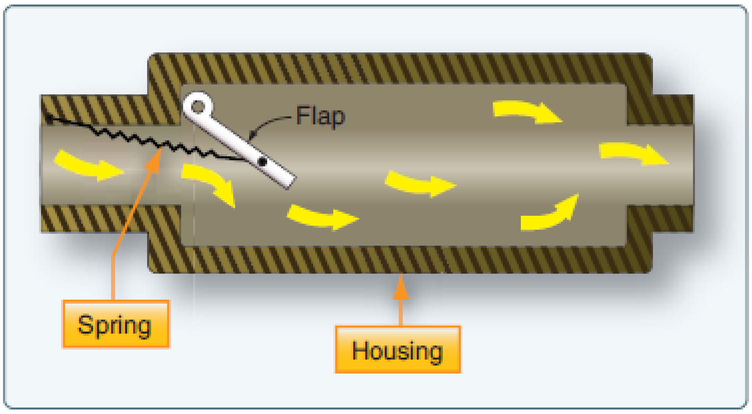
Figure illustrates how a valve is used to control emergency air brakes. The control valve consists of three-port housing, two poppet valves, and a control lever with two lobes.

In *Figure A*, the control valve is shown in the off position. A spring holds the left poppet closed so that compressed air entering the pressure port cannot flow to the brakes. In *Figure-B*, the control valve has been placed in the on position. One lobe of the lever holds the left poppet open, and a spring closes the right poppet. Compressed air now flows around the opened left poppet, through a drilled passage, and into a chamber below the right poppet.

Since the right poppet is closed, the high-pressure air flows out of the brake port and into the brake line to apply the brakes. To release the brakes, the control valve is returned to the off position. *[Figure A]* The left poppet now closes, stopping the flow of high-pressure air to the brakes. At the same time, the right poppet is opened, allowing compressed air in the brake line to exhaust through the vent port and into the atmosphere.

Check Valves

Check valves are used in both hydraulic and pneumatic systems. *Figure* illustrates a flap-type pneumatic check valve.

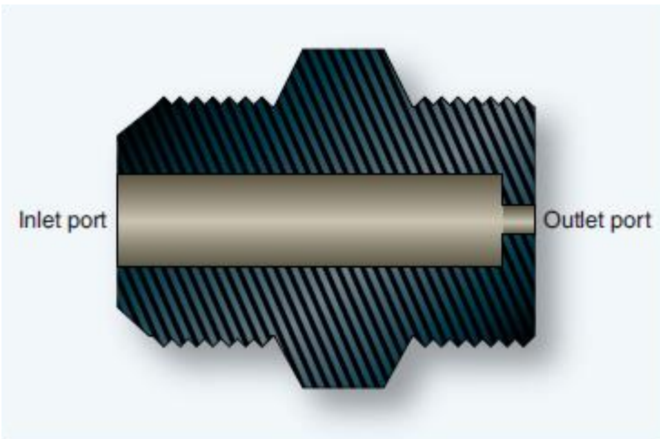


Flap-type pneumatic check valve.

Air enters the left port of the check valve, compresses a light spring, forcing the check valve open and allowing air to flow out the right port. But if air enters from the right, air pressure closes the valve, preventing a flow of air out the left port. Thus, a pneumatic check valve is a one-direction flow control valve.

Restrictors

Restrictors are a type of control valve used in pneumatic systems. *Figure* illustrates an orifice-type restrictor with a large inlet port and a small outlet port.

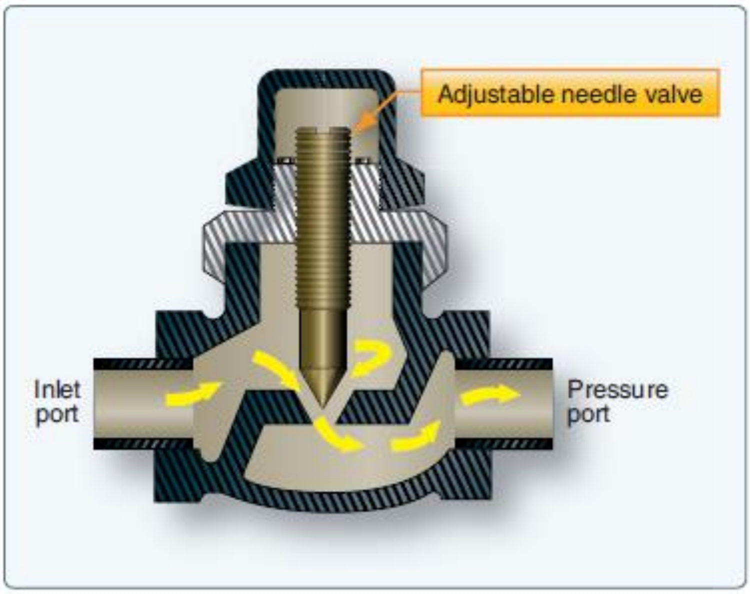


Pneumatic orifice valve.

The small outlet port reduces the rate of airflow and the speed of operation of an actuating unit.

Variable Restrictor

Another type of speed-regulating unit is the variable restrictor.



Variable pneumatic restrictor.

It contains an adjustable needle valve, which has threads around the top and a point on the lower end. Depending on the direction turned, the needle valve moves the sharp point either into or out of a small opening to decrease or increase the size of the opening. Since air entering the inlet port must pass through this opening before reaching the outlet port, this adjustment also determines the rate of airflow through the restrictor.

Filters

Pneumatic systems are protected against dirt by means of various types of filters. A micronic filter consists of housing with two ports, a replaceable cartridge, and a relief valve. Normally, air enters the inlet, circulates around the cellulose cartridge, and flows to the center of the cartridge and out the outlet port. If the cartridge becomes clogged with dirt, pressure forces the relief valve open and allows unfiltered air to flow out the outlet port.

A screen-type filter is similar to the micron filter but contains a permanent wire screen instead of a replaceable cartridge. In the screen filter, a handle extends through the top of the housing and can be used to clean the screen by rotating it against metal scrapers.

Desiccant/Moisture Separator

The moisture separator in a pneumatic system is always located downstream of the compressor. Its purpose is to remove any moisture caused by the compressor. A complete moisture separator consists of a reservoir, a pressure switch, a dump valve, and a check valve.

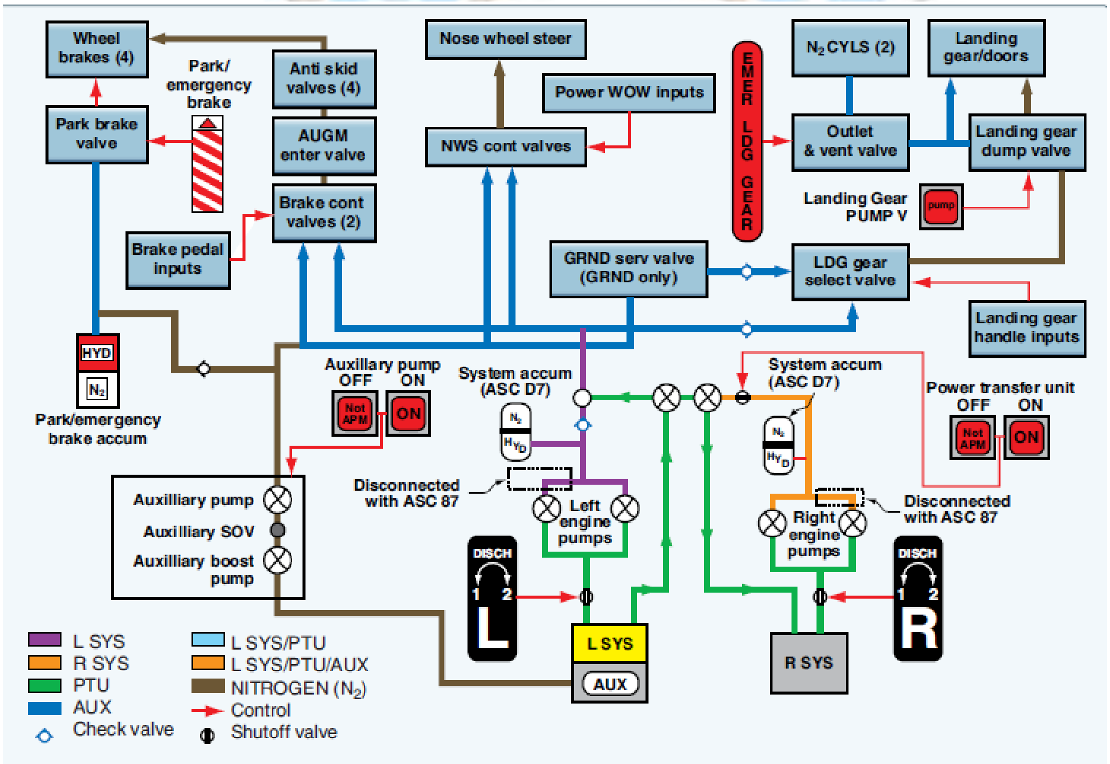
It may also include a regulator and a relief valve. The dump valve is energized and deenergized by the pressure switch. When deenergized, it completely purges the separator reservoir and lines up to the compressor. The check valve protects the system against pressure loss during the dumping cycle and prevents reverse flow through the separator.

Chemical Drier

Chemical driers are incorporated at various locations in a pneumatic system. Their purpose is to absorb any moisture that may collect in the lines and other parts of the system. Each drier contains a cartridge that should be blue in color. If otherwise noted, the cartridge is to be considered contaminated with moisture and should be replaced.

Emergency Backup Systems

Many aircraft use a high-pressure pneumatic back-up source of power to extend the landing gear or actuate the brakes, if the main hydraulic braking system fails. The nitrogen is not directly used to actuate the landing gear actuators or brake units but, instead, it applies the pressurized nitrogen to move hydraulic fluid to the actuator. This process is called pneudraulics. The following paragraph discusses the components and operation of an emergency pneumatic landing gear extension system used on a business jet.



Pneumatic emergency landing gear extension system.

Nitrogen Bottles

Nitrogen used for emergency landing gear extension is stored in two bottles, one bottle located on each side of the nose wheel well. Nitrogen from the bottles is released by actuation of an outlet valve. Once depleted, the bottles must be recharged by maintenance personnel. Fully serviced pressure is approximately 3,100 psi at 70 °F/21 °C, enough for only one extension of the landing gear.

Gear Emergency Extension Cable and Handle

The outlet valve is connected to a cable and handles assembly. The handle is located on the side of the co-pilot's console and is labelled EMER LDG GEAR. Pulling the handle fully upward opens the outlet valve, releasing compressed nitrogen into the landing gear extension system. Pushing the handle fully downward closes the outlet valve and allows any nitrogen present in the emergency landing gear extension system to be vented overboard. The venting process takes approximately 30 seconds.

Dump Valve

As compressed nitrogen is released to the landing gear selector/dump valve during emergency extension, the pneudraulic pressure actuates the dump valve portion of the landing gear selector/dump valve to isolate the landing gear system from the remainder of hydraulic system. When activated, a blue DUMP legend is illuminated on the LDG GR DUMP V switch, located on the cockpit overhead panel. A dump valve reset switch is used to reset the dump valve after the system has been used and serviced.

Emergency Extension Sequence:

1. Landing gear handle is placed in the DOWN position.

2. Red light in the landing gear control handle is illuminated.

3. EMER LDG GEAR handle is pulled fully outward.

4. Compressed nitrogen is released to the landing gear selector/dump valve.

5. Pneudraulic pressure actuates the dump valve portion of the landing gear selector/dump valve.

6. Blue DUMP legend is illuminated on the LDG GR DUMP switch.

7. Landing gear system is isolated from the remainder of hydraulic system.

8. Pneudraulic pressure is routed to the OPEN side of the landing gear door actuators, the UNLOCK side of the landing gear up lock actuators, and the EXTEND side of the main landing gear side brace actuators and nose landing gear extend/retract actuator.

9. Landing gear doors open.

10. Up lock actuators unlock.

11. Landing gear extends down and locks.

12. Three green DOWN AND LOCKED lights on the landing gear control panel are illuminated.

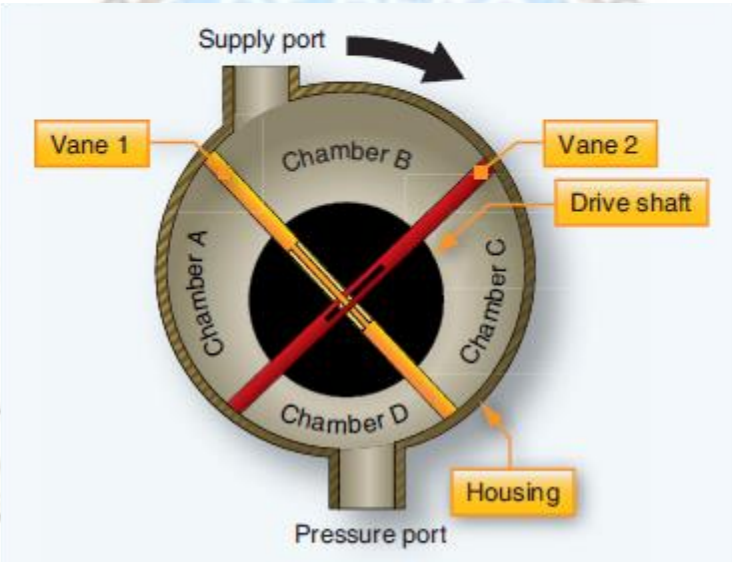
13. Landing gear doors remain open.

Medium-Pressure Systems

A medium-pressure pneumatic system (50–150 psi) usually does not include an air bottle. Instead, it generally draws air from the compressor section of a turbine engine. This process is often called bleed air and is used to provide pneumatic power for engine starts, engine de-icing, wing de-icing, and in some cases, it provides hydraulic power to the aircraft systems (if the hydraulic system is equipped with an air-driven hydraulic pump). Engine bleed air is also used to pressurize the reservoirs of the hydraulic system.

Low-Pressure Systems

Many aircraft equipped with reciprocating engines obtain a supply of low-pressure air from vane-type pumps. These pumps are driven by electric motors or by the aircraft engine.



Schematic of vane-type air pump.

Figure shows a schematic view of one of these pumps, which consists of housing with two ports, a drive shaft, and two vanes. The drive shaft and the vanes contain slots so the vanes can slide back and forth through the drive shaft. The shaft is eccentrically mounted in the housing, causing the vanes to form four different sizes of chambers (A, B, C, and D).

In the position shown, B is the largest chamber and is connected to the supply port. As depicted in *Figure,* outside air can enter chamber B of the pump. When the pump begins to operate, the drive shaft rotates and changes positions of the vanes and sizes of the chambers. Vane No.1 then moves to the right, separating chamber B from the supply port. Chamber B now contains trapped air. As the shaft continues to turn, chamber B moves downward and becomes increasingly smaller, gradually compressing its air. Near the bottom of the pump, chamber B connects to the pressure port and sends compressed air into the pressure line.

Then chamber B moves upward again becoming increasingly larger in area. At the supply port, it receives another supply of air. There are four such chambers in this pump and each goes through this same cycle of operation. Thus, the pump delivers to the pneumatic system a continuous supply of compressed air from 1 to 10 psi. Low-pressure systems are used for wing de-icing boot systems.

Pneumatic Power System Maintenance

Maintenance of the pneumatic power system consists of servicing, troubleshooting, removal, and installation of components, and operational testing. The air compressor's lubricating oil level should be checked daily in accordance with the applicable manufacturer's instructions. The oil level is indicated by means of a sight gauge or dipstick. When refilling the compressor oil tank, the oil (type specified in the applicable instructions manual) is added until the specified level. After the oil is added, ensure that the filler plug is torque and safety wire is properly installed. The pneumatic system should be purged periodically to remove the contamination, moisture, or oil from the components and lines. Purging the system is accomplished by pressurizing it and removing the plumbing from various components throughout the system. Removal of the pressurized lines causes a high rate of airflow through the system, causing foreign matter to be exhausted from the system. If an excessive amount of foreign matter, particularly oil, is exhausted from any one system, the lines and components should be removed and cleaned or replaced. Upon completion of pneumatic system purging and after reconnecting all the system components, the system air bottles should be drained to exhaust any moisture or impurities that may have accumulated there.

After draining the air bottles, service the system with nitrogen or clean, dry compressed air. The system should then be given a thorough operational check and an inspection for leaks and security.

Advantages of Pneumatic system

- Low inertia effect of pneumatic components due to low density of air.
- Pneumatic Systems are light in weight.
- Operating elements are cheaper and easy to operate
- Power losses are less due to low viscosity of air
- High output to weight ratio
- Pneumatic systems offers a safe power source in explosive environment
- Leakage is less and does not influence the systems. Moreover, leakage is not harmful

Disadvantages of Pneumatic systems

- Suitable only for low pressure and hence low force applications
- Compressed air actuators are economical up to 50 kN only.
- Generation of the compressed air is expensive compared to electricity
- Exhaust air noise is unpleasant and silence has to be used.
- Rigidity of the system is poor
- Weight to pressure ratio is large

- Less precise. It is not possible to achieve uniform speed due to compressibility of air
- Pneumatic systems is vulnerable to dirt and contamination

Advantages and Disadvantages of compressed air

Advantages of compressed air	Disadvantages of compressed air
Air is available in unlimited quantities Compressed air is easily conveyed in pipelines even over longer distances	Compressive air is relatively expensive means of conveying energy The higher costs are, however. Largely compensated by the cheaper elements. Simpler and more compact equipment
Compressed air can be stored	Compressed air requires good conditioning. No dirt or moisture residues may be contained in it. Dirt and dust leads to wear on tools and equipment
Compressed air need not be returned. It can be vented to atmosphere after it has performed work	It is not possible to achieve uniform and constant piston speeds(air is compressible)
Compressed air is insensitive to temperature fluctuation. This ensures reliable operation even in extreme temperature conditions	Compressed air is economical only up to certain force expenditure. Owing to the commonly used pressure of 7 bar and limit is about 20 to 50 kN, depending on the travel and the speed. If the force which is required exceeds this level, hydraulics is preferred
Compressed air is clean. This is especially important in food, pharmaceutical, textile, beverage industries	The exhaust is loud. As the result of intensive development work on materials for silencing purposes, this problems has however now largely been solved
Operating elements for compressed air operation are of simple and inexpensive construction.	The oil mist mixed with the air for lubricating the equipment escapes with the exhaust to atmosphere.
Compressed air is fast. Thus, high operational speed can be attained.	Air due to its low conductivity , cannot dissipate heat as much as hydraulic fluid
Speeds and forces of the pneumatics elements can be infinitely adjusted	Air cannot seal the fine gaps between the moving parts unlike hydraulic system
Tools and operating elements are overload proof. Straight line movement can be produced directly	Air is not a good lubricating medium unlike hydraulic fluid.

Comparison between Hydraulic and Pneumatic systems

Sl. No	Hydraulic system	Pneumatic system
1	It employs a pressurized liquid as fluid	it employs a compressed gas usually air as a fluid
2	Oil hydraulics system operates at pressures upto 700 bar.	Pneumatics systems usually operate at 5 to 10 bar.
3	Generally designed for closed systems	Pneumatic systems are usually designed as open system

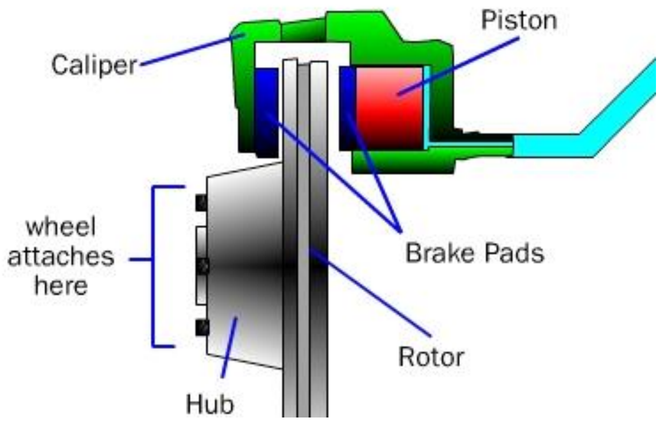
4	System get slow down of leakage occurs	Leakage does not affect the system much more
5	Valve operations are difficult	Easy to operate the valves
6	Heavier in weight	Light in weight
7	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gas
8	System is unsafe to fire hazards	System is free from fire hazards
9	Automatic lubrication is provided	Special arrangements for lubrication needed

AIRCRAFT BRAKING SYSTEM

Brakes are responsible for conversion of excess kinetic energy into thermal energy by increasing the friction. Increasing the amount of friction (i.e. is the resistance offered to motion of a vehicle) reduces the speed of motion of the vehicle. Braking systems employ this principle for slowing down or stopping the vehicles .Braking systems in aircraft are of three basic types: mechanical, hydraulic and pneumatic brakes.

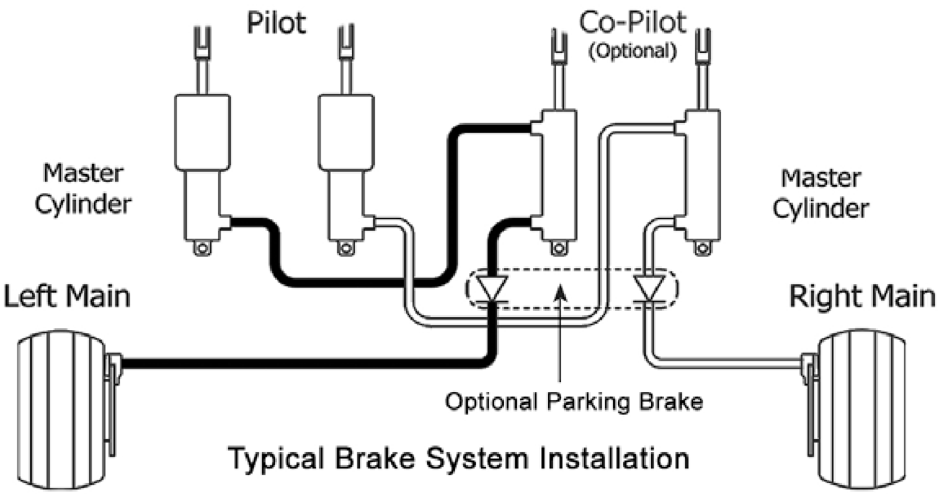
Mechanical brakes are those which are operated by the use of linkages, levers cams etc. Hydraulic brakes make use of fluid pressure for transmission of pressure to the braking components while Pneumatic brakes use air pressure for transmitting brake power. These systems either increase the surrounding air drag with the help of airbrakes, spoilers, flaps, reverse thrusters, drag chutes, etc or increase the ground drag using anchors, skids etc for effective braking.

Aircraft typically use disc and multi-disc brakes .It mainly consists of rotating disc attached to the wheel assembly, brake callipers which are held stationary and contains the brake pads made of material such as asbestos, ceramics, carbon etc. When brake pedal is pressed, brake fluid under pressure flows from master cylinder to the slave cylinder via tubes. The slave cylinder consists of piston which gets actuated by the force of incoming fluid pressure. The piston forces the brake pads against the rotating disc. The friction between the brake pad and disc surface, resist its rotating motion and stops it. Disc brakes used these days are differential type i.e. the left and right unit are independent of one another. This also provides increased manoeuvrability.



Aircraft Disc Brakes

Multiple disc brakes consist of series of discs, the steel stators which is a stationary unit is keyed to the bearing carrier and the rotors form the rotating part and are keyed to the wheel. Automatic adjuster is used for providing clearance between the rotor and stator layers. Under the action of hydraulic pressure, these series of disc get compressed, forcing the wheel to slow down due to friction. These days the discs are provided with slots for better heat dissipation at high temperature. Also, Carbon fibre is being extensively used as rotor material for the brakes because of its low weight and the ability to withstand high heat and temperature. Although it requires lesser maintenance than the conventional brakes but the cost of manufacturing is comparatively high.



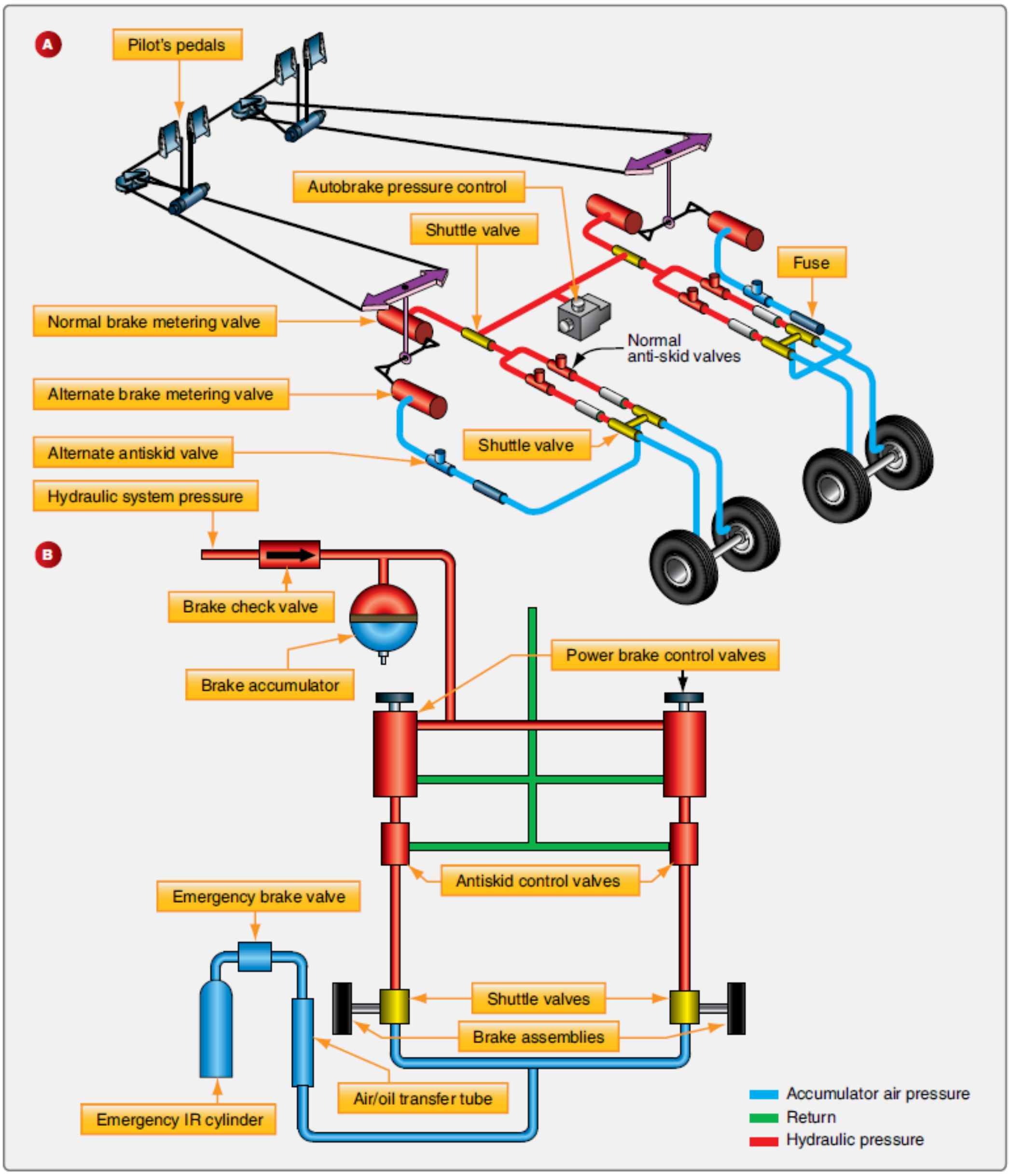
Illustrated to the right is the hydraulic portion of a typical aircraft brake system. In the illustration, the master cylinders on the pilot side incorporate an integral reservoir. Whether you use a master cylinder with integral reservoir, or remote reservoir, the most upstream component must be a reservoir.
It is critically important that the installation allows the brake cylinder piston rod to fully extend when no load is applied.

Types and Construction of Aircraft Brakes

- Single Disc Brakes
- Floating Disc Brakes
- Fixed-Disc Brakes
- Dual-Disc Brakes
- Multiple-Disc Brakes
- Segmented Rotor-Disc Brakes
- Carbon Brakes
- Expander Tube Brakes

Brake Actuating Systems

Different means of delivering the required hydraulic fluid pressure to brake assemblies are discussed in this section. There are three basic actuating systems:
1. An independent system not part of the aircraft main hydraulic system;
2. A booster system that uses the aircraft hydraulic system intermittently when needed; and
3. A power brake system that only uses the aircraft main hydraulic system(s) as a source of pressure.



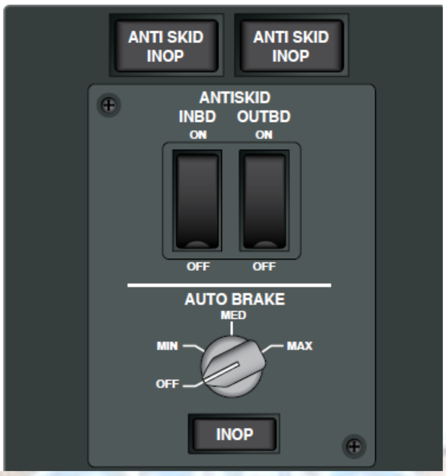
The orientation of components in a basic power brake system is shown in A. The general layout of an airliner power brake system is shown in B.

Anti-Skid

Large aircraft with power brakes require anti-skid systems. It is not possible to immediately ascertain in the flight deck when a wheel stops rotating and begins to skid, especially in aircraft with multiple-wheel main landing gear assemblies. A skid not corrected can quickly lead to a tire blowout, possible damage to the aircraft, and control of the aircraft may be lost.

System Operation

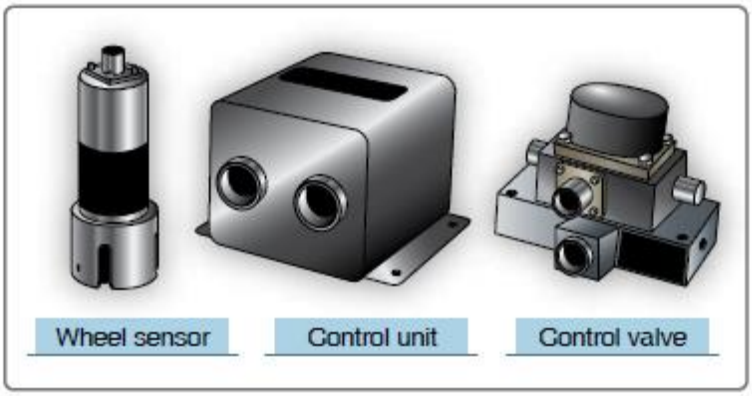
The anti-skid system not only detects wheel skid, it also detects when wheel skid is imminent. It automatically relieves pressure to the brake pistons of the wheel in question by momentarily connecting the pressurized brake fluid area to the hydraulic system return line. This allows the wheel to rotate and avoid a skid. Lower pressure is then maintained to the brake at a level that slows the wheel without causing it to skid. Maximum braking efficiency exists when the wheels are decelerating at a maximum rate but are not skidding. If a wheel decelerates too fast, it is an indication that the brakes are about to lock and cause a skid. To ensure that this does not happen, each wheel is monitored for a deceleration rate faster than a preset rate. When excessive deceleration is detected, hydraulic pressure is reduced to the brake on that wheel. To operate the anti-skid system, flight deck switches must be placed in the ON position.



Antiskid switches in the cockpit.

After the aircraft touches down, the pilot applies and holds full pressure to the rudder brake pedals. The anti-skid system then functions automatically until the speed of the aircraft has dropped to approximately 20 mph. The system returns to manual braking mode for slow taxi and ground maneuvering.

There are various designs of anti-skid systems. Most contain three main types of components: wheel speed sensors, antiskid control valves, and a control unit. These units work together without human interference. Some anti-skid systems provide complete automatic braking. The pilot needs only to turn on the auto brake system, and the anti-skid components slow the aircraft without pedal input. *[Above Figure]* Ground safety switches are wired into the circuitry for anti-skid and auto brake systems. Wheel speed sensors are located on each wheel equipped with a brake assembly. Each brake also has its own anti-skid control valve. Typically, a single control box contains the anti-skid comparative circuitry for all of the brakes on the aircraft.



A wheel sensor (left), a control unit (center), and a control valve (right) are components of an antiskid system. A sensor is located on each wheel equipped with a brake assembly. An antiskid control valve for each brake assembly is controlled from a single central control unit.

Wheel Speed Sensors

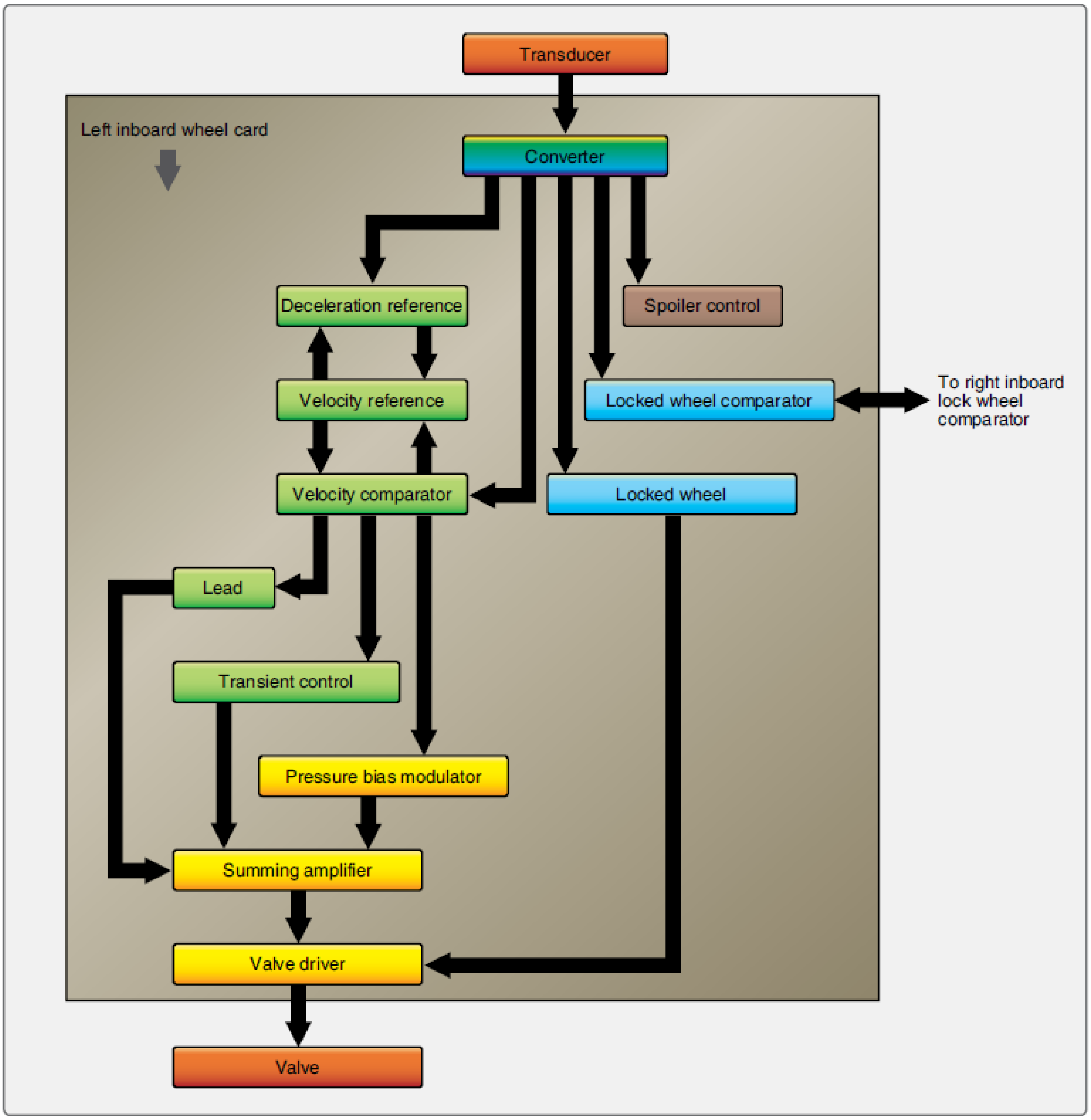
Wheel speed sensors are transducers. They may be alternating current (AC) or direct current (DC). The typical AC wheel speed sensor has a stator mounted in the wheel axle. A coil around it is connected to a controlled DC source so that when energized, the stator becomes an electromagnet. A rotor that turns inside the stator is connected to the rotating wheel hub assembly through a drive coupling so that it rotates at the speed of the wheel. Lobes on the rotor and stator cause the distance between the two components to constantly change during rotation. This alters the magnetic coupling or reluctance between the rotor and stator. As the electromagnetic field changes, a variable frequency AC is induced in the stator coil. The frequency is directly proportional to the speed of rotation of the wheel. The AC signal is fed to the control unit for processing. A DC wheel speed sensor is similar, except that a DC is produced the magnitude of which is directly proportional to wheel speed. *[Above Figure]*

Control Units

The control unit can be regarded as the brain of the antiskid system. It receives signals from each of the wheel sensors. Comparative circuits are used to determine if any of the signals indicate a skid is imminent or occurring on a particular wheel. If so, a signal is sent to the control valve of the wheel to relieve hydraulic pressure to that brake which prevents or relieves the skid. The control unit may or may not have external test switches and status indicating lights. It is common for it to be located in the avionics bay of the aircraft.

A rack mounted antiskid control unit from an airliner.

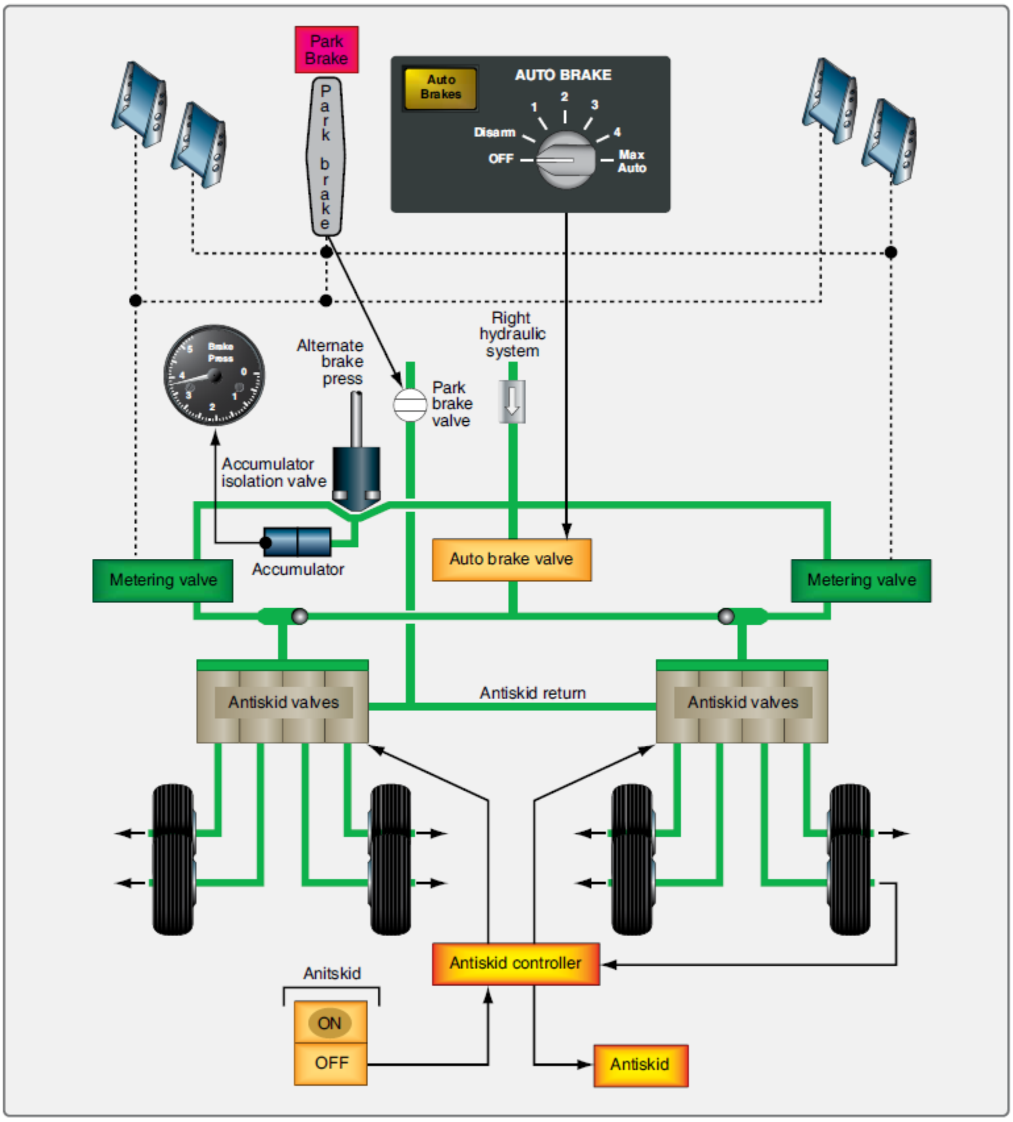
The Boeing anti-skid control valve block diagram in *Figure* below *gives* further detail on the functions of an antiskid control unit. Other aircraft may have different logic to achieve similar end results. DC systems do not require an input converter since DC is received from the wheel sensors, and the control unit circuitry operates primarily with DC.



A Boeing 737 antiskid control unit internal block diagram.

Only the functions on one circuit card for one wheel brake assembly are shown in *Figure*. Each wheel has its own identical circuitry card to facilitate simultaneous operation.
All cards are housed in a single control unit that Boeing calls a control shield. The converter shown changes the AC frequency received from the wheel sensor into DC voltage that is proportional to wheel speed. The output is used in a velocity reference loop that contains deceleration and velocity reference circuits. The converter also supplies input for the spoiler system and the locked wheel system, which is discussed at the end of this section. A velocity reference loop output voltage is produced, which represents the instantaneous velocity of the aircraft. This is compared to converter output in the velocity comparator. This comparison of voltages is essentially the comparison of the aircraft speed to wheel speed. The output from the velocity comparator is a positive or negative error voltage corresponding to whether the wheel speed is too fast or too slow for optimum braking efficiency for a given aircraft speed.

The error output voltage from the comparator feeds the pressure bias modulator circuit. This is a memory circuit that establishes a threshold where the pressure to the brakes provides optimum braking. The error voltage causes the modulator to either increase or decrease the pressure to the brakes in attempt to hold the modulator threshold. It produces a voltage output that is sent to the summing amplifier to do this. A lead output from the comparator anticipates when the tire is about to skid with a voltage that decreases the pressure to the brake. It sends this voltage to the summing amplifier as well. A transient control output from the comparator designed for rapid pressure dump when a sudden skid has occurred also sends voltage to the summing amp. As the name suggests, the input voltages to the amplifier are summed, and a composite voltage is sent to the valve driver. The driver prepares the current required to be sent to the control valve to adjust the position of the valve. Brake pressure increases, decreases, or holds steady depending on this value.



The Boeing 757 normal brake system with auto brake and antiskid.

LANDING GEAR SYSTEMS

Aircraft Landing Gear

The landing gear forms the principal support of an aircraft on the surface. The most common type of landing gear consists of wheels, but aircraft can also be equipped with floats for water operations or skis for landing on snow.

The landing gear supports the airplane during the take off, landing, and when parked.

The landing gear on small aircraft consists of three wheels: two main wheels (one located on each side of the fuselage) and a third wheel positioned either at the front or rear of the airplane. Landing gear employing a rear-mounted wheel is called conventional landing gear. Airplanes with conventional landing gear are often referred to as tail wheel airplanes. When the third wheel is located on the nose, it is called a nose wheel, and the design is referred to as a tricycle gear. A steerable nose wheel or tail wheel permits the airplane to be controlled throughout all operations while on the ground.

Tricycle Landing Gear Airplanes

A tricycle gear airplane has three advantages:

1. It allows more forceful application of the brakes during landings at high speeds without causing the aircraft to nose over.
2. It permits better forward visibility for the pilot during takeoff, landing, and taxiing.
3. It tends to prevent ground looping (swerving) by providing more directional stability during ground operation since the aircraft's center of gravity (CG) is forward of the main wheels. The forward CG keeps the airplane moving forward in a straight line rather than ground looping.

Nose wheels are either steerable or castering. Steerable nose wheels are linked to the rudders by cables or rods, while castering nose wheels are free to swivel. In both cases, the aircraft is steered using the rudder pedals. Aircraft with a castering nose wheel may require the pilot to combine the use of the rudder pedals with independent use of the brakes.

Tail wheel Landing Gear Airplanes

Tail wheel landing gear aircraft have two main wheels attached to the airframe ahead of its CG that support most of the weight of the structure. A tail wheel at the very back of the fuselage provides a third point of support. This arrangement allows adequate ground clearance for a larger propeller and is more desirable for operations on unimproved fields.

With the CG located behind the main gear, directional control of this type aircraft becomes more difficult while on the ground. This is the main disadvantage of the tail wheel landing gear. For example, if the pilot allows the aircraft to swerve while rolling on the ground at a low speed, he or she may not have sufficient rudder control and the CG will attempt to get ahead of the main gear which may cause the airplane to ground loop. Lack of good forward visibility when the tail wheel is on or near the ground is a second disadvantage of tail wheel landing gear aircraft. These inherent problems mean specific training is required in tail wheel aircraft.

Fixed and Retractable Landing Gear

Further classification of aircraft landing gear can be made into two categories: fixed and retractable. Many small, single engine light aircraft have fixed landing gear, as do a few light twins. This means the gear is attached to the airframe and remains exposed to the slipstream as the aircraft is flown. As discussed in Chapter 2 of this handbook, as the speed of an aircraft increases, so does parasite drag. Mechanisms to retract and stow the landing gear to eliminate parasite drag add weight to the aircraft. On slow aircraft, the penalty of this added weight is not overcome by the reduction of drag, so fixed gear is used. As the speed of the aircraft increases, the drag caused by the landing gear becomes greater and a means to retract the gear to eliminate parasite drag is required, despite the weight of the mechanism. A great deal of the parasite drag caused by light aircraft landing gear can be reduced by building gear as aerodynamically as possible and by adding fairings or wheel pants to streamline the airflow past the protruding assemblies. A small, smooth profile to the oncoming wind greatly reduces landing gear parasite drag. Illustrates a Cessna aircraft landing gear used on many of the manufacturer's light planes. The thin cross section of the spring steel struts combine with the fairings over the wheel and brake assemblies to raise performance of the fixed landing gear by keeping parasite drag to a minimum. Retractable landing gear stows in fuselage or wing compartments while in flight. Once in these wheel wells, gears are out of the slipstream and do not because parasites drag. Most retractable gear has a close fitting panel attached to them that fairs with the aircraft skin when the gear is fully retracted. Other aircraft have separate doors that open, allowing the gear to enter or leave, and then close again.

Shock Absorbing and Non-Shock Absorbing

Landing Gear

In addition to supporting the aircraft for taxi, the forces of impact on an aircraft during landing must be controlled by the landing gear.

This is done in two ways:

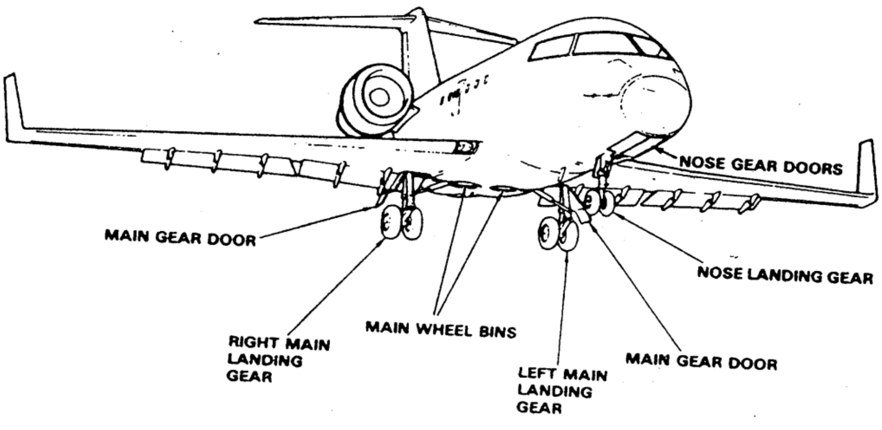
1) The shock energy is altered and transferred throughout the airframe at a different rate and time than the single strong pulse of impact, and

2) The shock is absorbed by converting the energy into heat energy.

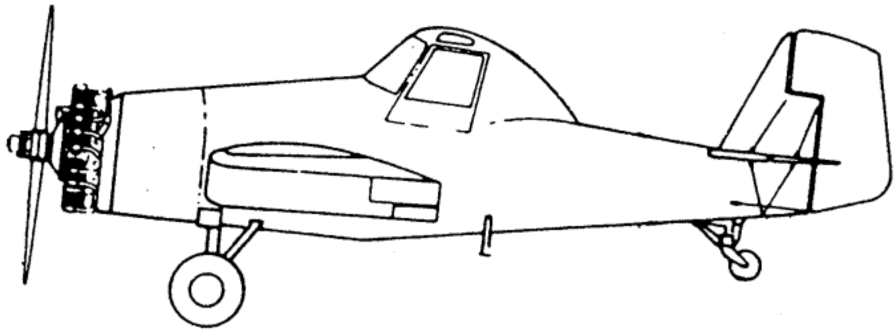
Fixed type of landing gear *Retractable type of landing gear*

Aircraft Landing-Gear System Configuration

i) Conventional Geared Aircraft (Retractable type of landing gear)



ii) Tricycle Landing Gear (Fixed landing gear)

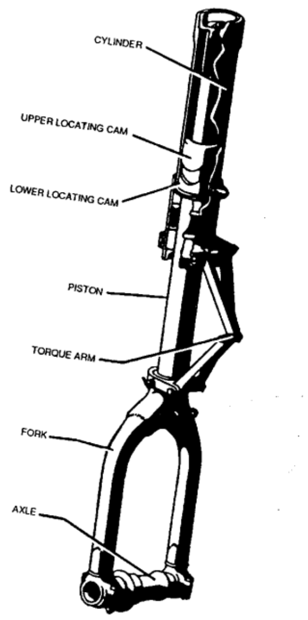


Classification of landing gear

- Non - Absorbing Landing Gear
    - Rigid Landing Gear
    - Shock-Cord Landing Gear
    - Spring-Type Gear
- Shock-Absorbing Landing Gear
    - Spring - Oleo
    - Air- Oleo
- Fixed Gear
- Retractable Gear
- Hulls and Floats

Landing-Gear Components

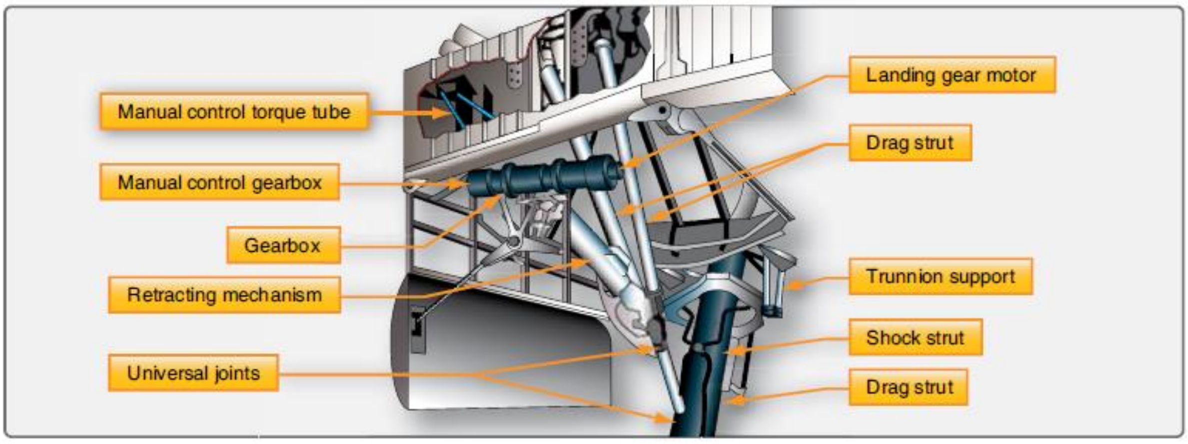
- Trunnion
- Struts
- Torque Links
- Truck or **Bogie**
- Drag Link or **Drag Strut**
- Side Brace Link or **Side Strut**
- Overcenter Link or **Down lock**
- Swivel Gland
- Shimmy Dampers



A typical landing gear strut

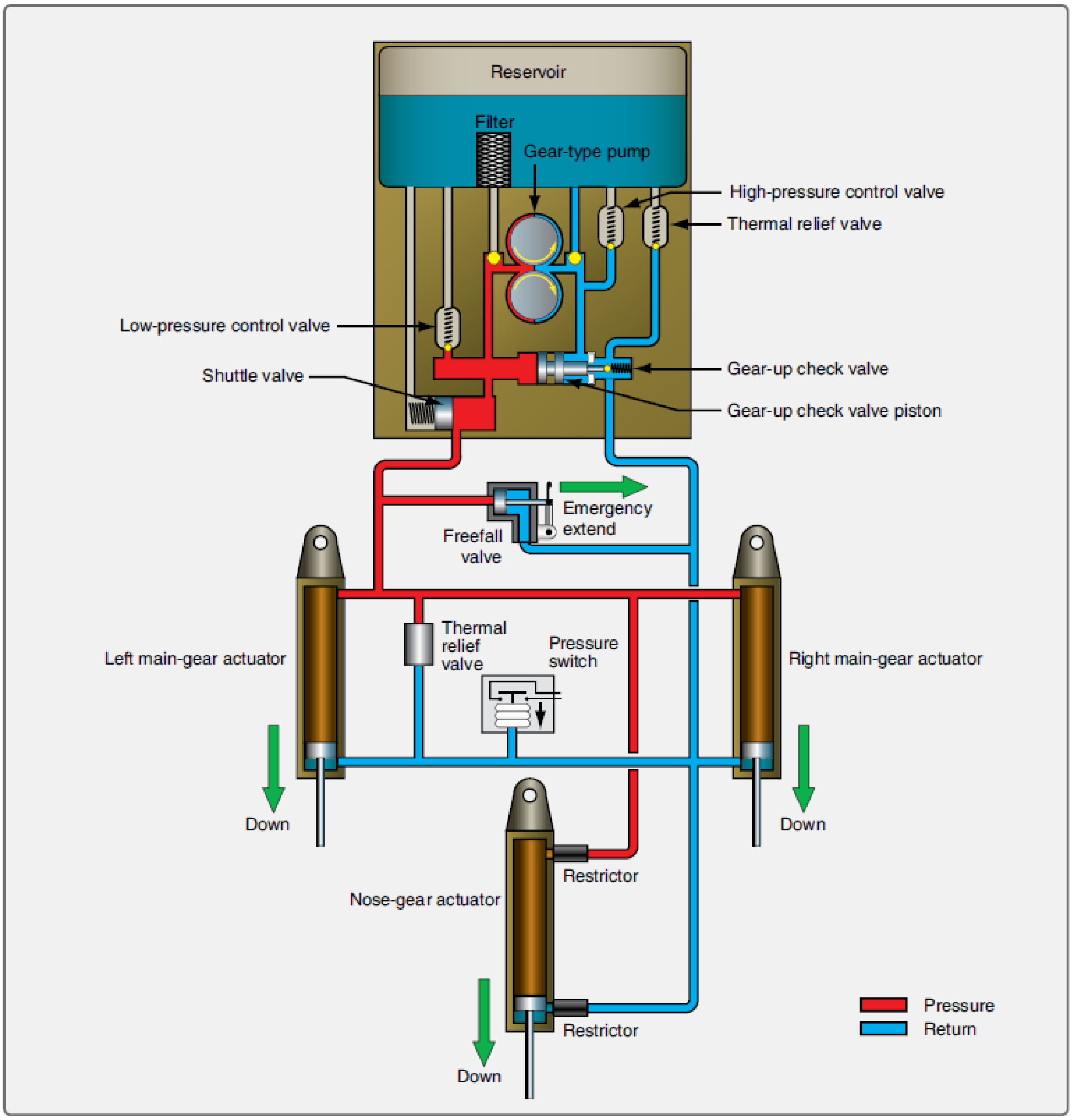
Small Aircraft Retraction Systems

As the speed of a light aircraft increases, there reaches a point where the parasite drag created by the landing gear in the wind is greater than the induced drag caused by the added weight of a retractable landing gear system. Thus, many light aircraft have retractable landing gear. There are many unique designs. The simplest contains a lever in the flight deck mechanically linked to the gear. Through mechanical advantage, the pilot extends and retracts the landing gear by operating the lever. Use of a roller chain, sprockets, and a hand crank to decrease the required force is common. Electrically operated landing gear systems are also found on light aircraft. An all-electric system uses an electric motor and gear reduction to move the gear. The rotary motion of the motor is converted to linear motion to actuate the gear. This is possible only with the relatively lightweight gear found on smaller aircraft. An all-electric gear retraction system is illustrated in *Figure*



A geared electric motor landing gear retraction system.

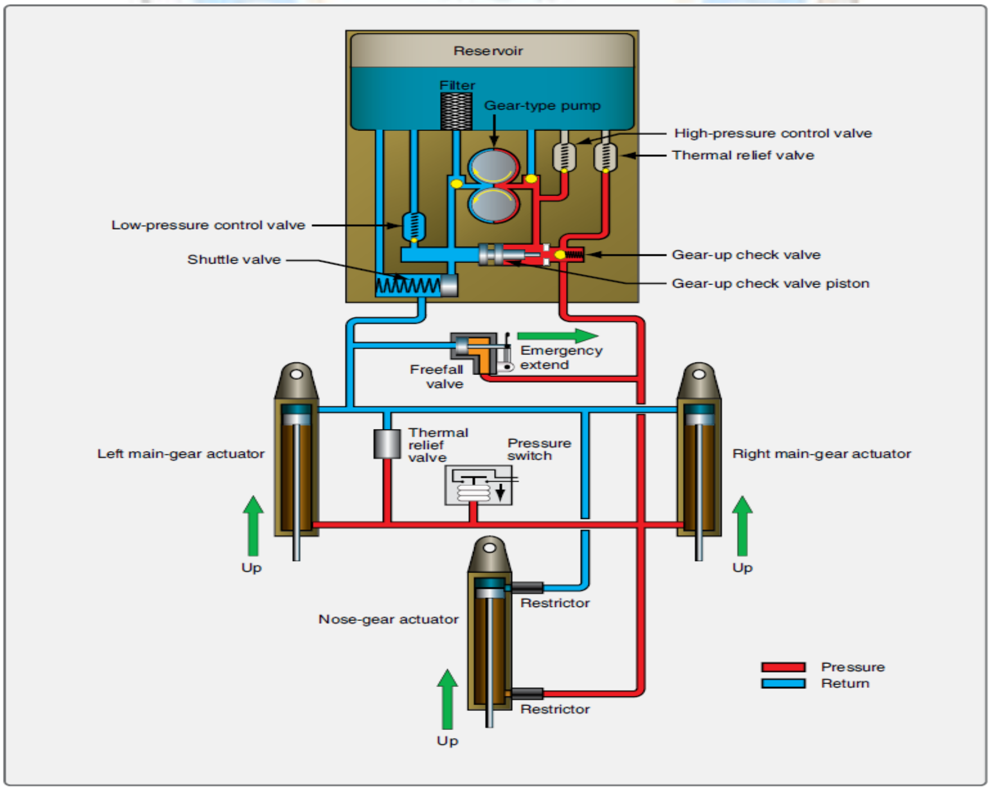
A more common use of electricity in gear retraction systems is that of an electric/hydraulic system found in many Cessna and Piper aircraft. This is also known as a power pack system. A small lightweight hydraulic power pack contains several components required in a hydraulic system. These include the reservoir, a reversible electric motor-driven hydraulic pump, a filter, high-and-low pressure control valves, a thermal relief valve, and a shuttle valve. Some power packs incorporate an emergency hand pump. A hydraulic actuator for each gear is driven to extend or retract the gear by fluid from the power pack. *Figure below* illustrates a power pack system while gear is being lowered.



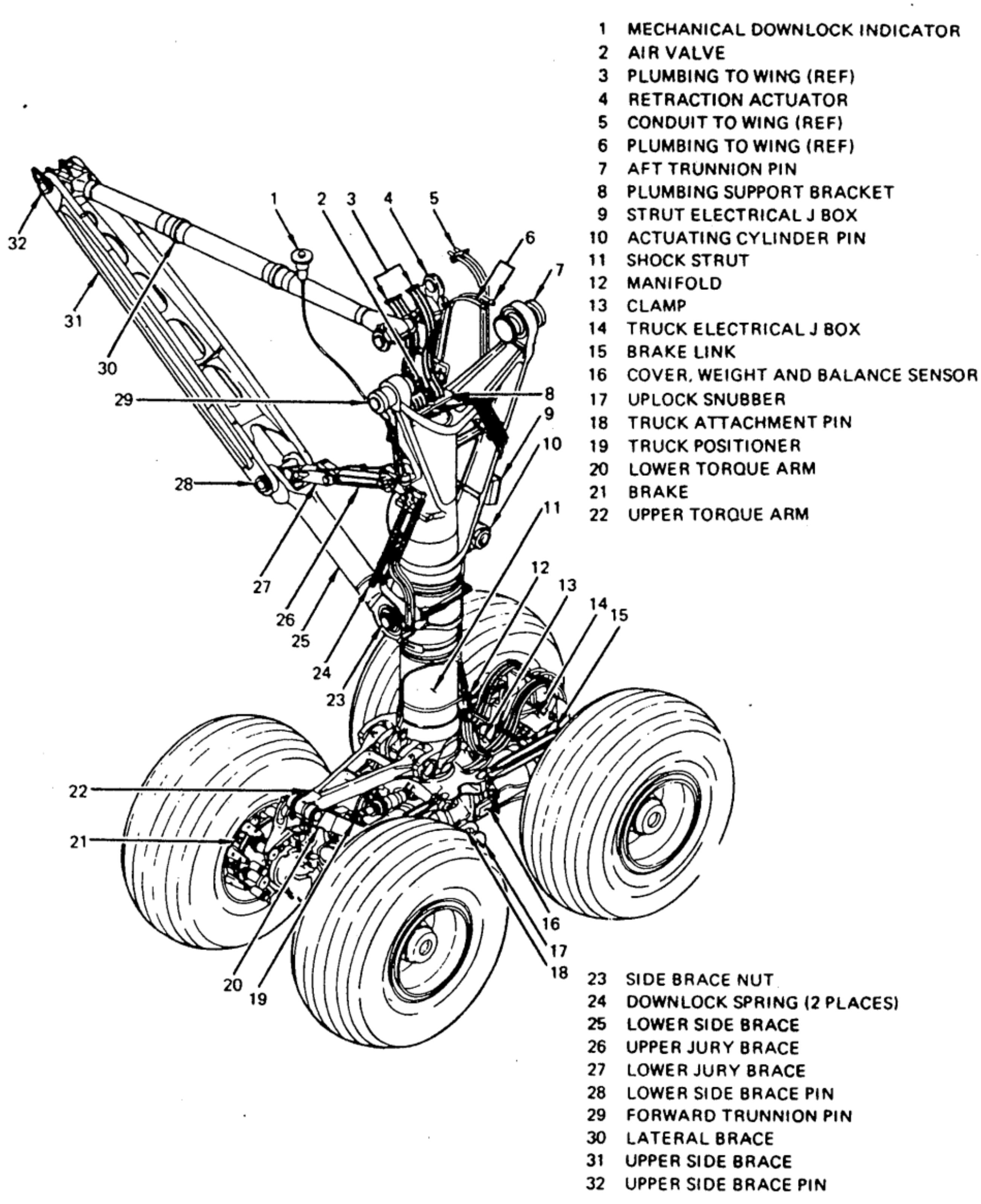
A popular light aircraft gear retraction system that uses a hydraulic power pack in the gear down condition.

Figure below shows the same system while the gear is being raised. When the flight deck gear selection handle is put in the gear down position, a switch is made that turns on the electric motor in the power pack. The motor turns in the direction to rotate the hydraulic gear pump so that it pumps fluid to the gear-down side of the actuating cylinders. Pump pressure moves the spring-loaded shuttle valve to the left to allow fluid to reach all three actuators. Restrictors are used in the nose wheel actuator inlet and outlet ports to slow down the motion of this lighter gear. While hydraulic fluid is pumped to extend the gear, fluid from the upside of the actuators returns to the reservoir through the gear-up check valve. When the gear reach the down and locked position, pressure builds in the gear-down line from the pump and the low-pressure control valve unseats to return the fluid to the reservoir. Electric limit switches turn off the pump when all three gears are down and locked.

To raise the gear, the flight deck gear handle is moved to the gear-up position. This sends current to the electric motor, which drives the hydraulic gear pump in the opposite direction causing fluid to be pumped to the gear-up side of the actuators. In this direction, pump inlet fluid flows through the filter. Fluid from the pump flows thought the gear-up check valve to the gear-up sides of the actuating cylinders. As the cylinders begin to move, the pistons release the mechanical down locks that hold the gear rigid for ground operations. Fluid from the gear-down side of the actuators returns to the reservoir through the shuttle valve. When the three gears are fully retracted, pressure builds in the system, and a pressure switch is opened that cuts power to the electric pump motor. The gears are held in the retracted position with hydraulic pressure. If pressure declines, the pressure switch closes to run the pump and raise the pressure until the pressure switch opens again.



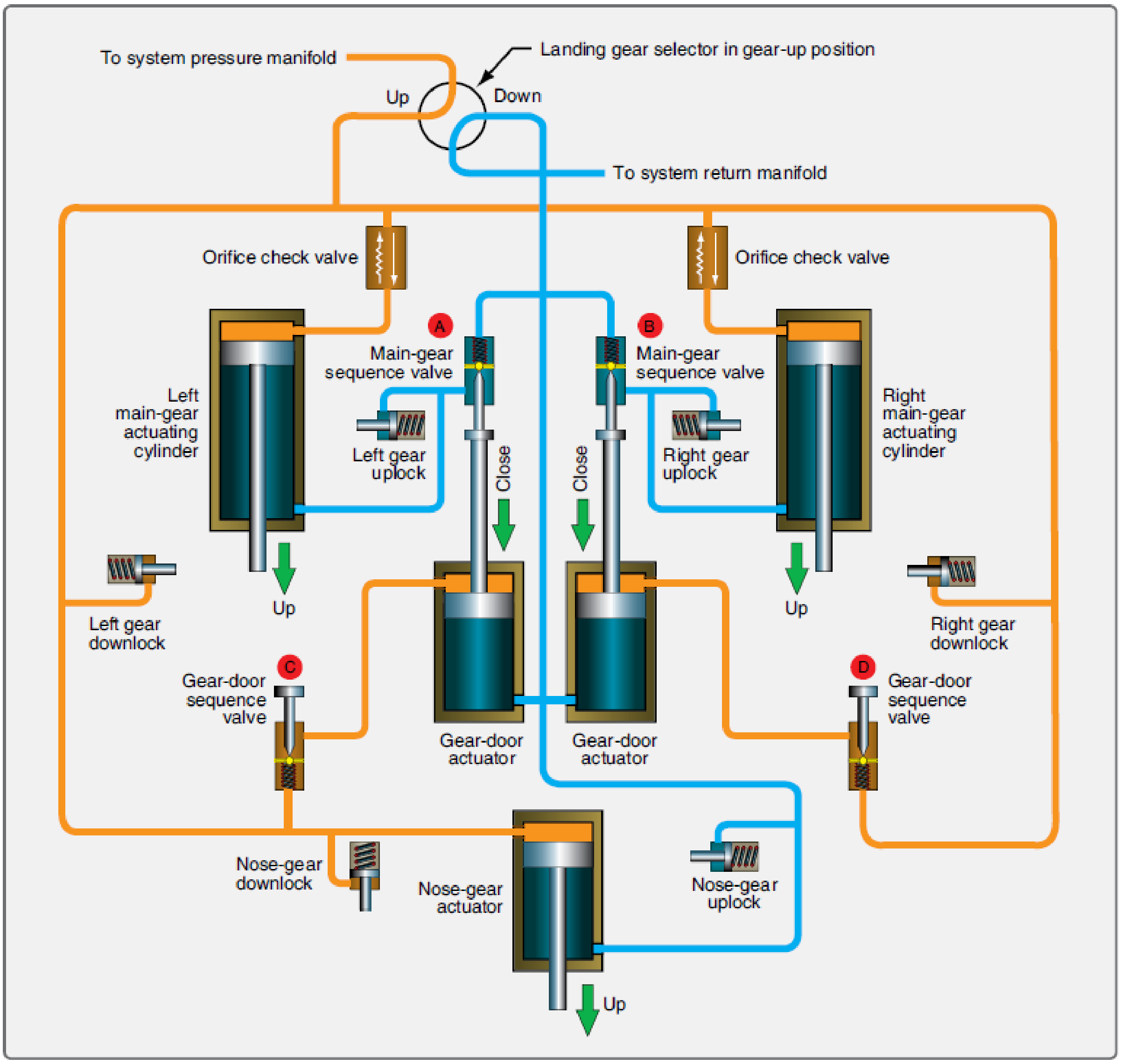
A hydraulic power pack gear retraction system in the gear up condition.



A typical landing gear system

Large Aircraft Retraction Systems

Large aircraft retraction systems are nearly always powered by hydraulics. Typically, the hydraulic pump is driven off of the engine accessory drive. Auxiliary electric hydraulic pumps are also common. Other devices used in a hydraulically-operated retraction system include actuating cylinders, selector valves, up locks, down locks, sequence valves, priority valves, tubing, and other conventional hydraulic system components. These units are interconnected so that they permit properly sequenced retraction and extension of the landing gear and the landing gear doors. The correct operation of any aircraft landing gear retraction system is extremely important.



A simple large aircraft hydraulic gear retraction system.

Figure illustrates an example of a simple large aircraft hydraulic landing gear system. The system is on an aircraft that has doors that open before the gear is extended and close after the gear is retracted. The nose gear doors operate via mechanical linkage and do not require hydraulic power. There are many gear and gear door arrangements on various aircraft. Some aircraft have gear doors that close to fair the wheel well after the gear is extended. Others have doors mechanically attached to the outside of the gear so that when it stows inward, the door stows with the gear and fairs with the fuselage skin.

In the system illustrated in *Figure above*, when the flight deck gear selector is moved to the gear-up position, it positions a selector valve to allow pump pressure from the hydraulic system manifold to access eight different components. The three down locks are pressurized and unlocked so the gear can be retracted. At the same time, the actuator cylinder on each gear also receives pressurized fluid to the gear-up side of the piston through an unrestricted orifice check valve. This drives the gear into the wheel well. Two sequence valves (C and D) also receive fluid pressure. Gear door operation must be controlled so that it occurs after the gear is stowed.

The sequence valves are closed and delay flow to the door actuators. When the gear cylinders are fully retracted, they mechanically contact the sequence valve plungers that openthe valves and allow fluid to flow into the close side of the door actuator cylinders. This closes the doors. Sequence valves A and B act as check valves during retraction. They allow fluid to flow one way from the gear-down side of the main gear cylinders back into the hydraulic system return manifold through the selector valve.

To lower the gear, the selector is put in the gear-down position. Pressurized hydraulic fluid flows from the hydraulic manifold to the nose gear up lock, which unlocks the nose gear. Fluid flows to the gear-down side of the nose gear actuator and extends it. Fluid also flows to the open side of the main gear door actuators. As the doors open, sequence valves A and B block fluid from unlocking the main gear up locks and prevent fluid from reaching the down side of the main gear actuators. When the doors are fully open, the door actuator engages the plungers of both sequence valves to open the valves. The main gear up locks then receives fluid pressure and unlock. The main gear cylinder actuators receive fluid on the down side through the open sequence valves to extend the gear. Fluid from each main gear cylinder up-side flows to the hydraulic system return manifold through restrictors in the orifice check valves. The restrictors slow the extension of the gear to prevent impact damage.

SHOCK ABSORBERS

Landing gear can also be classified as either fixed or retractable. A fixed gear always remains extended and has the advantage of simplicity combined with low maintenance. A retractable gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight.

Leaf-Type Spring Gear

Many aircraft utilize flexible spring steel, aluminum, or composite struts that receive the impact of landing and return it to the airframe to dissipate at a rate that is not harmful. The gear flexes initially and forces are transferred as it returns to its original position. The most common example of this type of non-shock absorbing landing gear are the thousands of single-engine Cessna aircraft that use it. Landing gear struts of this type made from composite materials are lighter in weight with greater flexibility and do not corrode.

Rigid

Before the development of curved spring steel landing struts, many early aircraft were designed with rigid, welded steel landing gear struts. Shock load transfer to the airframe is direct with this design. Use of pneumatic tires aids in softening the impact loads. Modern aircraft that use skid-type landing gear make use of rigid landing gear with no significant ill effects. Rotorcraft, for example, typically experience low impact landings that are able to be directly absorbed by the airframe through the rigid gear (skids).

Bungee Cord

The use of bungee cords on non-shock absorbing landing gear is common. The geometry of the gear allows the strut assembly to flex upon landing impact. Bungee cords are positioned between the rigid airframe structure and the flexing gear assembly to take up the loads and return them to the airframe at a non-damaging rate. The bungees are made of many individual small strands of elastic rubber that must be inspected for condition. Solid, donut-type rubber cushions are also used on some aircraft landing gear.

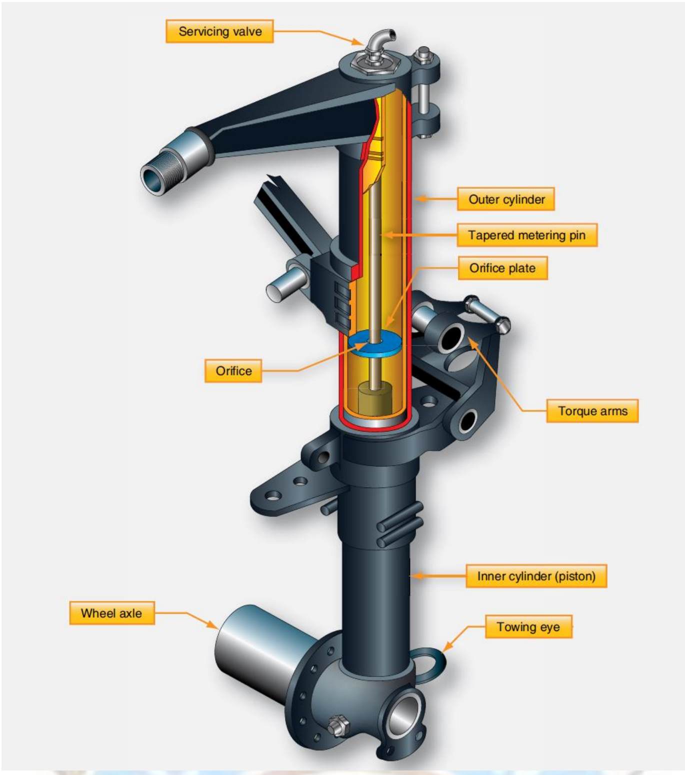
Piper Cub bungee cord landing gear transfer landing loads to the airframe (left and center). Rubber, donut-type shock transfer is used on some Mooney aircraft (right).

Shock Struts

True shock absorption occurs when the shock energy of landing impact is converted into heat energy, as in a shock strut landing gear. This is the most common method of landing shock dissipation in aviation. It is used on aircraft of all sizes. Shock struts are self-contained hydraulic units that support an aircraft while on the ground and protect the structure during landing. They must be inspected and serviced regularly to ensure proper operation there are many different designs of shock struts, but most operate in a similar manner. The following discussion is general in nature.

For information on the construction, operation, and servicing of a specific aircraft shock, consults the manufacturer’s maintenance instructions. A typical pneumatic/hydraulic shock strut uses compressed air or nitrogen combined with hydraulic fluid to absorb and dissipate shock loads. It is sometimes referred to as an air/oil or oleo strut.

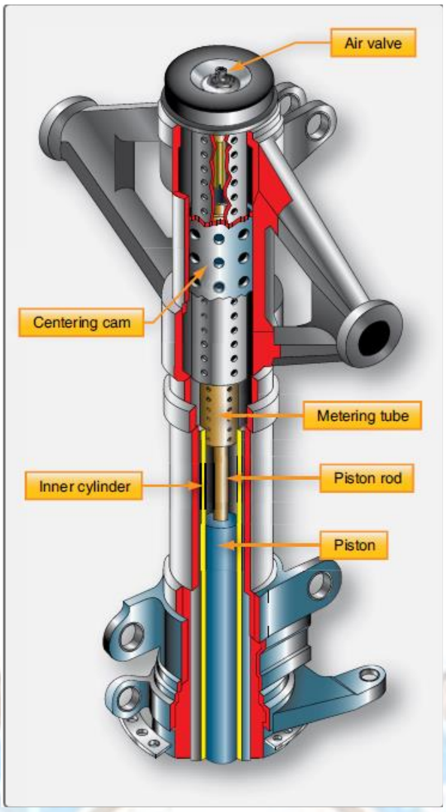
A shock strut is constructed of two telescoping cylinders or tubes that are closed on the external ends. The upper cylinder is fixed to the aircraft and does not move. The lower cylinder is called the piston and is free to slide in and out of the upper cylinder. Two chambers are formed. The lower chamber is always filled with hydraulic fluid and the upper chamber is filled with compressed air or nitrogen. An orifice located between the two cylinders provides a passage for the fluid from the bottom chamber to enter the top cylinder chamber when the strut is compressed.



A landing gear shock strut with a metering pin to control the flow of hydraulic fluid from the lower chamber to the upper chamber during compression.

Most shock struts employ a metering pin for controlling the rate of fluid flow from the lower chamber into the upper chamber. During the compression stroke, the rate of fluid flow is not constant. It is automatically controlled by the taper of the metering pin in the orifice. When a narrow portion of the pin is in the orifice, more fluid can pass to the upper chamber. As the diameter of the portion of the metering pin in the orifice increases, less fluid passes. Pressure build-up caused by strut compression and the hydraulic fluid being forced through the metered orifice causes heat. This heat is converted impact energy. It is dissipated through the structure of the strut

On some types of shock struts, a metering tube is used. The operational concept is the same as that in shock struts with metering pins, except the holes in the metering tube control the flow of fluid from the bottom chamber to the top chamber during compression.



Some landing gear shock struts use an internal metering tube rather than a metering pin to control the flow of fluid from the bottom cylinder to the top cylinder.

Upon lift off or rebound from compression, the shock strut tends to extend rapidly. This could result in a sharp impact at the end of the stroke and damage to the strut. It is typical for shock struts to be equipped with a damping or snubbing device to prevent this. A recoil valve on the piston or a recoil tube restricts the flow of fluid during the extension stroke, which slows the motion and prevents damaging impact forces. Most shock struts are equipped with an axle as part of the lower cylinder to provide installation of the aircraft wheels. Shock struts without an integral axle have provisions on the end of the lower cylinder for installation of the axle assembly. Suitable connections are provided on all shock strut upper cylinders to attach the strut to the airframe.

The upper cylinder of a shock strut typically contains a valve fitting assembly. It is located at or near the top of the cylinder. The valve provides a means of filling the strut with hydraulic fluid and inflating it with air or nitrogen as specified by the manufacturer. A packing gland is employed to seal the sliding joint between the upper and lower telescoping cylinders. It is installed in the open end of the outer cylinder. A packing gland wiper ring is also installed in a groove in the lower bearing or gland nut on most shock struts. It is designed to keep the sliding surface of the piston from carrying dirt, mud, ice, and snow into the packing gland and upper cylinder. Regular cleaning of the exposed portion of the strut piston helps the wiper do its job and decreases the possibility of damage to the packing gland, which could cause the strut to a leak. To keep the piston and wheels aligned, most shock struts are equipped with torque links or torque arms. One end of the links is attached to the fixed upper cylinder. The other end is attached to the lower cylinder (piston) so it cannot rotate. This keeps the wheels aligned. The links also retain the piston in the end of the upper cylinder when the strut is extended, such as after takeoff.

Torque links align the landing gear and retain the piston in the upper cylinder when the strut is extended.

Nose gear shock struts are provided with a locating cam assembly to keep the gear aligned. A cam protrusion is attached to the lower cylinder, and a mating lower cam recess is attached to the upper cylinder. These cams line up the wheel and axle assembly in the straight-ahead position when the shock strut is fully extended. This allows the nose wheel to enter the wheel well when the nose gear is retracted and prevents structural damage to the aircraft. It also aligns the wheels with the longitudinal axis of the aircraft prior to landing when the strut is fully extended. Many nose gear shock struts also have attachments for the installation of an external shimmy damper.

Nose gear struts are often equipped with a locking or disconnect pin to enable quick turning of the aircraft while towing or positioning the aircraft when on the ramp or in a hangar. Disengagement of this pin allows the wheel fork spindle on some aircraft to rotate 360°, thus enabling the aircraft to be turned in a tight radius. At no time should the nose wheel of any aircraft be rotated beyond limit lines marked on the airframe. Nose and main gear shock struts on many aircraft are also equipped with jacking points and towing lugs. Jacks should always be placed under the prescribed points. When towing lugs are provided, the towing bar should be attached only to these lugs.

Shock struts contain an instruction plate that gives directions for filling the strut with fluid and for inflating the strut. The instruction plate is usually attached near filler inlet and air valve assembly. It specifies the correct type of hydraulic fluid to use in the strut and the pressure to which the strut should be inflated. It is of utmost importance to become familiar with these instructions prior to filling a shock strut with hydraulic fluid or inflating it with air or nitrogen.

Shock Strut Operation

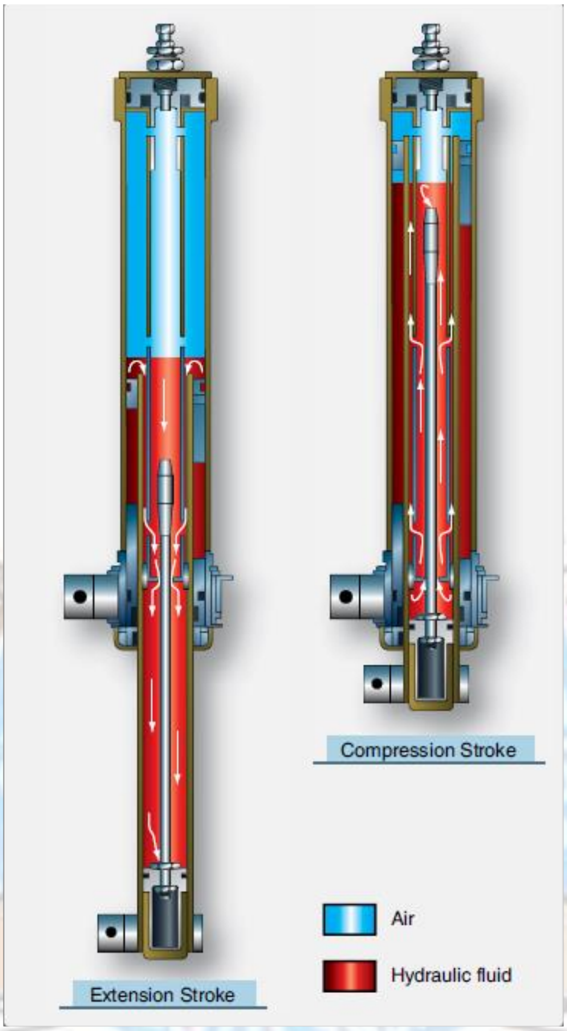


Figure illustrates the inner construction of a shock strut. Arrows show the movement of the fluid during compression and extension of the strut. The compression stroke of the shock strut begins as the aircraft wheels touch the ground. As the center of mass of the aircraft moves downward, the strut

NOSE WHEEL STEERING SYSTEMS

The nose wheel on most aircraft is steerable from the flight deck via a nose wheel steering system. This allows the aircraft to be directed during ground operation. A few simple aircraft have nose wheel assemblies that caster. Such aircraft are steered during taxi by differential braking.

Small Aircraft

Most small aircraft have steering capabilities through the use of a simple system of mechanical linkages connected to the rudder pedals. Push-pull tubes are connected to pedal horns on the lower strut cylinder. As the pedals are depressed, the movement is transferred to the strut piston axle and wheel assembly which rotates to the left or right. *[Figure below]*

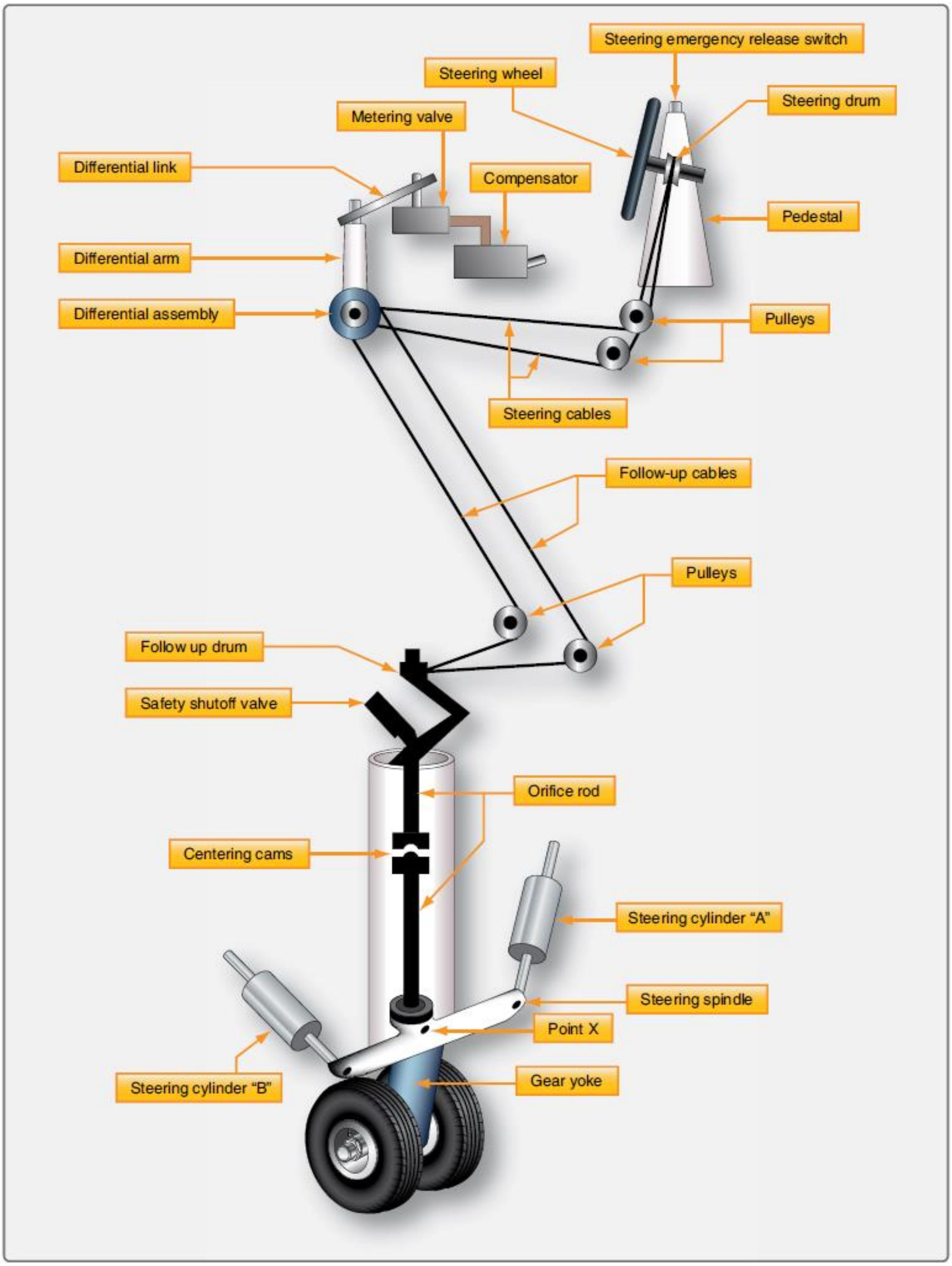
Nose wheel steering on a light aircraft often uses a push-pull rod system connected to the rudder pedals.

Large Aircraft

Due to their mass and the need for positive control, large aircraft utilize a power source for nose wheel steering. Hydraulic power predominates. There are many different designs for large aircraft nose steering systems. Most share similar characteristics and components. Control of the steering is from the flight deck through the use of a small wheel, tiller, or joystick typically mounted on the left side wall. Switching the system on and off is possible on some aircraft.

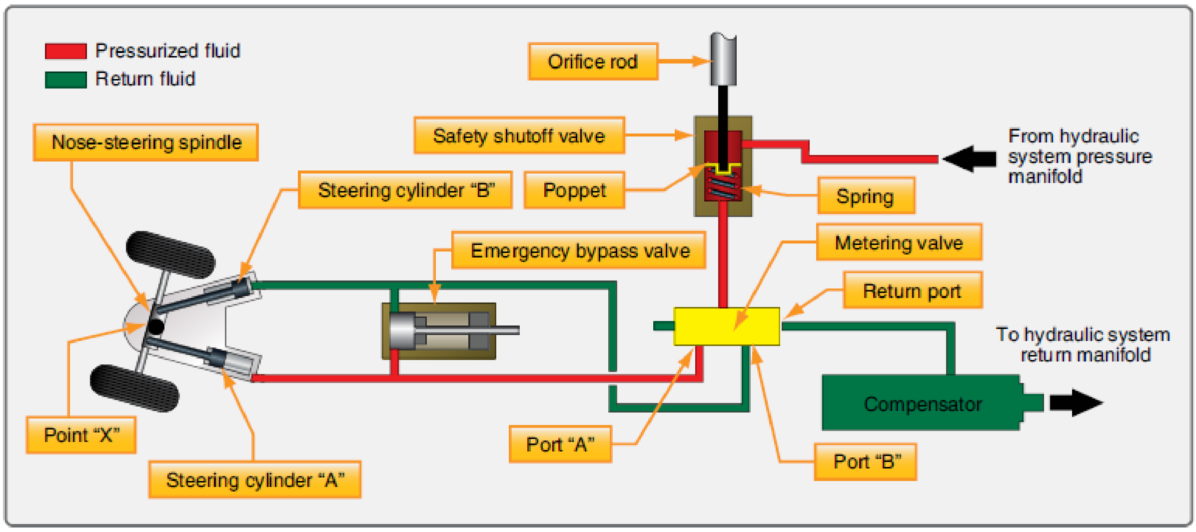
Mechanical, electrical, or hydraulic connections transmit the controller input movement to a steering control unit. The control unit is a hydraulic metering or control valve. It directs hydraulic fluid under pressure to one or two actuators designed with various linkages to rotate the lower strut. An accumulator and relief valve, or similar pressurizing assembly, keeps fluid in the actuators and system under pressure at all times. This permits the steering actuating cylinders to also act as shimmy dampers. A follow-up mechanism consists of various gears, cables, rods, drums, and/or bell-crank, etc. It returns the metering valve to a neutral position once the steering angle has been reached.

Many systems incorporate an input subsystem from the rudder pedals for small degrees of turns made while directing the aircraft at high speed during takeoff and landing. Safety valves are typical in all systems to relieve pressure during hydraulic failure so the nose wheel can swivel.



(A) Example of a large aircraft hydraulic nose wheel steering system with hydraulic and mechanical units.

The nose wheel steering wheel connects through a shaft to a steering drum located inside the flight deck control pedestal. The rotation of this drum transmits the steering signal by means of cables and pulleys to the control drum of the differential assembly. Movement of the differential assembly is transmitted by the differential link to the metering valve assembly where it moves the selector valve to the selected position. This provides the hydraulic power for turning the nose gear.

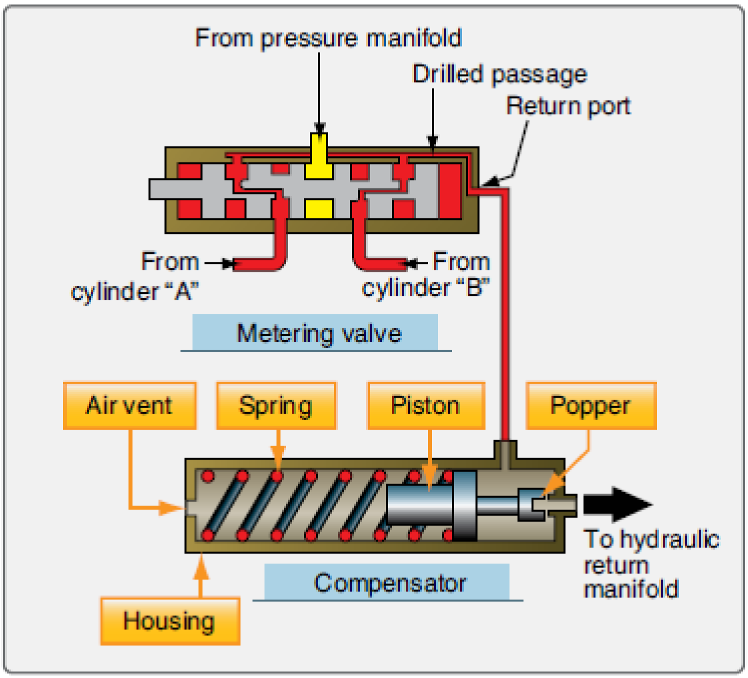


(B) Hydraulic system flow diagram of large aircraft nose wheel steering system.

As shown in above *Figure,* pressure from the aircraft hydraulic system is directed through the open safety shutoff valve into a line leading to the metering valve. The metering valve then routes the pressurized fluid out of port A, through the right turn alternating line, and into steering cylinder A. This is a one-port cylinder and pressure forces the piston to begin extension. Since the rod of this piston connects to the nose steering spindle on the nose gear shock strut which pivots at point X, the extension of the piston turns the steering spindle gradually toward the right. As the nose wheel turns, fluid is forced out of steering cylinder B through the left turn alternating line and into port B of the metering valve. The metering valve directs this return fluid into a compensator that routes the fluid into the aircraft hydraulic system return manifold.

As described, hydraulic pressure starts the nose gear turning. However, the gear should not be turned too far. The nose gear steering system contains devices to stop the gear at the selected angle of turn and hold it there. This is accomplished with follow-up linkage. As stated, the nose gear is turned by the steering spindle as the piston of cylinder A extends.

The rear of the spindle contains gear teeth that mesh with a gear on the bottom of the orifice rod. *[Figure (A)]* As the nose gear and spindle turn, the orifice rod also turns but in the opposite direction. This rotation is transmitted by the two sections of the orifice rod to the scissor follow-up links located at the top of the nose gear strut. As the follow-up links return, they rotate the connected follow-up drum, which transmits the movement by cables and pulleys to the differential assembly. Operation of the differential assembly causes the differential arm and links to move the metering valve back toward the neutral position.



(C) Hydraulic system flow diagram of large aircraft nose wheel steering system.

The metering valve and the compensator unit of the nose wheel steering system are illustrated in *Figure (C)*. The compensator unit system keeps fluid in the steering cylinders pressurized at all times. This hydraulic unit consists of a three-port housing that encloses a spring-loaded piston and poppet. The left port is an air vent that prevents trapped air at the rear of the piston from interfering with the movement of the piston. The second port located at the top of the compensator connects through a line to the metering valve return port. The third port is located at the right side of the compensator. This port connects to the hydraulic system return manifold. It routes the steering system return fluid into the manifold when the poppet valve is open.

The compensator poppet opens when pressure acting on the piston becomes high enough to compress the spring. In this system, 100 psi is required. Therefore, fluid in the metering valve return line is contained under that pressure. The 100 psi pressure also exists throughout the metering valve and back through the cylinder return lines. This pressurizes the steering cylinders at all times and permits them to function as shimmy dampers.

SHIMMY DAMPERS

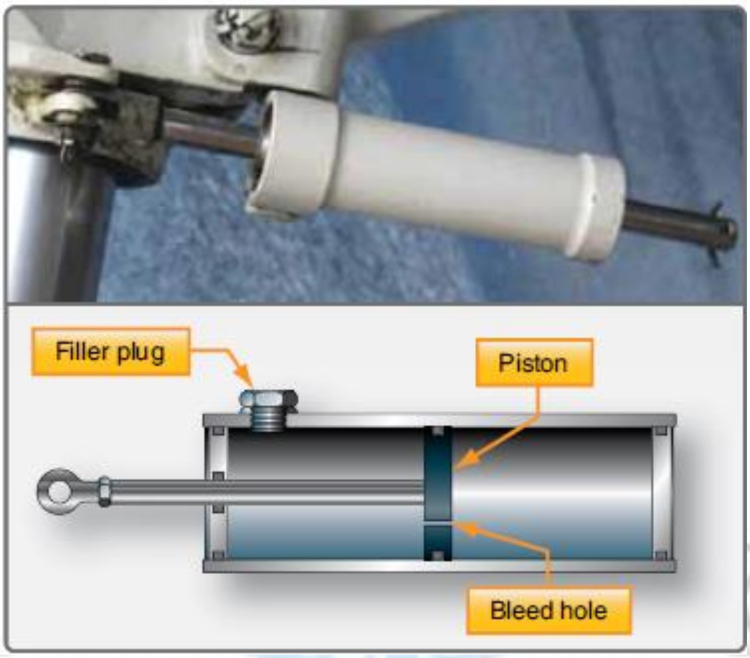
Torque links attached from the stationary upper cylinder of a nose wheel strut to the bottom moveable cylinder or piston of the strut are not sufficient to prevent most nose gear from the tendency to oscillate rapidly, or shimmy, at certain speeds. This vibration must be controlled through the use of a shimmy damper. A shimmy damper controls nose wheel shimmy through hydraulic damping. The damper can be built integrally within the nose gear, but most often it is an external unit attached between the upper and lower shock struts. It is active during all phases of ground operation while permitting the nose gear steering system to function normally.

Steering Damper

As mentioned above, large aircraft with hydraulic steering hold pressure in the steering cylinders to provide the required damping. This is known as steering damping. Some older transport category aircraft have steering dampers that are vane-type. Nevertheless, they function to steer the nose wheel, as well as to dampen vibration.

Piston-Type

Aircraft not equipped with hydraulic nose wheel steering utilize an additional external shimmy damper unit. The case is attached firmly to the upper shock strut cylinder. The shaft is attached to the lower shock strut cylinder and to a piston inside the shimmy damper. As the lower strut cylinder tries to shimmy, hydraulic fluid is forced through a bleed hole in the piston. The restricted flow through the bleed hole dampens the oscillation. *[Figure below]*

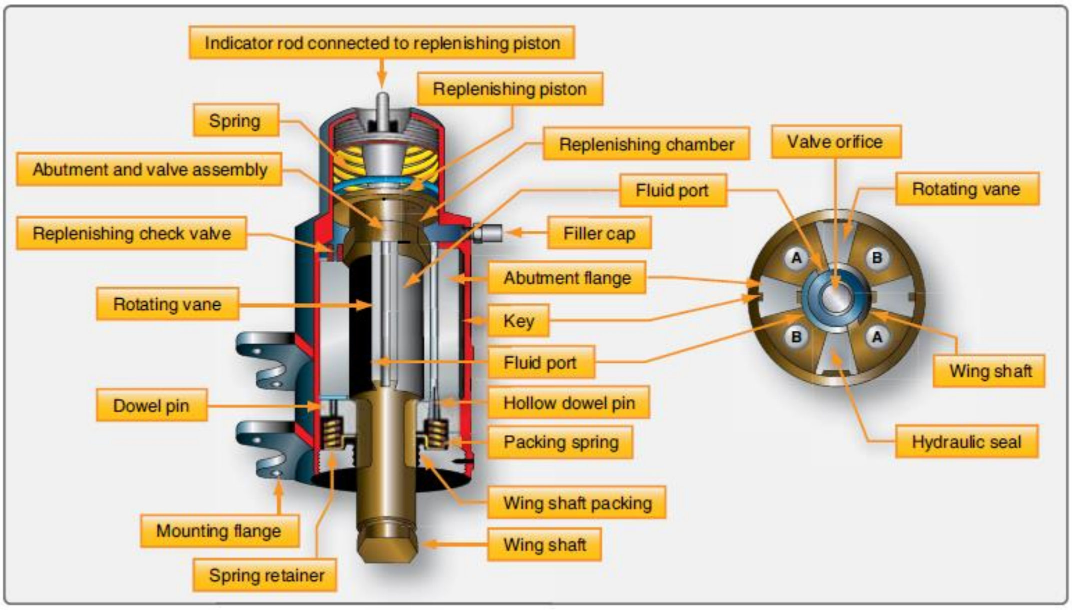


A shimmy damper on the nose struts of a small aircraft. The diagram shows the basic internal arrangement of most shimmy dampers. The damper in the photo is essentially the same except the piston shaft extends through both ends of the damper cylinder body.

A piston-type shimmy damper may contain a fill port to add fluid or it may be a sealed unit. Regardless, the unit should be checked for leaks regularly. To ensure proper operation, a piston-type hydraulic shimmy damper should be filled to capacity.

Vane-Type

A vane-type shimmy damper is sometime used. *[Figure below]* It uses fluid chambers created by the vanes separated by a valve orifice in a center shaft. As the nose gear tries to oscillate, vanes rotate to change the size of internal chambers filled with fluid. The chamber size can only change as fast as the fluid can be forced through the orifice. Thus, the gear oscillation is dissipated by the rate of fluid flow. An internal spring-loaded replenishing reservoir keeps pressurized fluid in the working chambers and thermal compensation of the orifice size is included. As with the piston type shimmy damper, the vane-type damper should be inspected for leaks and kept serviced. A fluid level indicator protrudes from the reservoir end of the unit.



A typical vane-type shimmy damper.

Non-Hydraulic Shimmy Damper

Non-hydraulic shimmy dampers are currently certified for many aircraft. They look and fit similar to piston-type shimmy dampers but contain no fluid inside. In place of the metal piston, a rubber piston presses out against the inner diameter of the damper housing when the shimmy motion is received through the shaft.

The rubber piston rides on a very thin film of grease and the rubbing action between the piston and the housing provides the damping. This is known as surface-effect damping. The materials use to construct this type of shimmy damper provide a long service life without the need to ever add fluid to the unit.*[Figure below]*

A non-hydraulic shimmy damper uses a rubber piston with lubricant that dampens via motion against the inner diameter of the unit housing.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-III NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 5AN3 **SEMESTER: V**

SUBJECT NAME: AIRCRAFT SYSTEMS

FUEL SYSTEMS

Types of fuels, their properties and testing, colour codes, fuel requirements, pumps, fuel transfer systems, fuel tanks, plumbing, valves, indications and warnings.

INTRODUCTION

Fuel is a substance that, when combined with oxygen will burn and produce heat. Fuels may be classified according to their physical state as solid, gaseous, or liquid.

Solid Fuels

Solid fuels are used extensively for external-combustion engines, such as a steam engine, where the burning takes place under boilers or in furnaces. They include such fuels as wood and coal. Solid fuels are not used in reciprocating engines, where the burning takes place inside the cylinder, because of their slow rate of burning, low heat value, and numerous other disadvantages.

Gaseous Fuels

Gaseous fuels are used to some extent for internal-combustion engines, where a large supply of combustible gas is readily available. Natural gas and liquefied petroleum gas are two of the more common types. Gaseous fuels can be disregarded for use in aircraft engines. The large space they occupy limits the supply of fuel that can be carried-

Liquid Fuels

Liquid fuels, in many respects, are the ideal fuel for use in internal-combustion engines. Liquid fuels are classified as either non-volatile or volatile. The non-volatile fuels are the heavy oils used in diesel engines. The volatile class includes those fuels that are commonly used with a fuel metering device and are carried into the engine cylinder or combustion chamber in a vaporized or partially vaporized condition. Among these are alcohol, benzol, kerosene, and gasoline.

Aviation fuel is a liquid containing chemical energy that, through combustion, is released as heat energy and then converted to mechanical energy by the engine. This mechanical energy is used to produce thrust, which propels the aircraft. Gasoline and kerosene are the two most widely used aviation fuels;

OPERATIONAL PROPERTIES OF FUELS

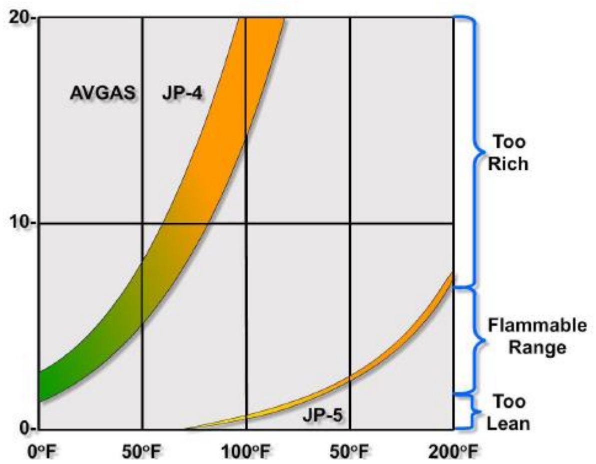
Due to the wide range of operating conditions and high rate of fuel consumption, jet engines require specific fuels to operate efficiently and maintain a reasonable engine service life. Various grades of jet fuels were developed to meet specific operating or handling characteristics. A study of the basic characteristics of turbine fuels will help you understand the importance of delivering the proper fuel to the aircraft. Such a study is also valuable in understanding the need for safety and caution in handling these fuels. This section includes basic characteristics of engine fuels.

Characteristics

Aircraft engine fuels are petroleum products manufactured from crude oil by oil refineries. They are classified as inflammable liquids. Any material easily ignited that burns rapidly is inflammable. Under proper conditions, fuel can explode with force similar to dynamite. Death can result if the vapours of fuel are inhaled in sufficient quantities. Serious skin irritation can result from contact with the fuel in the liquid state. In liquid form, aircraft fuels are lighter than water, and in vapour form they are heavier than air. Consequently, water in the fuel usually settles to the bottom of the container.
Vapours of these fuels, when released in the air, tend to remain close to the ground, thus increasing the danger to personnel and property. From a safety and health standpoint, aircraft engine fuels must be handled with caution.
In the selection of a fuel, several factors must be considered. Because one fuel cannot have all the requirements to the greatest degree, the fuel selected is a compromise of various factors. Specific properties of fuels are determined through testing. These tests determine the volatility, density, heating value, combustion, safety, and handling characteristics of the fuels. There are hundreds of tests that determine the physical, chemical, and performance properties of fuel. We limit this discussion to the most common and important ones, as follows:
•Volatility (vapour pressure and distillation)
•Flash point and fire point
•Heat energy content
•Viscosity
•Handling characteristics
•Combustion products
•Effects of additives and impurities
•Freeze point

Volatility

Volatility measures the ability of a liquid to convert to a vaporous state. Fuel must vaporize and the vapour must be mixed in a given percentage of air for it to burn or explode. Only fuel-air mixtures within the flammable range will burn (*Figure 4-1*).



Vaporization of aviation fuels at atmospheric pressure.

Volatility of a fuel affects starting, range, and safety. A highly volatile fuel helps the engines starts easier, especially at low temperatures or under adverse conditions, and has less range due to fuel evaporation in flight. The fuel has a higher tendency to vapour lock and is more susceptible to a fire during a crash. The volatility of a petroleum fuel is usually measured in terms of vapour pressure and distillation.

The vapour pressure shows the tendency to vaporize at specific temperatures. Vapour pressure is measured in a Reid vapour pressure test bomb. In the test, one volume of fuel and four volumes of air are contained in a sealed bomb fitted with a pressure gauge. The container and fuel are heated to 100 °F and shaken; then, the pressure on the gauge is read. The pressure shown on the gauge is known as the Reid vapour pressure (RVP) and is expressed in psi. A highly volatile fuel helps engines start easier, especially at low temperatures or adverse conditions. The distillation measurement for volatility measures the amount of fuel boiled off at specific temperatures. Because turbine fuels are a mixture of hydrocarbons (gasoline and kerosene), they have a wide range of boiling points. This test records the boiling ranges. The military specification for fuels will give these temperatures and the percentages of the fuel allowed to boil off to meet the desired standards.

Flash Point and Fire Point

The flash point is the temperature at which the fuel vaporizes enough to ignite with an outside heat source. The flash point of a fuel is an index of its potential safety for handling and storage. Ships require at least a 140 °F flash point for storage and safety reasons. The fire point is the temperature at which the vapours continue to burn without an outside heat source.

Heat Energy Content

For aircraft engine use, it is important that the fuel contain as much heat energy (thermal value) as possible, both per unit weight and per unit volume. The thermal value is the amount of heat produced as a result of complete combustion and is expressed in calories or British thermal units (Btu).

Thermal value per unit of weight increases as gravity increases. Energy content and density influence fuel selection when range or payloads are the limiting factors. All these factors are important to understand when the aircraft will be weight-limited rather than volume-limited.

Viscosity

Is the internal resistance of a liquid that tends to prevent it from flowing?

Turbojet engine fuels should be able to flow through the fuel system and strainers under the lowest operating temperatures to which the engine will be subjected. Fuel viscosity and density also have considerable effect on nozzle performance, especially when varied over a wide range. The most important fuel property influencing nozzle performance is viscosity. It affects drop size, flow range, and spray angle. Changes in fuel density affect fuel flow.

Handling Characteristics

For a fuel to have satisfactory handling characteristics, it must be noncorrosive and should not clog fuel filters, even at very low temperatures. The fuel should not produce vapour lock in the fuel tanks or various fuel pumps or slugging out of the fuel tank vents (Slugging is the process by which liquid fuel is carried along with vaporized fuel when the vapour escapes to the atmosphere). As much as possible, the fuel should have enough of the properties of a lubricant to avoid significant wear of the fuel-metering pumps.

Combustion Products

Aircraft fuels must have a minimum tendency to form solids or carbon on combustion. A loss in the efficiency of the engine results when these deposits build up in the engine.

Additives, Impurities, and Their Effects

Only materials that will be effective when added in a maximum concentration of 5 percent are considered as liquid additives. Beyond this concentration, the material may be considered as a fuel.

Gum inhibitors used in military gas turbine fuels are the same as those used for military aviation gasolines. In aviation gasoline, gum is almost always completely soluble and becomes apparent only when the gasoline is evaporated. Both soluble and insoluble gum, especially the insoluble form can be expected to have serious effects on the fuel system of turbine engines. The fuel-metering pumps, fuel pumps, and fuel filters are likely to be seriously affected by insoluble gum. The soluble type can cause difficulty in the fuel system at points where microscopic leakage occurs and exposes thin films of fuel to air, and thus to evaporation. The microscopic fuel leaks will usually appear at fuel valves.

Certain aircraft require a minimum concentration of fuel system icing inhibitors (FSIIs). These are put in the fuel to prevent icing in the airframe fuel system, engine filter, or engine fuel control. FSII materials are considered to be dangerous before they are added to fuel; therefore, shipboard injection is not approved.

Freeze Point

The freezing point of a fuel is the temperature at which solid particles begin to form in the fuel. These particles are waxy crystals normally held in suspension in the fuel. These particles can readily block the filters in an aircraft fuel system. The fuel almost always becomes cloudy before the solid particles form. This cloud is caused by dissolved water coming out of the solution and freezing.

Characteristics and Properties of Aviation Gasoline

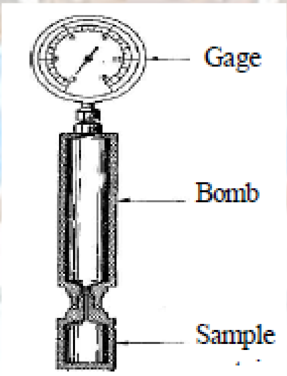
Aviation gasoline consists almost entirely of hydrocarbons, namely, compounds consisting of hydrogen and carbon. Some impurities *in* the form of sulphur and dissolved water will be present. The water cannot be avoided, since the gasoline is exposed to moisture in the atmosphere. A small amount of sulphur, always present in crude petroleum, is left in the process of manufacture.

Tetraethyl lead (TEL) is added to the gasoline to improve its performance in the engine. Organic bromides and chlorides are mixed with TEL so that during combustion volatile lead halides will be formed. These then are exhausted with the combustion products. TEL, if added alone, would burn to a solid lead oxide and remain in the engine cylinder. Inhibitors are added to gasoline to suppress the formation of substances that would be left as solids when the gasoline evaporates.

Certain properties of the fuel affect engine performance. These properties are volatility, the manner in which the fuel burns during the combustion process, and the heating value of the fuel. Also important is the corrosiveness of the gasoline as well as its tendency to form deposits in the engine during use. These latter two factors are important because of their effect on general cleanliness, which has a bearing on the time between engine overhauls.

Volatility

Volatility is a measure of the tendency of a liquid substance to vaporize under given hydrocarbon compounds that have a wide range of boiling points and vapour pressures. It is blended in such a way that a straight chain of boiling points is obtained. This is necessary to obtain the required starting, acceleration, power, and fuel mixture characteristics for the engine.
Gasoline is a complex blend of volatile
If the gasoline vaporizes too readily, fuel lines may become filled with vapour and cause decreased fuel flow. If the fuel does not vaporize readily enough, it can result in hard-starting, slow warm-up, poor acceleration, and uneven fuel distribution to cylinders, and excessive crankcase dilution.



Vapour pressure test apparatus

The lower grades of automobile fuel are not held within the tolerances required for aviation gasoline and usually contain a considerable amount of cracked gasoline, which may form excessive gum deposits. For these reasons, automobile fuels should not be used in aircraft engines, especially air-cooled engines operating at high cylinder temperatures.

Vapour Lock

Vaporization of gasoline in fuel lines results in a reduced supply of gasoline to the engine. In severe cases, it may result in engine stoppage. This phenomenon is referred to as vapour locking. A measure of a gasoline's tendency to vapour lock is obtained from the Reid vapour pressure test. In this test a sample of the fuel is sealed in a "bomb" equipped with a pressure gage.
The apparatus (see figure) is then immersed in a constant-temperature bath and the indicated pressure is noted. The higher the corrected vapour pressure of the sample under test, the more susceptible it is to vapour locking. Aviation gasolines are limited to a maximum of 7 p.s.i. because of their increased tendency to vapour lock at high altitudes.

Carburettor Icing

Carburettor icing is also related to volatility. When the fuel changes from a liquid to a vapour state, it extracts heat from its surroundings to make this change. The more volatile the fuel, the more rapid the heat extraction will be. As the gasoline leaving the carburettor discharge nozzle vaporizes, it can freeze water vapour contained in the incoming air. The moisture freezes on the walls of the induction system, the venturi throat, and the throttle valves. This type of ice formation restricts the fuel and air passages of the carburettor. It causes loss of power and, if not eliminated, eventual engine stoppage. Extreme icing conditions can make operation of the throttle controls impossible. This icing condition is most severe in the temperature range of 30° to 40° F. outside air temperature.

Aromatic Fuels

Some fuels may contain considerable quantities of aromatic hydrocarbons, which are added to increase the rich mixture performance rating of the fuel. Such fuels, known as aromatic fuels, have a strong solvent and swelling action on some types of hose and other rubber parts of the fuel system. For this reason, aromatic-resistant hose and rubber parts have been developed for use with aromatic fuels.

Detonation

In an engine that is operating in a normal manner, the flame front traverses the charge at a steady velocity of about 100 feet per second until the charge is consumed. When detonation occurs, the first portion of the charge burns in a normal manner but the last portion burns almost instantaneously, creating an excessive momentary pres- sure unbalance in the combustion chamber. This abnormal type of combustion is called detonation. This tremendous increase in the speed of burning causes the cylinder head temperature to rise. In severe cases, the increase in burning speed will decrease engine efficiency and may cause structural damage to the cylinder head or piston.
During normal combustion, the expansion of the burning gases presses the head of the piston down firmly and smoothly without excessive shock. The increased pressure of detonation exerted in a short period of time produces a heavy shock load to the walls of the combustion chamber and the piston head. It is this shock to the combustion chamber that is heard as an audible knock in an automobile engine. If other sounds could be filtered out, the knock would be equally audible in an aircraft engine. Generally, it is necessary to depend upon instruments to detect detonation in an aircraft engine.

Surface Ignition

Ignition of the fuel/air mixture by hot spots or surfaces in the combustion chamber is called surface ignition. If this occurs before the normal ignition event, the phenomenon is referred to as pre-ignition. When it is prevalent, the result is power loss and engine roughness. Pre-ignition is generally attributed to overheating of such parts as spark plug electrodes, exhaust valves, carbon deposits, etc. Where pre-ignition is present, an engine may continue to operate even though the ignition has been turned off.
Present information indicates that gasoline high in aromatic hydrocarbon content is much more likely to cause surface ignition than fuels with a low content.

Octane and Performance Number Rating:

Octane and performance numbers designate the antiknock value of the fuel mixture in an engine cylinder. Aircraft engines of high power output have been made possible principally as a result of blending to produce fuels of high octane ratings. The use of such fuels has permitted increases in compression ratio and manifold pressure, resulting in improved engine power and efficiency. However, even the high-octane fuels will detonate under severe operating conditions and when certain engine controls are improperly operated.

Antiknock qualities of aviation fuel are designated by grades. The higher the grade, the more compression the fuel can stand without detonating. For fuels that have two numbers, the first number indicates the lean-mixture rating and the second the rich-mixture rating. Thus, grade 100/130 fuel has a lean-mixture rating of 100 and a rich-mixture rating of 130. Two different scales are used to designate fuel grade. For fuels below grade 100, octane numbers are used to designate grade. The octane number system is based on a comparison of any fuel with mixtures of iso-octane and normal heptane. The octane number of a fuel is the percentage of iso-octane in the mixture that duplicates the knock characteristics of the particular fuel being rated. Thus, grade 91 fuel has the same knock characteristics as a blend of 91 percent iso-octane and 9 percent normal heptane.

With the advent of fuels having antiknock characteristics superior to iso-octane, another scale was adopted to designate the grade of fuels above the 100-octane number. This scale represents the performance rating of the fuel—its knock-free power available as compared with that available with pure iso-octane. It is arbitrarily assumed that 100 percent power is obtained from iso-octane alone. An engine that has a knock-limited horsepower of 1,000 with 100-octane fuel will have a knock-limited horsepower of 1.3 times as much (1,300 horsepower) with 130 performance number fuel.

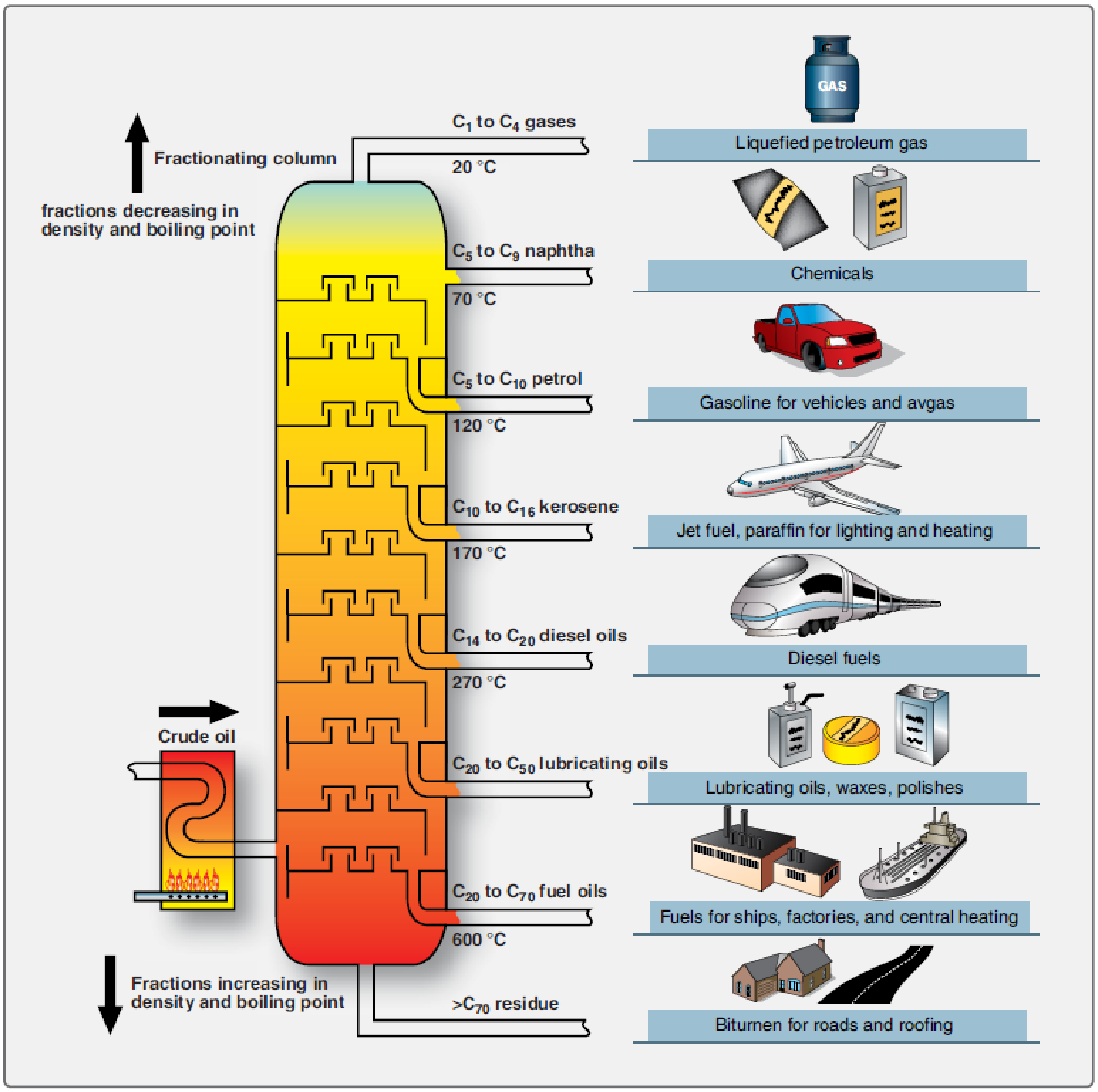
The grade of an aviation gasoline is no indication of its fire hazard. Grade 91/96 gasoline is as easy to ignite as grade 115/145 and explodes with as much force. The grade indicates only the gasoline's performance in the aircraft's engine.
A convenient means of improving the antiknock characteristics of a fuel is to add a knock inhibitor. Such a fluid must have a minimum of corrosive or other undesirable qualities, and probably the best available inhibitor in general use at present is TEL (tetraethyl lead). The few difficulties encountered because of the corrosion tendencies of ethylized gasoline are insignificant when compared with the results obtained from the high antiknock value of the fuel. For most aviation fuels the addition of more than 6 ml. per gallon is not permitted. Amounts in excess of this have little effect on the antiknock value, but increase corrosion and spark plug trouble.
There are two distinct types of corrosion caused by the use of ethyl gasoline. The first is caused by the reaction of the lead bromide with hot metallic surfaces, and occurs when the engine is in operation; the second is caused by the condensed products of combustion, chiefly hydro-bromic acid, when the engine is not running.

Purity

Aviation fuels must be free of impurities that would interfere with the operation of the engine or the units in the fuel and induction system.
Even though all precautions are observed in storing and handling gasoline, it is not uncommon to find a small amount of water and sediment in an aircraft fuel system. A small amount of such contamination is usually retained in the strainers in the fuel system. Generally, this is not considered a source of great danger, provided the strainers are drained and cleaned at frequent intervals. However, the water can present a serious problem because it settles to the bottom of the fuel tank and can then be circulated through the fuel system. A small quantity of water will flow with the gasoline through the carburettor metering jets and

will not be especially harmful. An excessive amount of water will displace the fuel passing through the jets and restrict the flow of fuel; it will cause loss of power and can result in engine stoppage.

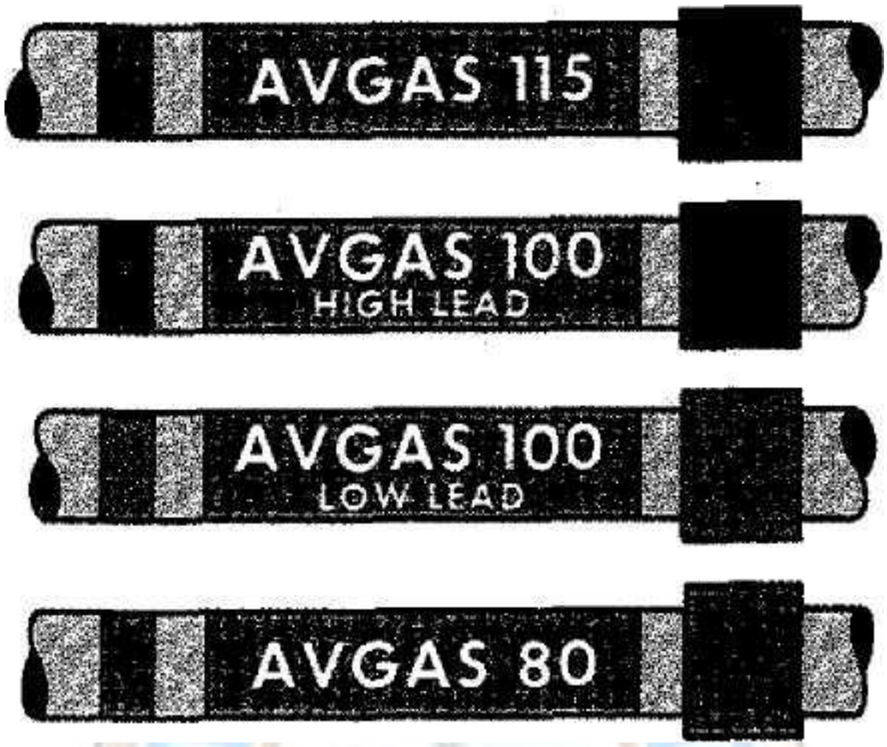
Under certain conditions of temperature and humidity, condensation of moisture (from the air) occurs on the inner surfaces of the fuel tanks. Since this condensation occurs on the portion of the tank above the fuel level, it is obvious that the practice of servicing an airplane immediately after flight will do much to minimize this hazard.



Petroleum products are produced by distillation. Various fractions condense and are collected at different temperatures that correspond to the height of collection in the distillation tower. As can be seen, there are significant differences between turbine engine fuel and ordinary AVGAS.

Fuel Identification

Gasoline's containing TEL must be colored to conform to the law. In addition, gasoline may be colored-for purposes of identification. For example, grade 100 low lead aviation gasoline is *blue*, grade 100 is *green* and grade 80 is *red.* See figure.

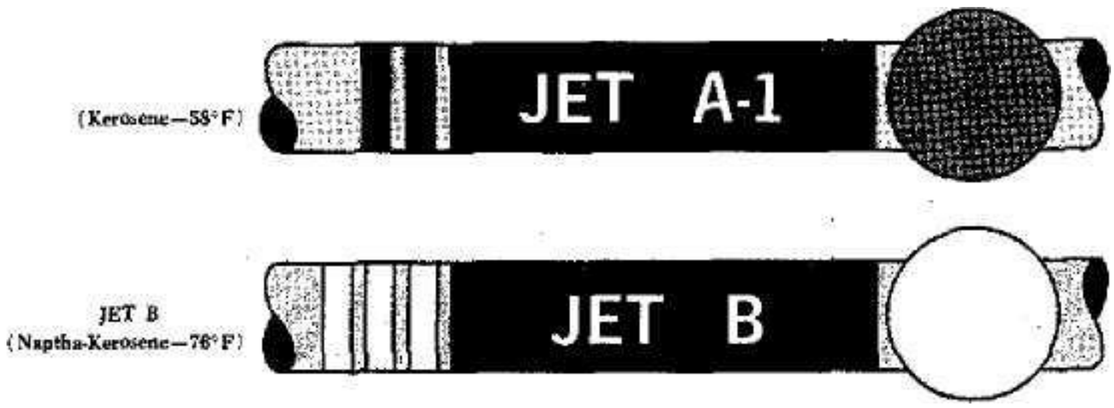


100/130 gasoline is manufactured (1975) in two grades high-lead, up to 4.6 millilitres of lead per gallon and low-lead, not over 2.0 millilitres per gallon. The purpose being to eliminate two grades of lower octane fuel (80/87) and 91/96). The high-lead will continue to be colored green whereas the low-lead will be blue.

The low-lead will replace the 80/87 and 91/96 octane fuels as they are phased out.
Engine manufacturers have prepared instructions to be followed in making adjustments necessary for changeover to the 100 octane fuel.

A change in colour of an aviation gasoline usually indicates contamination with another product or a loss of fuel quality. A colour change can also be caused by a chemical reaction that has weakened the lighter dye component. This colour change in itself may not affect the quality of the fuel.

A colour change can also be caused by the preservative in a new hose. Grade 115/145 gasoline that has been trapped for a short period of time in new hose may appear green. Flushing a small amount of gasoline through the hose usually removes all traces of colour Change.



Fuel Type and Grade	Color of Fuel	Equipment Control Color	Pipe Banding and Marking	Refueler Decal
AVGAS 82UL	Purple	82UL AVGAS	AVGAS 82UL	82UL AVGAS
AVGAS 100	Green	100 AVGAS	AVGAS 100	100 AVGAS
AVGAS 100LL	Blue	100LL AVGAS	AVGAS 100LL	100LL AVGAS
JET A	Colorless or straw	JET A	JET A	JET A
JET A-1	Colorless or straw	JET A-1	JET A-1	JET A-1
JET B	Colorless or straw	JET B	JET B	JET B

TYPES OF JET FUEL

The U.S. Military grades of jet fuel are designated by the letters JP followed by a number. The grade number merely shows the approximate sequence the fuel specifications were accepted by the military. North Atlantic Treaty Organization (NATO) codes show compatible fuel standards. When changing to a different fuel, it is usually unnecessary to drain out the old fuel. Some aircraft prohibit fuel mixing or require different settings on some fuel components (fuel controls) when switching fuel grades.

JP–4

JP–4 (NATO Code F–40) is an alternate fuel to JP–5 for United States Navy (USN) jet aircraft used at shore stations only. It is never used on ships. Its low vapour pressure reduces fuel tank loss and vapour lock tendencies. Its fuel density is 6.5 pounds per gallon (ppg), and its flash point is below 0 degrees Fahrenheit (°F). When switching to JP–4 from JP–5, engine operating characteristics may change. Changes include easier starting, slower acceleration, lower operating temperature, and shorter range.

JP–5

JP–5 (NATO Code F–44) is the Navy's primary jet fuel. It is relatively safe to store, is thermally stable, and has high heat content per gallon. JP–5 is a kerosene-type fuel with a vapour pressure close to 0 pounds per square inch (psi). Its high flash point makes it safe for shipboard handling. In fact, it is the only jet aircraft fuel used aboard ships. It has a lower tendency to vaporize than the more volatile grades. The vapour-air mixture in tanks or containers above its liquid surfaces generally will be too lean to be ignited until the surface of the liquid reaches a temperature of about 140 °F.

JP–8

JP–8 (NATO Code F–34) is similar to JP–5 in most characteristics, except flash point and freeze point. JP–8 is available only in Europe. JP–8 represents significant advantages over JP–4 in fuel handling and operational safety. However, like JP–4, its flash point is lower than shipboard safety standards. The disadvantages of cost, availability, and low temperature starting problems prevent it from replacing JP–4.

Commercial Fuel

Common commercial fuels used include types A, A–1, and B. Commercial fuels are authorized for use in military aircraft when JP fuel is not available. The characteristics of commercial fuel are similar to military fuels. A–1 is designated NATO code F–34, or equal to JP–8. Jet A is equal to JP–5, and Jet B is equal to JP–4.

TURBINE ENGINE FUELS

The aircraft gas turbine is designed to operate on a distillate fuel, commonly called jet fuel. Jet fuels are also composed of hydrocarbons with a little more carbon and usually a higher sulphur content than gasoline. Inhibitors may be added to reduce corrosion and oxidation. Antiicing additives are also being blended to prevent fuel icing.
Two types of jet fuel in common use today are: (1) Kerosene grade turbine fuel, now named jet A; and (2) a blend of gasoline and kerosene fractions, designated Jet B. There is a third type, called Jet A-l, which is made for operation at extremely low temperatures. See figure.
There is very little physical difference between Jet A (JP-5) fuel and commercial kerosene.

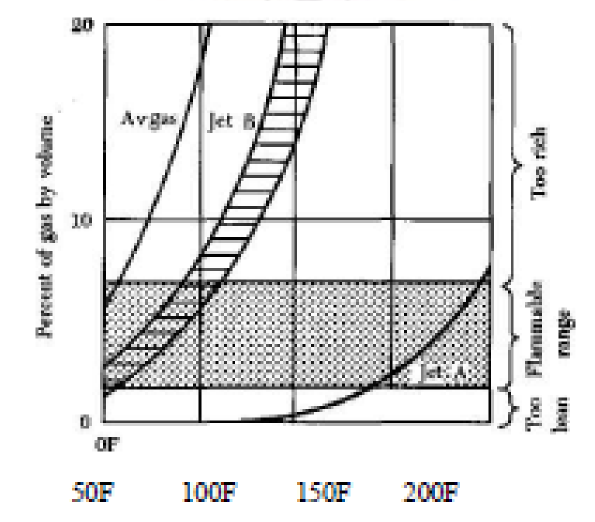
Jet A was developed as a heavy kerosene having a higher flash point and lower freezing point than most kerosenes. It has a very low vapour pressure, so there is little loss of fuel from evaporation or boil-off at higher altitudes. It contains more heat energy per gallon than does Jet B (JP-4).

Jet B is similar to Jet A. It is a blend of gasoline and kerosene fractions. Most commercial turbine engines will operate on either Jet A or Jet B fuel. However, the difference in the specific gravity of the fuels may require fuel control adjustments. Therefore, the fuels cannot always be considered interchangeable.

Both Jet A and Jet B fuels are blends of heavy distillates and tend to absorb water. The specific gravity of jet fuels, especially kerosene, is closer to water than is aviation gasoline; thus, any water introduced into the fuel, either through refuelling or condensation, will take an appreciable time to settle out. At high altitudes, where low temperatures are encountered, water droplets combine with the fuel to form a frozen substance referred to as "gel." The mass of "gel" or "icing" that may be generated from moisture held in suspension in jet fuel can be much greater than in gasoline.

Volatility

One of the most important characteristics of a jet fuel is its volatility. It must, of necessity, be a compromise between several opposing factors. A highly volatile fuel is desirable to aid in starting in cold weather and to make aerial restarts easier and surer. Low volatility is desirable to reduce the possibility of vapour lock and to reduce fuel losses by evaporation.



Temperature Vaporization of aviation fuels at atmospheric pressure.

At normal temperatures, gasoline in a closed container or tank can give off so much vapour that the fuel/air mixture may be too rich to burn. Under the same conditions, the vapour given off by Jet B fuel can be in the flammable or explosive range. Jet A fuel has such a low volatility that at normal temperatures it gives off very little vapour and does not form flammable or explosive fuel/air mixtures. Figure above shows the vaporization of aviation fuels at atmospheric pressure.

Identification

Because jet fuels are not dyed, there is no on-sight identification for them. They range in colour from a colourless liquid to a straw-colored (amber) liquid, depending on age or the crude petroleum source.
Jet fuel numbers are type numbers and have no relation to the fuel's performance in the aircraft engine.

FUEL SYSTEM CONTAMINATION

There are several forms of contamination in aviation fuel. The higher the viscosity of the fuel, the greater is its ability to hold contaminants in suspension. For this reason, jet fuels having a high viscosity are more susceptible to contamination than aviation gasoline. The principal contaminants that reduce the quality of both gasoline and turbine fuels are other petroleum products, water, rust or scale, and dirt.

Water

Water can be present in the fuel in two forms:
(1) Dissolved in the fuel or
(2) Entrained or suspended in the fuel.
Entrained water can be detected with the naked eye. The finely divided droplets reflect light and in high concentrations give the fuel a dull, hazy, or cloudy appearance.
Particles of entrained water may unite to form droplets of free water.
Fuel can be cloudy for a number of reasons. If the fuel is cloudy and the cloud disappears at the bottom, air is present. If the cloud disappears at the top, water is present. A cloud usually indicates a water-in-fuel suspension. Free water can cause icing of the aircraft fuel system, usually in the aircraft boost-pump screens and low-pressure filters. Fuel gage readings may become erratic because the water short-circuits the aircrafts electrical fuel cell quantity probe. Large amounts of water can cause engine stoppage. If the free water is saline, it can cause corrosion of the fuel system components.

Foreign Particles

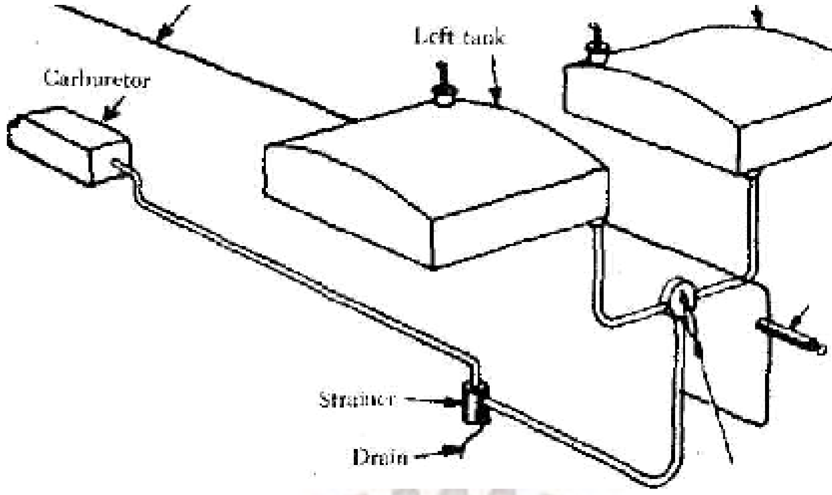
Most foreign particles are found as sediment in the fuel. They are composed of almost any material with which the fuel comes into contact. The most common types are rust, sand, aluminum and magnesium compounds, brass shavings, and rubber.

Rust is found in two forms:
(1) Red rust, which is nonmagnetic and
(2) Black rust, which is magnetic.
They appear in the fuel as red or black powder (which may resemble a dye), rouge, or grains. Sand or dust appears in the fuel in a crystalline, granular, or glasslike form.

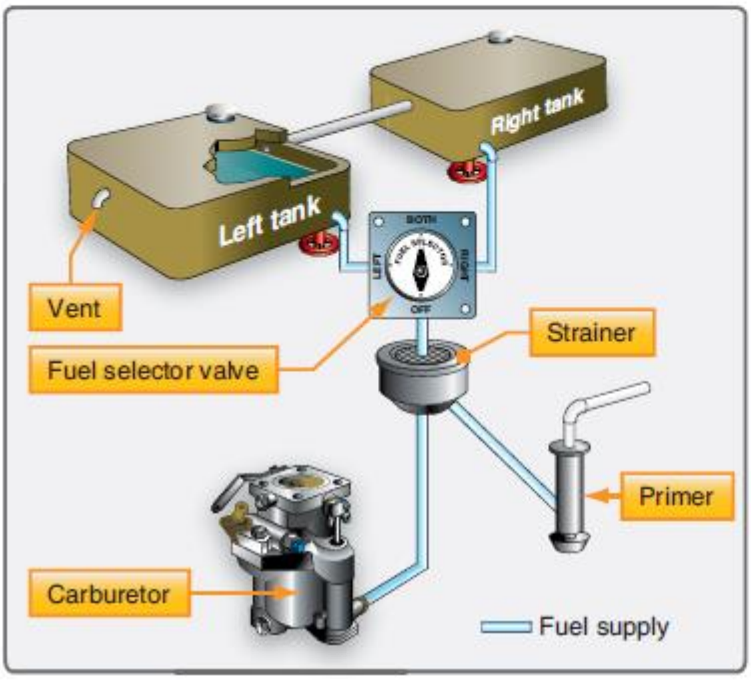
Aluminum or magnesium compounds appear in the fuel as a form of white or gray powder or paste. This powder or paste becomes very sticky or gelatinous when water is present. Brass is found in the fuel as bright gold-colored chips or dust. Rubber appears in the fuel as fairly large irregular bits. All of these forms of contamination can cause sticking or malfunctions of fuel metering devices, flow dividers, pumps, and nozzles.

FUEL SYSTEM

The aircraft fuel system stores fuel and delivers the proper amount of clean fuel at the right pressure to meet the demands of the engine. A well-designed fuel system ensures positive and reliable fuel flow throughout all phases of flight, which include changes in altitude, violent maneuvers and sudden acceleration and deceleration. Furthermore, the system must be reasonably free from tendency to vapor lock, which can result from changes in ground and in-flight climatic conditions. Such indicators as fuel pressure gages, warning signals, and tank quantity gages are provided to give continuous indications of how the system is functioning.



***Gravity feed fuel system*.**



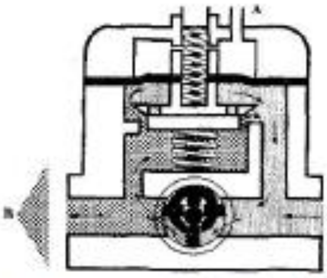
The gravity-feed fuel system in a single-engine high wing aircraft is the simplest aircraft fuel system.

Engine-Driven Fuel Pump

The purpose of the engine-driven fuel pump is to deliver a continuous supply of fuel at the proper pressure at all times during engine operation. The pump widely used at the present time is the positive-displacement, rotary-vane-type pump.

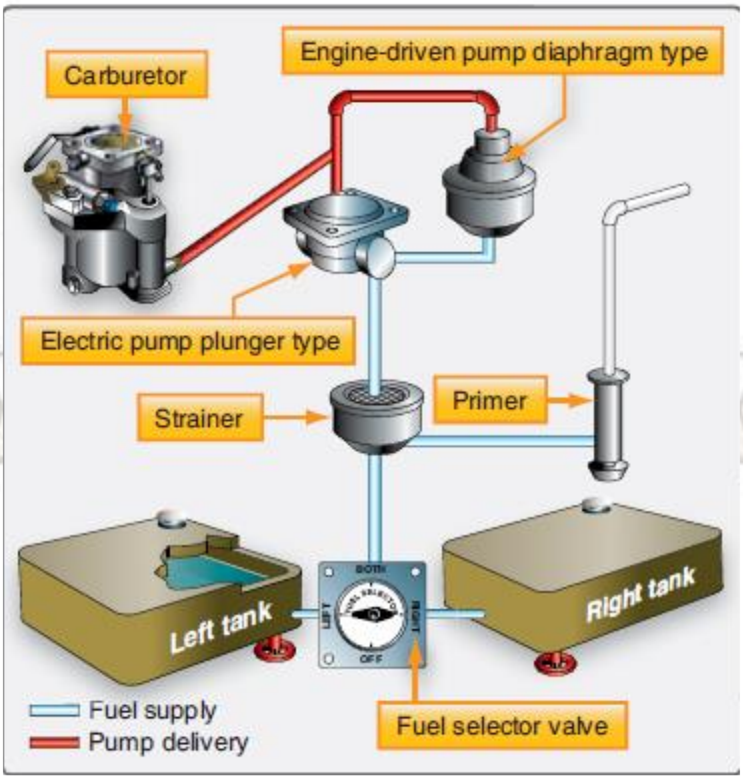
A schematic diagram of a typical engine-driven pump (vane-type) is shown in figure.

Regardless of variations in design, the operating principle of all vane-type fuel pumps is the same.



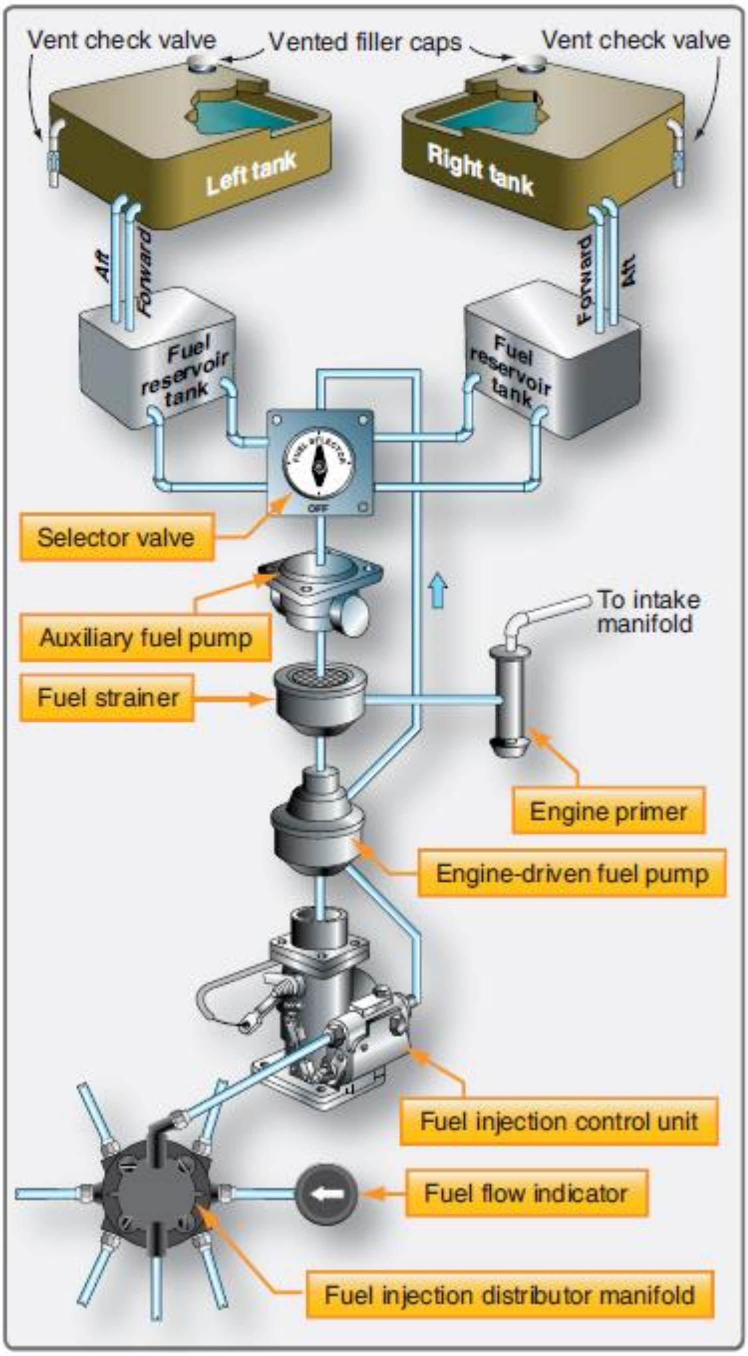
Engine-driven fuels pump (pressure delivery).

The engine-driven pump is usually mounted on the accessory section of the engine.
The rotor, with its sliding vanes, is driven by the crankshaft through the accessory gearing. Note how the vanes carry fuel from the inlet to the outlet as the rotor turns in the direction indicated. A seal prevents leakage at the point where the drive shaft enters the pump body, and a drain carries away any fuel that leaks past the seal. Since the fuel provides enough lubrication for the pump, no special lubrication is necessary.



A single reciprocating engine aircraft with fuel tanks located in wings below the engine uses pumps to draw fuel from the tanks and deliver it to the engine.

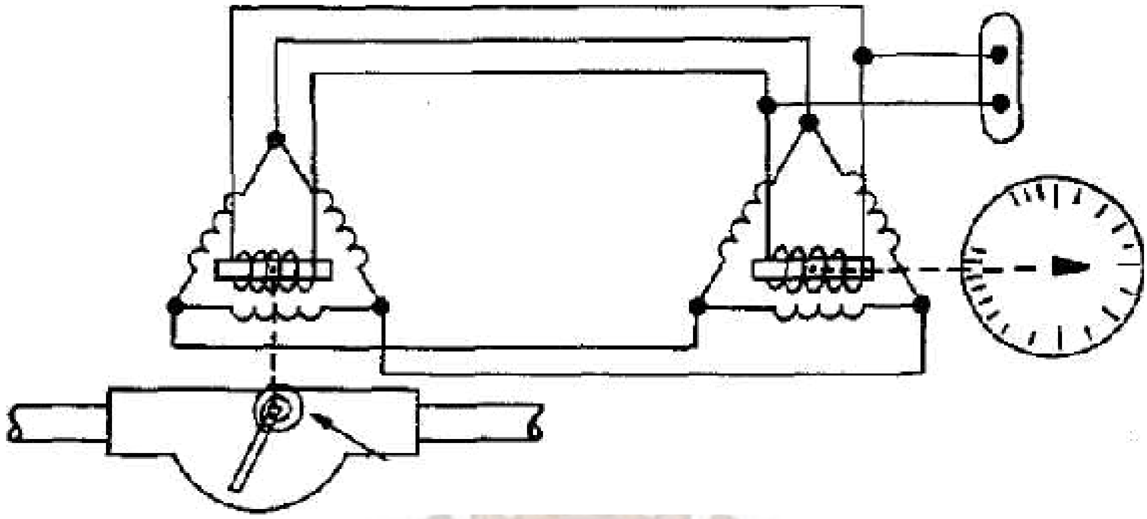
Since the engine-driven fuel pump normally discharges more fuel than the engine requires, there must be some way of relieving excess fuel to prevent excessive fuel pressures at the fuel inlet of the carburettor. This is accomplished through the use of a spring-loaded relief valve that can be adjusted to deliver fuel at the recommended pressure for a particular carburettor. Figure, shows the pressure relief valve in operation, by passing excess fuel hack to the inlet side of the pump. Adjustment is made by increasing or decreasing the tension of the spring.



The relief valve of the engine-driven pump is designed to open at the set pressure regardless of the pressure of the fuel entering the pump. To maintain the proper relation between fuel pressure and carburettor inlet air pressure, the chamber above the fuel pump relief valve is vented either to the atmosphere or through a balance line to carburettor air inlet pressure.

Fuel Pressure Gage

The fuel pressure gage indicates the pressure of the fuel entering the carburettor. This gage may be included with the oil pressure gage and the oil temperature gage in one casing, called the engine gage unit. Most aircraft today have separate gages for these functions. An engine gage unit is shown in figure the fuel pressure gage is a differential pressure indicator with two connections on the back of the indicator housing. The air connection (see figure) is vented to the carburettor air inlet, and the fuel connection is attached to the fuel flow.



FUEL IGNITION SYSTEMS

A fuel ignition system is required for transport category and general aviation-aircraft if the maximum take-off weight exceeds the maximum landing weight. The maximum take-off and landing weights are design specifications and may be found in the Aircraft Type Certificate data sheets.

A fuel ignition system must be able to ignition enough fuel within 10 minutes for general aviation, or 15 minutes for transport category aircraft, to meet the requirements of the specifications and Federal Air Regulations. It must be operable under the conditions encountered during all operations of the aircraft.

Design requirements are that fuel ignitioning must be stopped with a minimum of fuel for 45 minutes of cruise at maximum continuous power for reciprocating engines.
Turbine powered aircraft require enough fuel for take-off and landing and 45 minutes cruising time.

The fuel ignitioning system is usually divided into two separate, independent systems, one for each wing, so that lateral stability can be maintained by ignitioning fuel from the "heavy" wing if it is necessary to do so. Normally, if an unbalanced fuel load exists, fuel will be used from the "heavy" wing by supplying fuel to engines on the opposite wing.

The system consists of lines, valves, dump chutes and chute-operating mechanisms. Each wing contains either a fixed or an extendable dump chute depending upon system design. In either case the fuel must discharge clear of the airplane.

AIRCARFT FUEL SYSTEM:

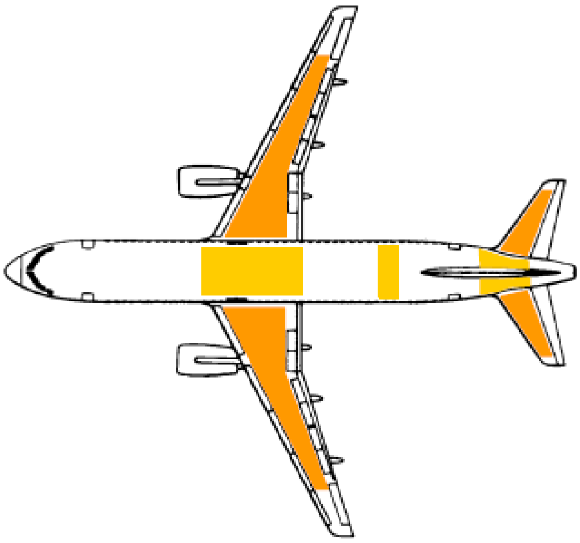
The fuel system must store the fuel in suitable areas of the aircraft and supply it to the engines. Old piston engine aircraft had simple systems, where usually the engine was fuel supplied by gravity. Current jet engines require high fuel rate, to be sometimes distributed along considerable lengths, then needing important studies of the system layout and sizing.

Safety of the fuel system is also a major issue, because the fatality rate during accidents is significantly increased by post-crash fire. Therefore great efforts are being done to reduce this hazard, in two directions: modification of the chemical properties of fuels, to reduce the risk of ignition outside the combustion chamber, and crashworthiness of tanks and pipes, to reduce the risk of leakage during impacts.

The components and features that will be described are as follows:
Tanks;
Refuel/defuel;
Pumps;
Valves;
Quantity measurement;
Engine feed.

Tanks

The fuel mass is a significant fraction of the total aircraft mass; for turboprop or turbofan airliners and helicopters the fuel mass is in the range 20 – 30 % of the maximum take-off mass, for a combat aircraft up to 40 %, for a bomber more than 50 %. This little statistics shows the importance of fuel storage layout and location on board, and its influence on flight trimming.
For fixed wing aircraft a typical choice is wing tanks, which gives many advantages:
A free and available volume is used;
The location is not far from the aircraft centre of gravity;
The wing root bending moment is reduced with respect of a configuration where the fuel is stored in fuselage tanks.
On the other hand this solution has some drawbacks for aerobatics because it increases the roll moment of inertia, and for combat aircraft because the wing is a wide exposed surface and, in particular for supersonic aircraft, the wing is very thin, the providing limited room for fuel recovery.
Commonly an additional centre wing tank is installed; sometimes fuel is stored in the vertical and horizontal tail and other areas of the fuselage, so that the tank layout can be often composed by a high number of small tanks distributed in different areas of the aircraft.

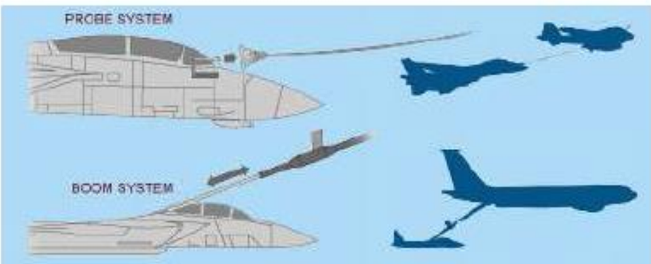


Possible tank locations on modern airliners

On rotary-wing aircraft fuel storage presents more difficulties, because there is not a wing or any other structure that is free and available for fuel containment. Moreover crashworthiness requirements are very tight: the fuel must be far from cabin, engines and those areas mainly exposed to crash. Often the tanks are then located in bays aft of the cabin, with a suitable distance from the occupants and bottom structure.
Tanks can be integral, rigid or flexible.
An integral tank, like most part of the wing tanks, is part of the structure; this solution, when possible, gives obvious weight advantage, even if it requires sealing and maintenance. An integral tank is then made normally of aluminium alloy.
When the structure cannot be used as a tank, then flexible or rigid tanks are installed. In the first case a bladder is located in a bay that have anyway the function to contain the tank (common helicopter solution), made of rubber or nylon; in the second case there is no interference of the tank with the structure with exception of the anchoring points (common fuselage solution).
External tanks can be used to further increase the range. In particular military aircraft in long-range missions can hold under wing or ventral tanks, which may be jettisoned before combat.
Fuel contained in wide tanks, like those in the wings, can easily slosh in any aircraft manoeuvre; this can cause fluctuations of the centre of gravity and errors in quantity measurement. Anti-slosh baffles are normally used in these tanks.
The risk of significant liquid sloshing would be particularly high in the wing tanks, but here the effect is well attenuated by the ribs; moreover the rib lightening holes are often closed with flap check valves that allow the fuel to be collected in the root area and prevent it to slosh towards the tip area.
In some cases the tanks are pressurised, to favour the flow from a tank to another when gravity is not sufficient and no transfer pumps are installed.
In many cases the fuel is transferred and consolidated in collector tanks before feeding to the engines by the booster pumps. The pumps in combat and aerobatic aircraft have the suction pipe extremity immersed in a region of the tank where part of the fuel can be trapped, in case of reverse or negative-g flight.

Refuel and defuel

Refuelling is normally done under 0.35 MPa pressure by ground tankers and controlled by a fuel management system. The liquid is sent in a first collecting tank and from there it is distributed to all the tanks. For each tank a refuel valve, controlled by the system, will shut off at full tank or, more commonly, at a preset value of filling.
A vent system allows for air compensation, from the top of the tanks, during fuelling, defueling and fuel transfer operations.
Most military aircraft have the possibility of in-flight refuelling, with great improvement of mission range and flexibility. Two techniques are currently used: probe/drogue and boom/receptacle method, shown in figure.



Probe and boom refuelling techniques

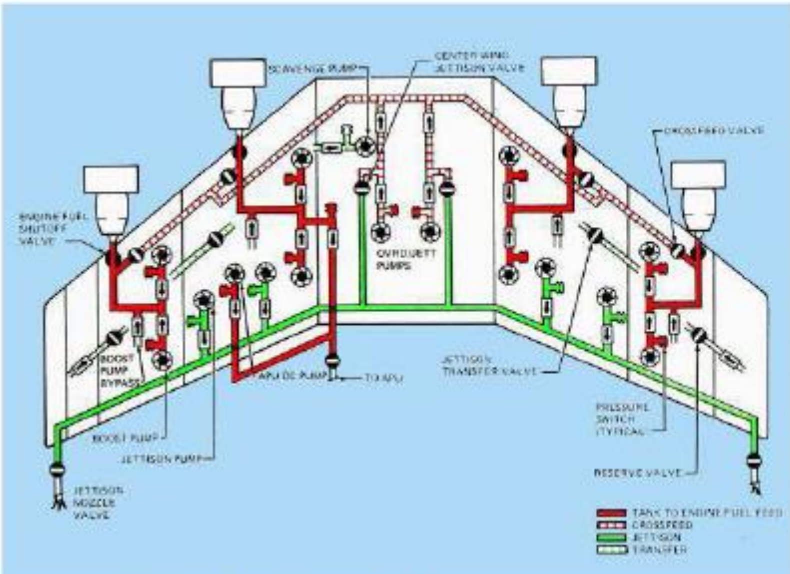
In the first case, a flexible pipe is lowered in the air stream from the tanker aircraft, with a large cone-shaped metal basket at the end. The recipient aircraft has a probe and the pilot must control the flight in order to insert the probe into the basket. The centre of the basket has a hose connection with a quick-locking mechanism; when the probes pulls in, it is locked and high pressure refuelling starts, with a flow that may reach 2500 kg/minute. As the probe stops pulling, the mechanism is unlocked and the flow is shut off so that there is no loss of fuel. A tanker may have one centre hose and two on the wings, with the possibility to refuel three aircraft in the same time. This system is mostly used by the European aviation.

US aviation has a method developed by Boeing, where the pipe from the air tanker is a telescopic boom lowered under the tail, and the inlet to the recipient is a receptacle on top of the aircraft. The boom is controlled by an operator on board the tanker, and the boom end is out of the recipient pilot view in the final part of the operation, so that this technique is more risky than the probe/drogue, but allows a faster refuelling up to 3500 kg/minute.

Apart from a normal defueling that can be done for maintenance reasons, the aircraft may be in the condition to jettison a large quantity of fuel. This may happen in emergency landing conditions, especially when the aircraft is in the first part of its flight and needs to bring its weight down to the maximum landing weight or even to a nearly zero-fuel condition, if a crash landing is expected.

Typical positions for jettison valves are along the feed line to the engines, where the fuel has a pressure that allows it to be tapped off with a considerable flow rate.

When possible dumping is obtained from outlets located rear of the wing tips, then far from the engines and other aircraft parts.



Boeing 747 fuel jettison system

Figure shows the schematic representation of the Boeing 747 fuel feed system including the jettison sections. In this case 2 additional outlets are located under the centre wing.

Pumps and valves

Two kinds of pumps can be found in a fuel system: transfer and booster pumps. The first ones must transfer fuel among tanks; this is necessary for instance when a fuselage collector tank

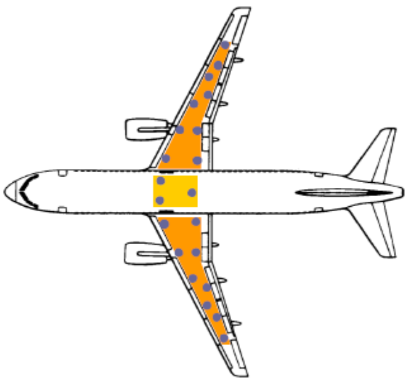
is installed where fuel is consolidated before engine feed, or for pitch and roll trim reasons by balancing the fuel distribution in the tanks; the booster pumps feed the engines.
In both cases flow rates (depending of course on aircraft category) are in the range 2 – 6 kg/s, with pressures around 0.05 – 0.2 MPa. Smaller pumps are usually operated by DC motors, larger ones by three-phase AC motors. In some cases they are operated by a hydraulic motor or, in emergency, by RAT's.

Even if they are designed to be lubricated directly by the fuel, they may run in dry environment for hours. Most of them are in fact of the centrifugal type, so that there are no significant parts in relative sliding that can wear and heat up if there is no lubricating and cooling liquid. The characteristic functioning diagram of a pump of this type is shown in figure where the delivered pressure is a function of the allowed flow rate.

A booster pump does not feed directly the engine combustion chamber, but must provide the entire fuel rate that can be requested by the engine with a suitable inlet pressure; one or more displacement pumps integrated in the engine perform final feeding to the combustion chamber. Main valves in a fuel system are shut off valves, which can be located on the feed line to the engine, between tanks, between segments of the system (cross-feed valves), and on the jettison lines (dump valves). Usually those valves that must have a controlled position are driven by electric motors, those that have an on/off position by solenoids.

Fuel quantity measurement
Fuel level measurement can be done by different devices. The classic one is the floating type, where a floater is connected to a stick that modify a resistor when the level changes, but nowadays the most common systems are based o capacitance and ultrasonic probes.
In the first case a capacitor made of two cylindrical co-axial armatures is used; the dielectric is made by the fuel and air that fill the room between the armatures. Then depending on the fuel level a different capacitance may be measured. To compensate for fuel permittivity change due to temperature, reference units are usually integrated in the probes.
In the second case ultrasonic transducers are used to measure the fuel level. They are located in the bottom of the tank and the level measure is based on the time the ultrasound takes to run to the fuel surface and be reflected back to the sensor.

In both cases a level is measured. To find the volume the shape of the tank must be known, and sometimes it is complex. Therefore all modern systems are based on a computer signal processing that relates level measures to volume measures. The operation is done by processing the signals coming from a network of probes suitably located in the tanks. Figure is a schematic example in case of wing tank.



Probe distribution

Finally a measure of the temperature is used to convert the volume measure to mass measure, based on fuel density tables.

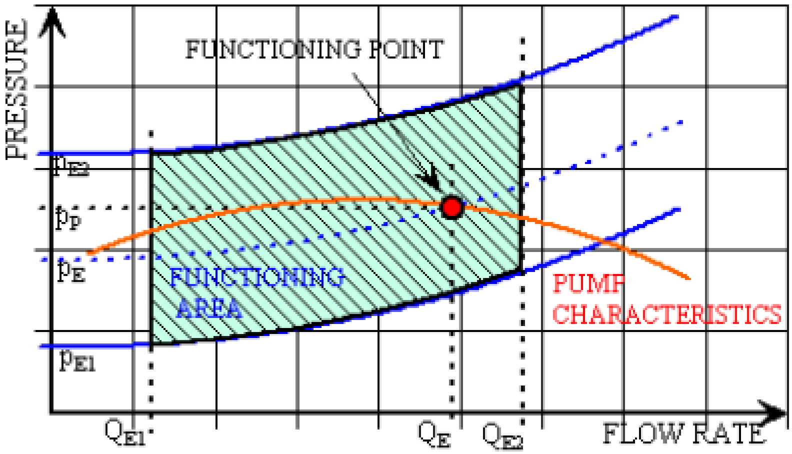
Engine feed

Depending on the engine speed, a different flow rate must be supplied to the engine, in a range specified by the engine manufacturer. The pressure at engine inlet must also be limited in a range. Because the booster pumps are located in the tanks and the engines may sometimes be located many meters far from the tanks, head losses play an important role in pump choice, pipeline design and layout. Moreover the fuel system layout must be able to feed the engines in emergency conditions too.

First information comes from comparing the characteristic pump functioning diagram with the head loss diagram; the head loss, or flow pressure difference between a section in the pipeline at the pump outlet *pP* and a section at engine inlet *pE*, can be derived by eq. 2.6, as follows:

$$p_P - p_E = f\frac{L}{D}\frac{1}{2}\rho v^2,$$

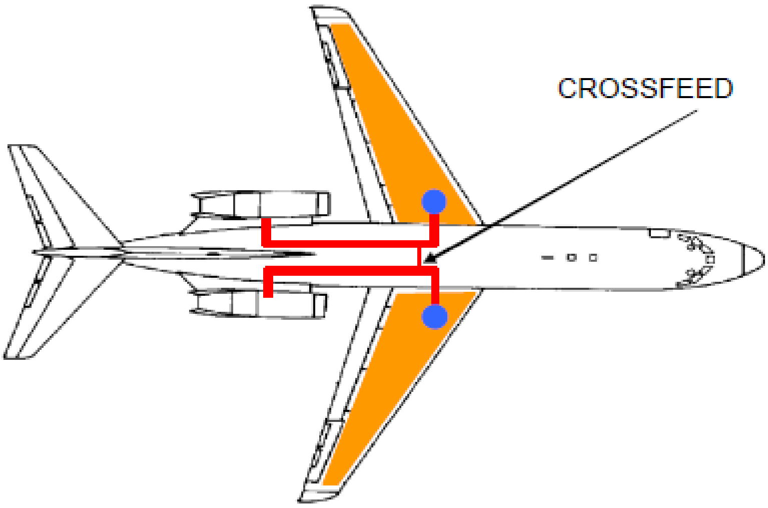
In particular the friction factor *f* is linear with flow velocity *v* for laminar flow, becoming almost independent from *v* in turbulent flow and high Reynolds number. Then the plot of pump characteristics and head loss is substantially as shown in figigure,



Definition of pump functioning area and point

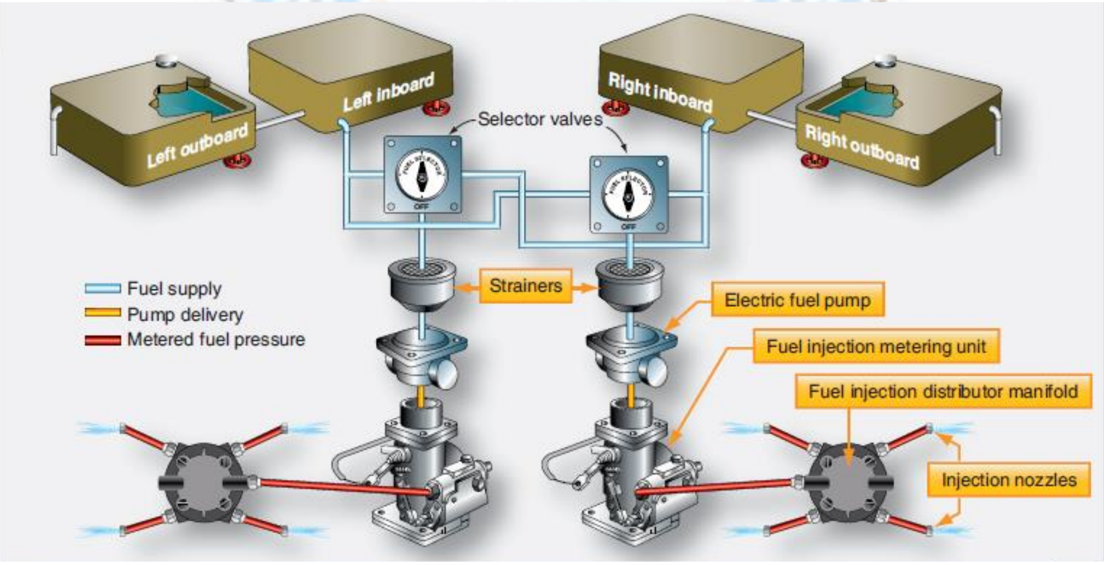
Where the pressure is that measured at pump outlet, *pE1* and *pE2* are the min and max pressure requested at engine inlet to work properly and *QE1* and *QE2* define the min and max flow rate that can be requested by the engine. First of all these data are sufficient to define a functioning area, i.e. a flow rate range where the pump characteristic diagram must be within pressure range. If the current range is *QE*, then the pump will work generating a pressure *pP* that, after the head loss, will have value *pE* at the engine inlet.

The system must work also in emergency conditions. This means that, in case of fault of one pump, or leakage in one tank, this branch must be isolated by the shut off valves and the other branch (or branches) must be able to supply enough fuel for all the engines. The problem can be better outlined in the case of a twin engine aircraft, like that shown in figure.

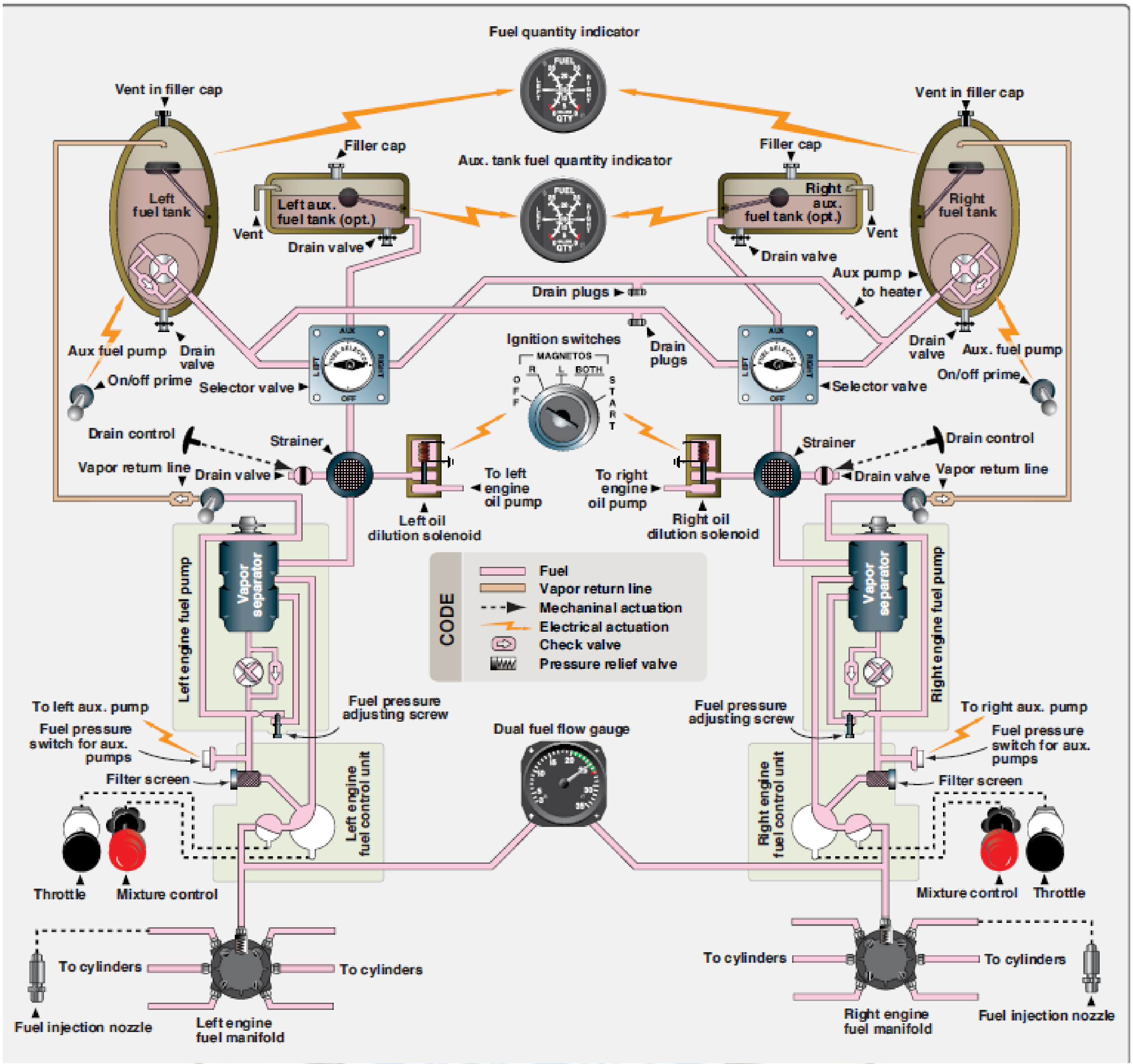


Emergency cross feed

Normally one booster pump feed one engine. In case of malfunction of one feeding branch, the other must supply both the engines. This means that:
1. One pump must be able to supply enough fuel flow rate for both the engines;
2. A cross feed line must be open to link the two branches.
For head loss reasons it is clear that the cross feed line should be installed as close as possible to the tanks. In this case, in fact, the flow is immediately split into two parallel pipes, with no significant increase of head loss with respect to the normal operation condition. If the cross feed line is located near the engines, a considerable pipe length has double flow rate with respect to normal conditions, that means double or quadruple head loss (depending on the flow type), that would bring to a major sizing of the booster pumps.



A simple high-wing fuel injection fuel system for a light twin reciprocating-engine aircraft.



A low-wing, twin-engine, light aircraft fuel system.

Fuel System Indicators

Aircraft fuel systems utilize various indicators. All systems are required to have some sort of fuel quantity indicator. Fuel flow, pressure, and temperature are monitored on many aircraft. Valve position indicators and various warning lights and annunciations are also used.

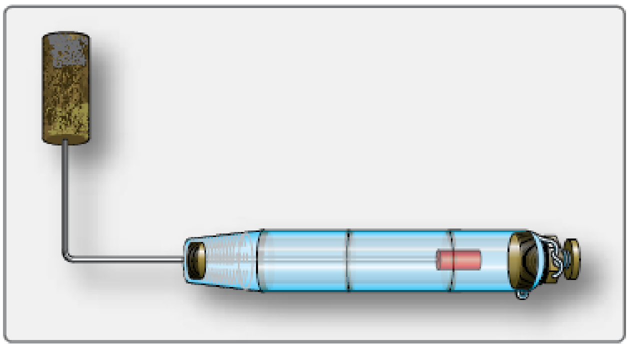
Fuel Quantity Indicating Systems

All aircraft fuel systems must have some form of fuel quantity indicator. These devices vary widely depending on the complexity of the fuel system and the aircraft on which they are installed. Simple indicators requiring no electrical power were the earliest type of quantity indicators and are still in use today. The use of these direct reading indicators is possible only on light aircraft in which the fuel tanks are in close proximity to the cockpit. Other light aircraft and larger aircraft require electric indicators or electronic capacitance type indicators.

A sight glass is a clear glass or plastic tube open to the fuel tank that fills with fuel to the same level as the fuel in the tank. It can be calibrated in gallons or fractions of a full tank that can be read by the pilot. Another type of sight gauge makes use of a float with an indicating rod attached to it. As the float moves up and down with the fuel level in the tank, the portion of the rod that extends through the fuel cap indicates the quantity of fuel in the tank. *[Figure below]*

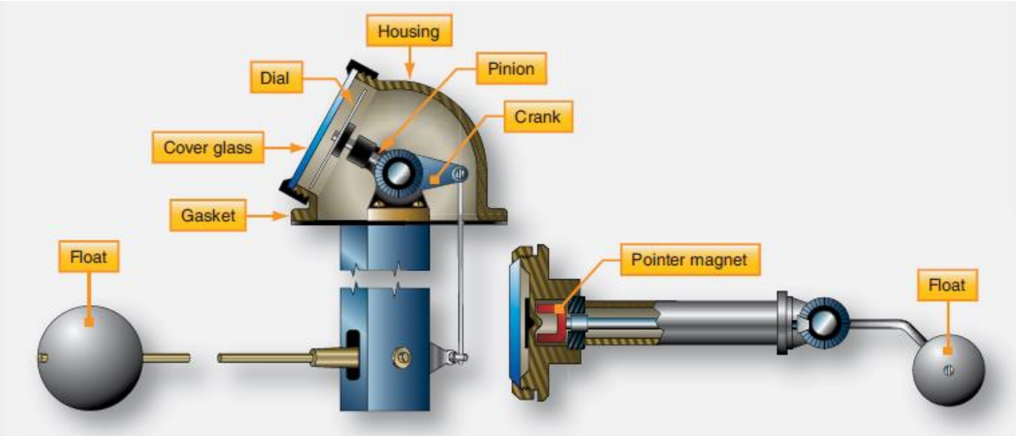
The fuel quantity indicator on this Piper Cub is a float attached to a rod that protrudes through the fuel cap.

These two mechanisms are combined in yet another simple fuel quantity indicator in which the float is attached to a rod that moves up or down in a calibrated cylinder. *[Figure below]*



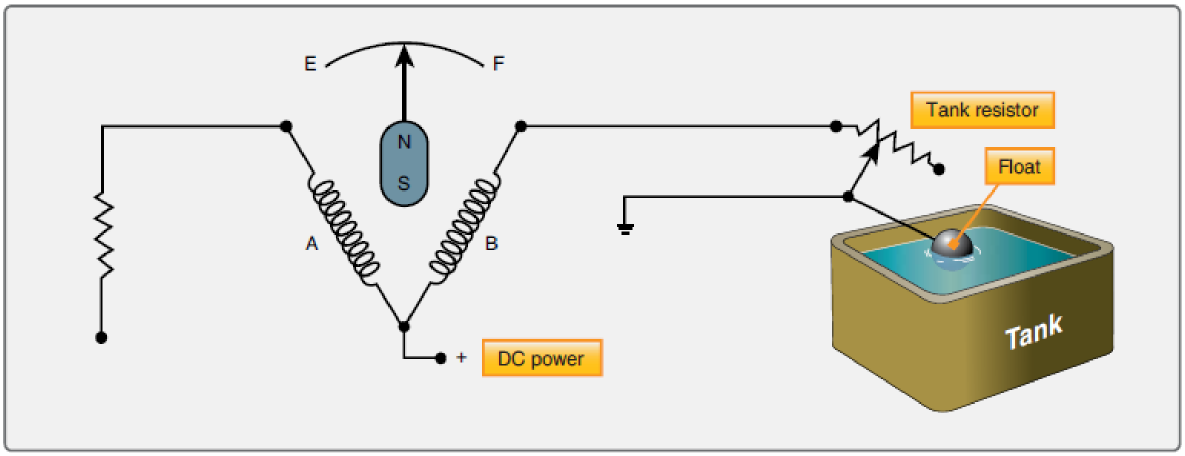
A float-type sight gauge fuel quantity indicator.

More sophisticated mechanical fuel quantity gauges are common. A float that follows the fuel level remains the primary sensing element, but a mechanical linkage is connected to move a pointer across the dial face of an instrument. This can be done with a crank and pinion arrangement that drives the pointer with gears, or with a magnetic coupling, to the pointer. *[Figure below]*



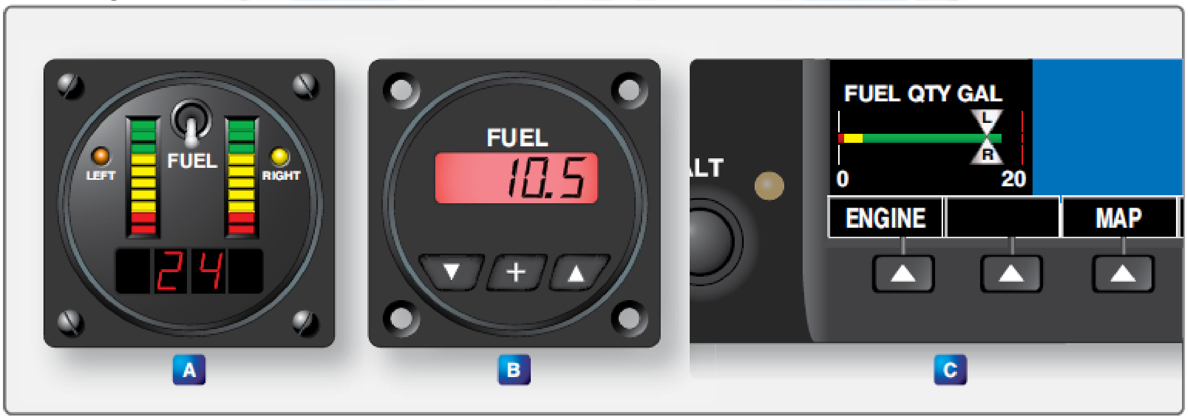
Simple mechanical fuel indicators used on light aircraft with fuel tanks in close proximity to the pilot.

Electric fuel quantity indicators are more common than mechanical indicators in modern aircraft. Most of these units operate with direct current (DC) and use variable resistance in a circuit to drive a ratiometer-type indicator. The movement of a float in the tank moves a connecting arm to the wiper on a variable resistor in the tank unit. This resistor is wired in series with one of the coils of the ratiometer-type fuel gauge in the instrument panel. Changes to the current flowing through the tank unit resistor change the current flowing through one of the coils in the indicator. This alters the magnetic field in which the indicating pointer pivots. The calibrated dial indicates the corresponding fuel quantity. *[Figure 14-70]*



A DC electric fuel quantity indicator uses a variable resistor in the tank unit, which is moved by a float arm.

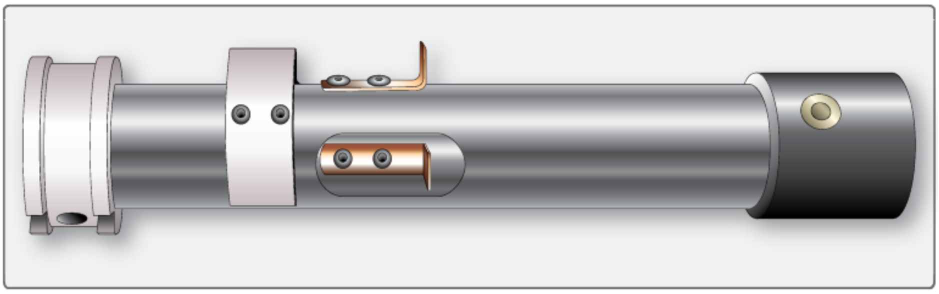
Digital indicators are available that work with the same variable resistance signal from the tank unit. They convert the variable resistance into a digital display in the cockpit instrument head. *[Figure below]*



Digital fuel quantity gauges that work off of variable resistance from the tank unit are shown in A and B. The fuel quantity indication of a Garmin G-1000 flat screen display is shown in C.

Fully digital instrumentation systems, such as those found in a glass cockpit aircraft, convert the variable resistance into a digital signal to be processed in a computer and displayed on a flat screen panel.

Large and high-performance aircraft typically utilize electronic fuel quantity systems. These more costly systems have the advantage of having no moving parts in the tank sending units. Variable capacitance transmitters are installed in the fuel tanks extending from the top to the bottom of each tank in the usable fuel. Several of these tank units, or fuel probes as they are sometimes called, may be installed in a large tank. *[Figure 14-72]*



A fuel tank transmitter for a capacitance-type fuel quantity indicating system.

They are wired in parallel. As the level of the fuel changes, the capacitance of each unit changes. The capacitance transmitted by all of the probes in a tank is totalled and compared in a bridge circuit by a microchip computer in the tank's digital fuel quantity indicator in the cockpit. As the aircraft manoeuvres, some probes are in more fuel than others due to the attitude of the aircraft. The indication remains steady, because the total capacitance transmitted by all of the probes remains the same. A trimmer is used to match the capacitance output with the precalibrated quantity indicator.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-IV NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 5AN3 **SEMESTER: V**

SUBJECT NAME: AIRCRAFT SYSTEMS

AUXILIARY SYSTEM

Various types systems, components and operation of air-conditioning System, Pressurization System, Oxygen Systems, Fire Protection Systems, De-icing and Anti icing systems.
Seat Safety System: Ejection seats, survival packs, parachutes, pilot's personal equipment, life rafts, doors, windows, emergency exits and seat belts.

Aircraft Oxygen Systems

The negative effects of reduced atmospheric pressure at flight altitudes, forcing less oxygen into the blood, can be overcome. There are two ways this is commonly done: increase the pressure of the oxygen or increase the quantity of oxygen in the air mixture. Large transport-category and high performance passenger aircraft pressurize the air in the cabin. This serves to push more of the normal 21 percent oxygen found in the air into the blood for saturation. Techniques for pressurization are discussed later in this chapter. When utilized, the percentage of oxygen available for breathing remains the same; only the pressure is increased. By increasing the quantity of oxygen available in the lungs, less pressure is required to saturate the blood. This is the basic function of an aircraft oxygen system. Increasing the level of oxygen above the 21 percent found in the atmosphere can offset the reduced pressure encountered as altitude increases.

Oxygen may be regulated into the air that is breathed so as to maintain a sufficient amount for blood saturation. Normal mental and physical activity can be maintained at indicated altitudes of up to about 40,000 feet with the sole use of supplemental oxygen. Oxygen systems that increase the quantity of oxygen in breathing air are most commonly used as primary systems in small and medium size aircraft designed without cabin pressurization. Pressurized aircraft utilize oxygen systems as a means of redundancy should pressurization fail. Portable oxygen equipment may also be aboard for first aid purposes.

Forms of Oxygen

- Gaseous Oxygen
- Liquid Oxygen
- Chemical or Solid Oxygen

Onboard Oxygen Generating Systems (OBOGS)

The molecular sieve method of separating oxygen from the other gases in air has application in flight, as well as on the ground. The sieves are relatively light in weight and relieve the aviator of a need for ground support for the oxygen supply. Onboard oxygen generating systems on military aircraft pass bleed air from turbine engines through a sieve that separates the oxygen for breathing use. Some of the separated oxygen is also used to purge the sieve of the nitrogen and other gases that keep it fresh for use. Use of this type of oxygen production in civilian aircraft is anticipated. *[Figure 16-8]*

Oxygen Systems and Components

Built-in and portable oxygen systems are used in civilian aviation. They use gaseous or solid oxygen (oxygen generators) as suits the purpose and aircraft. LOX systems and molecular sieve oxygen systems are not discussed, as current applications on civilian aircraft are limited.

Gaseous Oxygen Systems

The use of gaseous oxygen in aviation is common; however, applications vary. On a light aircraft, it may consist of a small carry-on portable cylinder with a single mask attached via a hose to a regulator on the bottle. Larger portable cylinders may be fitted with a regulator that divides the outlet flow for 2–4 people. Built-in oxygen systems on high performance and light twin-engine aircraft typically have a location where oxygen cylinders are installed to feed a distribution system via tubing and a regulator. The passenger compartment may have multiple breathing stations plumbed so that each passenger can individually plug in a hose and mask if oxygen is needed. A central regulator is normally controlled by the flight crew who may have their own separate regulator and oxygen cylinder. Transport category aircraft may use an elaborate built-in gaseous oxygen system as a backup system to cabin pressurization. In all of these cases, oxygen is stored as a gas at atmospheric temperature in high-pressure cylinders. It is distributed through a system with various components that are described in this section.

Oxygen Storage Cylinders

Gaseous oxygen is stored and transported in high-pressure cylinders. Traditionally, these have been heavy steel tanks rated for 1800–1850 psi of pressure and capable of maintaining pressure up to 2,400 psi. While these performed adequately, lighter weight tanks were sought. Some newer cylinders are comprised of a lightweight aluminum shell wrapped by Kevlar®. These cylinders are capable of carrying the same amount of oxygen at the same pressure as steel tanks, but weigh much less. Also available are heavy-walled all-aluminum cylinders. These units are common as carry-on portable oxygen used in light aircraft.

Most oxygen storage cylinders are painted green, but yellow and other colours may be used as well. They are certified to Department of Transportation (DOT) specifications. To ensure serviceability, cylinders must be hydrostatically tested periodically. In general, a hydrostatic test consists of filling the container with water and pressurizing it to 5⁄3 of its certified rating. It should not leak, rupture, or deform beyond an established limit.

Oxygen Systems and Regulators

The design of the various oxygen systems used in aircraft depends largely on the type of aircraft, its operational requirements, and whether the aircraft has a pressurization system. Systems are often characterized by the type of regulator used to dispense the oxygen: continuous-flow and demand flow. In some aircraft, a continuous-flow oxygen system is installed for both passengers and crew. The pressure demand system is widely used as a crew system, especially on the larger transport aircraft. Many aircraft have a combination of both systems that may be augmented by portable equipment.

Continuous-Flow Systems

In its simplest form, a continuous-flow oxygen system allows oxygen to exit the storage tank through a valve and passes it through a regulator/reducer attached to the top of the tank. The flow of high-pressure oxygen passes through a section of the regulator that reduces the pressure of the oxygen, which is then fed into a hose attached to a mask worn by the user. Once the valve is opened, the flow of oxygen is continuous. Even when the user is exhaling, or when the mask is not in use, a preset flow of oxygen continues until the tank valve is closed. On some systems, fine adjustment to the flow can be made with an adjustable flow indicator that is installed in the hose in line to the mask. A portable oxygen setup for a light aircraft exemplifies this type of continuous-flow system.

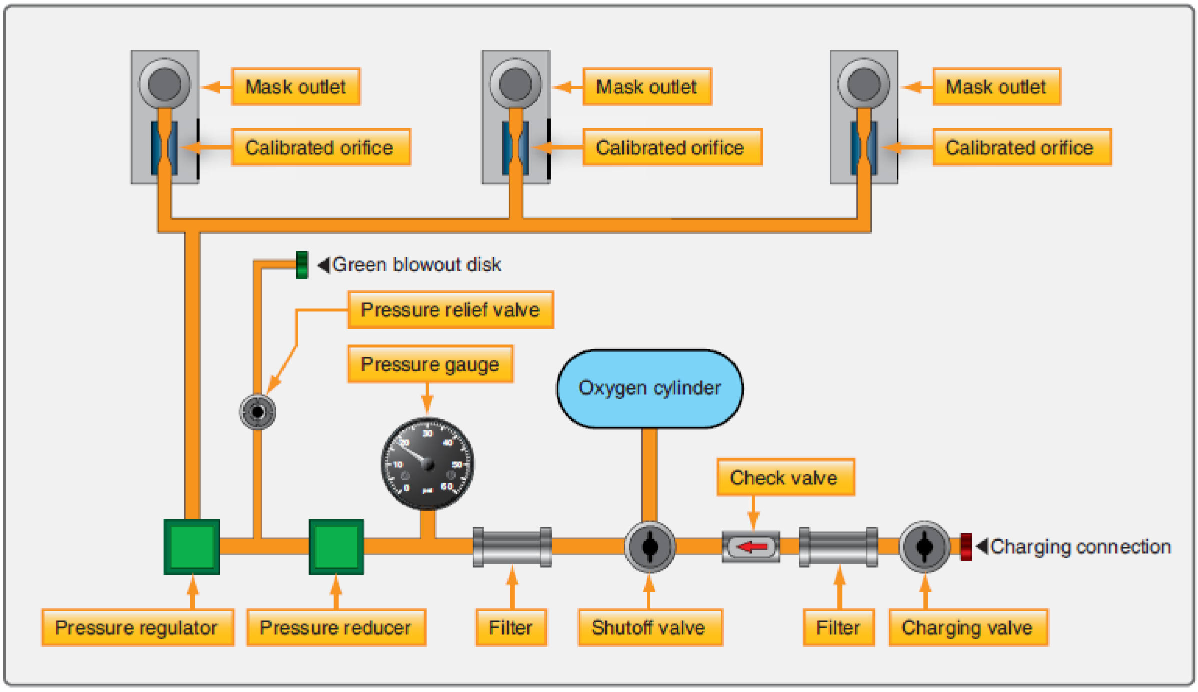
A more sophisticated continuous-flow oxygen system uses a regulator that is adjustable to provide varying amounts of oxygen flow to match increasing need as altitude increases.

These regulators can be manual or automatic in design. Manual continuous-flow regulators are adjusted by the crew as altitude changes. Automatic continuous-flow regulators have a built in aneroid. As the aneroid expands with altitude, a mechanism allows more oxygen to flow though the regulator to the users.

A manual continuous flow oxygen system may have a regulator that is adjusted by the pilot as altitude varies. By turning the knob, the left gauge can be made to match the flight altitude thus increasing and decreasing flow as altitude changes.

Many continuous-flow systems include a fixed location for the oxygen cylinders with permanent delivery plumbing installed to all passenger and crew stations in the cabin.

In large aircraft, separate storage cylinders for crew and passengers are typical. Fully integrated oxygen systems usually have separate, remotely mounted components to reduce pressure and regulate flow. A pressure relief valve is also typically installed in the system, as is some sort of filter and a gauge to indicate the amount of oxygen pressure remaining in the storage cylinder(s). Figure below diagrams the type of continuous-flow system that is found on small to medium sized aircraft.

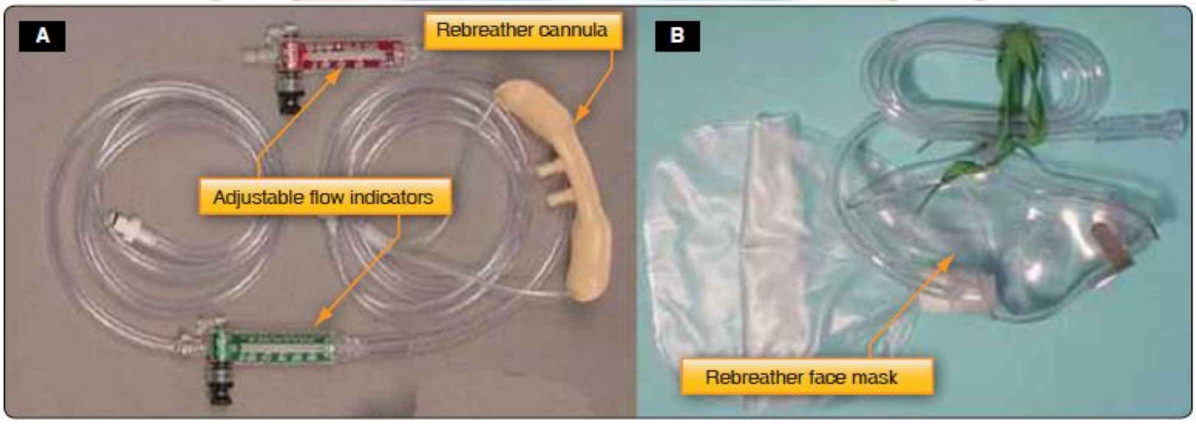


Continuous flow oxygen system found on small to medium size aircraft.

Built-in continuous-flow gaseous oxygen systems accomplish a final flow rate to individual user stations through the use of a calibrated orifice in each mask. Larger diameter orifices are usually used in crew masks to provide greater flow than that for passengers. Special oxygen masks provide even greater flow via larger orifices for passengers travelling with medical conditions requiring full saturation of the blood with oxygen.

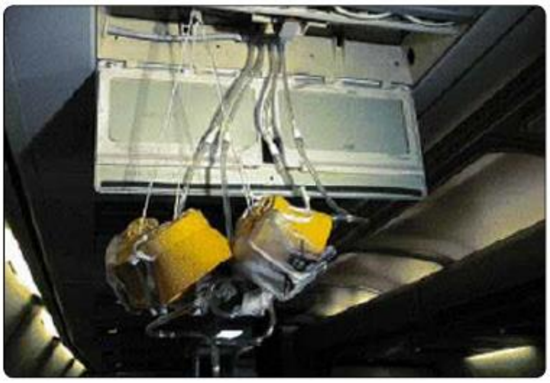
Allowing oxygen to continuously flow from the storage cylinder can be wasteful. Lowest sufficient flow rates can be accomplished through the use of rebreather apparatus.

Oxygen and air that is exhaled still contains usable oxygen. By capturing this oxygen in a bag, or in a cannula with oxygen absorbing reservoirs, it can be inhaled with the next breath, reducing waste.



A rebreather cannula (A) and rebreather bag (B) capture exhaled oxygen to be inhaled on the next breath. This conserves oxygen by permitting lower flow rates in continuous flow systems. The red and green devices are optional flow indicators that allow the user to monitor oxygen flow rate. The type shown also contains needle valves for final regulation of the flow rate to each user.

The passenger section of a continuous-flow oxygen system may consist of a series of plug-in supply sockets fitted to the cabin walls adjacent to the passenger seats to which oxygen masks can be connected. Flow is inhibited until a passenger manually plugs in. When used as an emergency system in pressurized aircraft, depressurization automatically triggers the deployment of oxygen ready continuous-flow masks at each passenger station. A lanyard attached to the mask turns on the flow to each mask when it is pulled toward the passenger for use.



A passenger service unit (psu) is hinged over each row of seats in an airliner. Four yellow continuous flow oxygen masks are shown deployed. They are normally stored behind a separate hinged panel that opens to allow the masks to fall from the PSU for use.

The masks are normally stowed overhead in the passenger service unit (PSU). *[Figure 16-15]* Deployment of the emergency continuous-flow passenger oxygen masks may also be controlled by the crew.

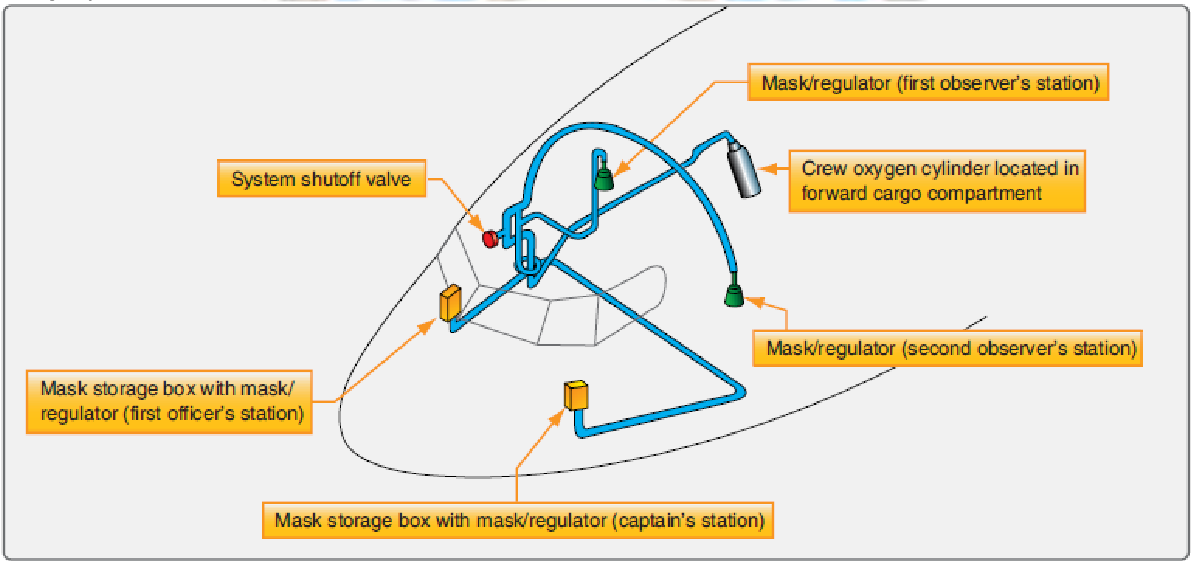
The crew can deploy passenger emergency continuous flow oxygen masks and supply with a switch in the cockpit.

Continuous-flow oxygen masks are simple devices made to direct flow to the nose and mouth of the wearer. They fit snugly but are not air tight. Vent holes allow cabin air to mix with the oxygen and provide escape for exhalation. In a rebreather mask, the vents allow the exhaled mixture that is not trapped in the rebreather bag to escape. This is appropriate, because this is the air-oxygen mixture that has been in the lungs the longest, so it has less recoverable oxygen to be breathed again.

Examples of different continuous-flow oxygen masks.

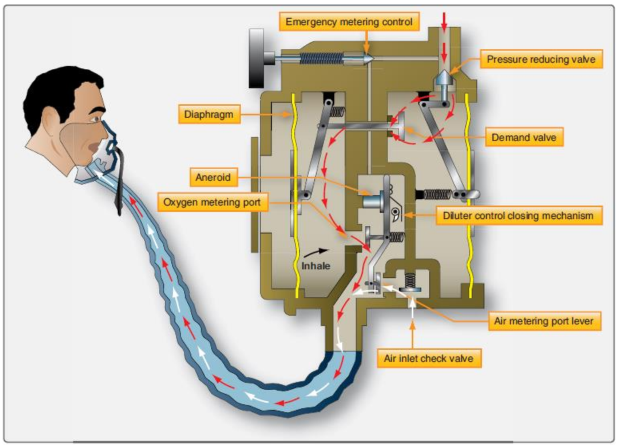
Demand-Flow Systems

When oxygen is delivered only as the user inhales, or on demand, it is known as a demand-flow system. During the hold and exhalation periods of breathing, the oxygen supply is stopped. Thus, the duration of the oxygen supply is prolonged as none is wasted. Demand-flow systems are used most frequently by the crew on high performance and air transport category aircraft.



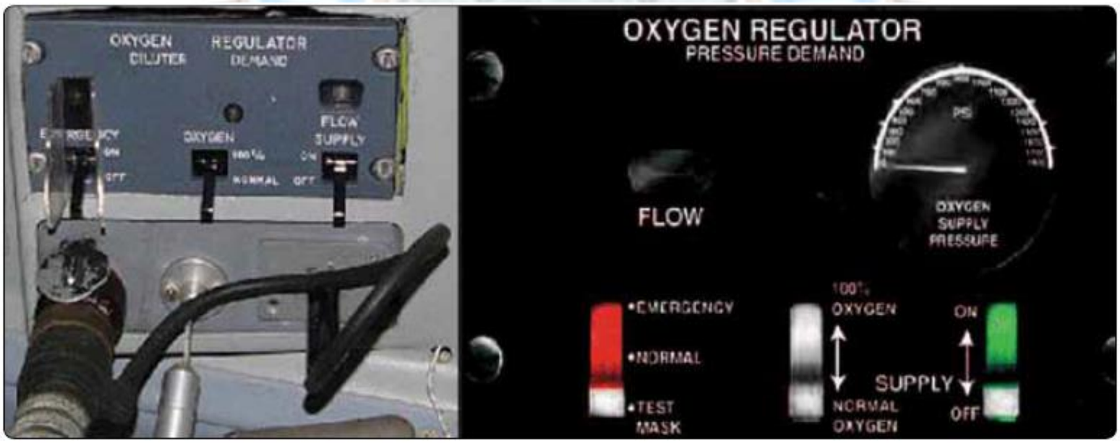
Location of demand-flow oxygen components on a transport category aircraft.

Demand-flow systems are similar to continuous-flow systems in that a cylinder delivers oxygen through a valve when opened. The tank pressure gauge, filter(s), pressure relief valve, and any plumbing installed to refill the cylinder while installed on the aircraft are all similar to those in a continuous flow system. The high-pressure oxygen also passes through a pressure reducer and a regulator to adjust the pressure and flow to the user. But, demand-flow oxygen regulators differ significantly from continuous-flow oxygen regulators. They work in conjunction with close-fitting demand-type masks to control the flow of oxygen. *[Figure 16-19]*



A demand regulator and demand-type mask work together to control flow and conserve oxygen. Demand-flow masks are close fitting so that when the user inhales, low pressure is created in the regulator, which allows oxygen to flow. Exhaled air escapes through ports in the mask, and the regulator ceases the flow of oxygen until the next inhalation.

In a demand-flow oxygen system, the system pressure reducing valve is sometimes called a pressure regulator. This device lowers the oxygen pressure from the storage cylinder(s) to roughly 60–85 psi and delivers it to individual regulators dedicated for each user. A pressure reduction also occurs at the inlet of the individual regulator by limiting the size of the inlet orifice. There are two types of individual regulators: the diluter-demand type and the pressure-demand type. *[Figure below]*



The two basic types of regulators used in demand flow oxygen systems. The panel below the diluter demand regulator on the left is available for mask hose plug in (left), lanyard mask hanger (center), and microphone plug in (right). Most high performance demand type masks have a microphone built-in.

The diluter-demand type regulator holds back the flow of oxygen until the user inhales with a demand-type oxygen mask. The regulator dilutes the pure oxygen supply with cabin air each time a breath is drawn. With its control toggle switch set to normal, the amount of dilution depends on the cabin altitude. As altitude increases, an aneroid allows more oxygen and less cabin air to be delivered to the user by adjusting flows through a metering valve. At approximately 34,000 feet, the diluter-demand regulator meters 100 percent oxygen.
This should not be needed unless cabin pressurization fails. Additionally, the user may select 100 percent oxygen delivery at any time by positioning the oxygen selection lever on the

regulator. A built-in emergency switch also delivers 100 percent oxygen, but in a continuous flow as the demand function is bypassed. *[Figure below]*

Pressure-demand oxygen systems operate similarly to diluter demand systems, except that oxygen is delivered through the individual pressure regulator(s) under higher pressure. When the demand valve is unseated, oxygen under pressure forces its way into the lungs of the user. The demand function still operates, extending the overall supply of oxygen beyond that of a continuous-flow system. Dilution with cabin air also occurs if cabin altitude is less than 34,000 feet.

Pressure-demand regulators are used on aircraft that regularly fly at 40,000 feet and above. They are also found on many airliners and high-performance aircraft that may not typically fly that high. Forcing oxygen into the lungs under pressure ensures saturation of the blood, regardless of altitude or cabin altitude. Both diluter-demand and pressure-demand regulators also come in mask-mounted versions. The operation is essentially the same as that of panel-mounted regulators. *[Figure below]*

A mask-mounted version of a miniature diluter-demand regulator designed for use in general aviation (left), a mechanical quick-donning diluter-demand mask with the regulator on the mask (center), and an inflatable quick-donning mask (right). Squeezing the red grips directs oxygen into the hollow straps.

Flow Indicators

Flow indicators, or flow meters, are common in all oxygen systems. They usually consist of a lightweight object, or apparatus, that is moved by the oxygen stream. When flow exists, this movement signals the user in some way. Many flow meters in continuous-flow oxygen systems also double as flow rate adjusters. Needle valves fitted into the flow indicator housing can fine-adjust the oxygen delivery rate. Demand-flow oxygen systems usually have flow indicators built into the individual regulators at each user station. Some contain a blinking device that activates when the user inhales and oxygen is delivered. Others move a colored pith object into a window. Regardless, flow indicators provide a quick verification that an oxygen system is functioning.

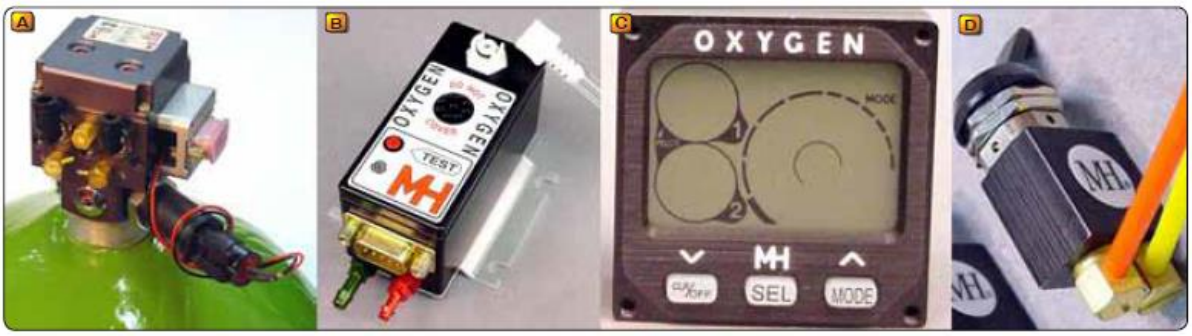
Different flow indicators are used to provide verification that the oxygen system is functioning. Other demand-flow indicators are built into the oxygen regulators. *[Figure below]*

Different flow indicators are used to provide verification that the oxygen system is functioning: continuous-flow, in-line (left); continuous-flow, in-line with valve adjuster (center); and old style demand flow (right).

A recent development in general aviation oxygen systems is the electronic pulse demand oxygen delivery system (EDS). A small, portable EDS unit is made to connect between the oxygen source and the mask in a continuous-flow oxygen system. It delivers timed pulses of oxygen to the wearer on demand, saving oxygen normally lost during the hold and exhale segments of the breathing cycle. Advanced pressure sensing and processing allows the unit to deliver oxygen only when an inhalation starts. It can also sense differences in users' breathing cycles and physiologies and adjust the flow of oxygen accordingly. A built-in pressure-sensing device adjusts the amount of oxygen released as altitude changes.
[Figure below]

A portable two-person electronic pulse-demand (EPD) oxygen regulating unit.

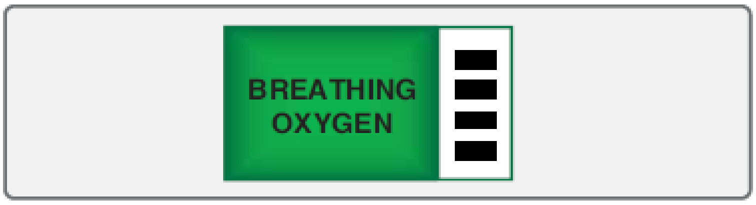
Permanently mounted EPD systems are also available. They typically integrate with an electronic valve/regulator on the oxygen cylinder and come with an emergency bypass switch to provide continuous-flow oxygen should the system malfunction. A liquid crystal display (LCD) monitor/control panel displays numerous system operating parameters and allows adjustments to the automatic settings. This type of electronic metering of oxygen has also been developed for passenger emergency oxygen use in airliners.



The key components of a built-in electronic pulse demand oxygen metering system: (A) electronic regulator, (B) oxygen station distributer unit, (C) command/display unit, (D) emergency bypass switch.

Oxygen Plumbing and Valves

Tubing and fittings make up most of the oxygen system plumbing and connect the various components. Most lines are metal in permanent installations. High-pressure lines are usually stainless steel. Tubing in the low-pressure parts of the oxygen system is typically aluminum. Flexible plastic hosing is used deliver oxygen to the masks; its use is increasing in permanent installations to save weight. Installed oxygen tubing is usually identified with colour coded tape applied to each end of the tubing, and at specified intervals along its length. The tape coding consists of a green band overprinted with the words “BREATHING OXYGEN” and a black rectangular symbol overprinted on a white background border strip.



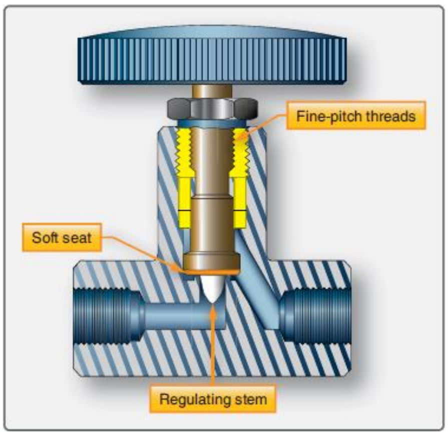
Colour-coded tape used to identify oxygen tubing.

Tubing-to-tubing fittings in oxygen systems are often designed with straight threads to receive flared tube connections. Tubing-to-component fittings usually have straight threads on the tubing end and external pipe threads (tapered) on the other end for attachment to the component.

The fittings are typically made of the same material as the tubing (i.e., aluminum or steel). Flared and flareless fittings are both used, depending on the system. Five types of valves are commonly found in high-pressure gaseous oxygen systems: filler, check, shutoff, pressure reducer, and pressure relief. They function as they would in any other system with one exception: oxygen system shutoff valves are specifically designed to open slowly.

The ignition point for any substances is lower in pure oxygen than it is in air. When high-pressure oxygen is allowed to rush into a low-pressure area, its velocity could reach the speed of sound. If it encounters an obstruction (a valve seat, an elbow, a piece of contaminant, etc.), the oxygen compresses. With this compression, known as adiabatic compression (since it builds so quickly no heat is lost to its surroundings), comes high temperature. Under pressure, this high temperature exceeds the ignition point of the material the oxygen encounters and a fire or explosion results. A stainless steel line, for example, would not normally burn and is used for carrying numerous fluids under high pressure. But under high pressure and temperature in the presence of 100 percent oxygen, even stainless steel can ignite.

To combat this issue, all oxygen shutoff valves are slow, opening valves designed to decrease velocity.



This high-pressure oxygen system shutoff valve has fine-pitch threads and a regulating stem to slow the flow of oxygen through the valve. A soft valve seat is also included to assure the valve closes completely.

Additionally, technicians should always open all oxygen valves slowly. Keeping oxygen from rushing into a low pressure area should be a major concern when working with high-pressure gaseous oxygen systems.

Oxygen cylinder valves and high-pressure systems are often provided with a relief valve should the desired pressure be exceeded. Often, the valve is ported to an indicating or blowout disk. This is located in a conspicuous place, such as the fuselage skin, where it can be seen during walk-around inspection. Most blowout disks are green. The absence of the green disk indicates the relief valve has opened, and the cause should be investigated before flight.

An oxygen blowout plug on the side of the fuselage indicates when pressure relief has occurred and should be investigated.

Chemical Oxygen Systems

The two primary types of chemical oxygen systems are the portable type, much like a portable carry-on gaseous oxygen cylinder, and the fully integrated supplementary oxygen system used as backup on pressurized aircraft in case of pressurization failure. This latter use of solid chemical oxygen generators is most common on airliners. The generators are stored in the overhead PSU attached to hoses and masks for every passenger on board the aircraft. When a depressurization occurs, or the flight crew activates a switch, a compartment door opens and the masks and hoses fall out in front of the passengers. The action of pulling the mask down to a usable position actuates an electric current, or ignition hammer, that ignites the oxygen candle and initiates the flow of oxygen. Typically, 10 to 20 minutes of oxygen is available for each user. This is calculated to be enough time for the aircraft to descend to a safe altitude for unassisted breathing.

An oxygen generator mounted in place in an overhead passenger service unit of an air transport category aircraft.

Chemical oxygen systems are unique in that they do not produce the oxygen until it is time to be used. This allows safer transportation of the oxygen supply with less maintenance. Chemical oxygen-generating systems also require less space and weigh less than gaseous oxygen systems supplying the same number of people. Long runs of tubing, fittings, regulators, and other components are avoided, as are heavy gaseous oxygen storage cylinders. Each passenger row grouping has its own fully independent chemical oxygen generator. The generators, which often weigh less than a pound, are insulated and can burn completely without getting hot. The size of the orifice opening in the hose-attach nipples regulates the continuous flow of oxygen to the users.

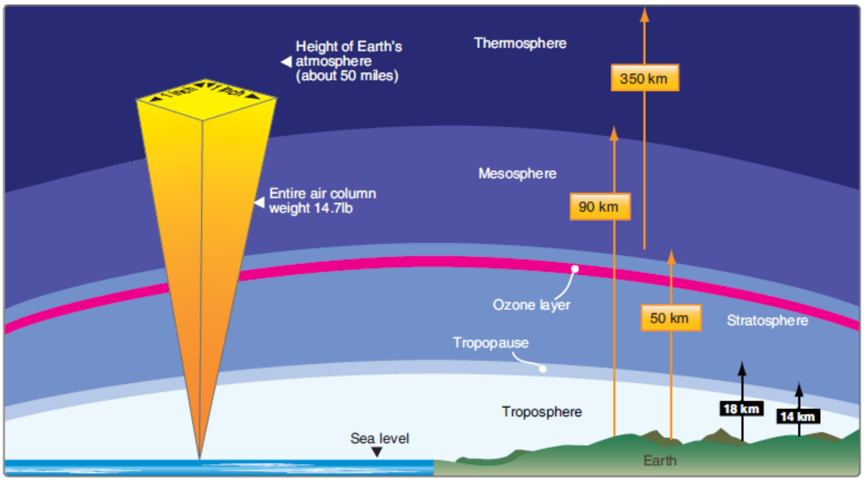
LOX Systems

LOX systems are rarely used in civilian aviation. They may be encountered on former military aircraft now in the civilian fleet. As mentioned, the storage of LOX requires a special container system. The plumbing arrangement to convert the liquid to a usable gas is also unique. It basically consists of a controlled heat exchange assembly of tubing and valves. Overboard pressure relief is provided for excessive temperature situations. Once gaseous, the LOX system is the same as it is in any comparable gaseous oxygen delivery system. Use of pressure-demand regulators and masks is common. Consult the manufacturer's maintenance manual for further information if a LOX system is encountered.

AIRCRAFT PRESSURIZATION SYSTEMS

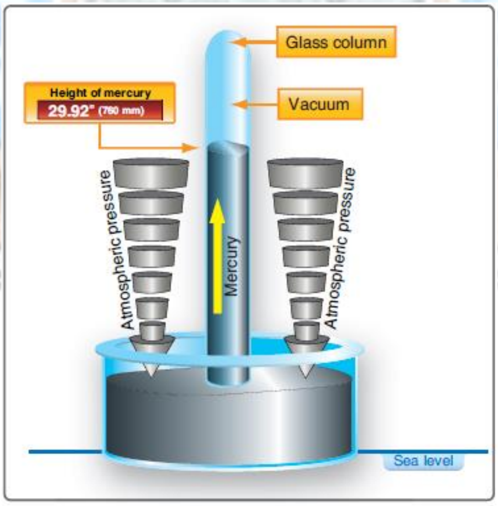
Pressure of the Atmosphere

The gases of the atmosphere (air), although invisible, have weight. A one square inch column of air stretching from sea level into space weighs 14.7 pounds. Therefore, it can be stated that the pressure of the atmosphere, or atmospheric pressure, at sea level is 14.7 psi.



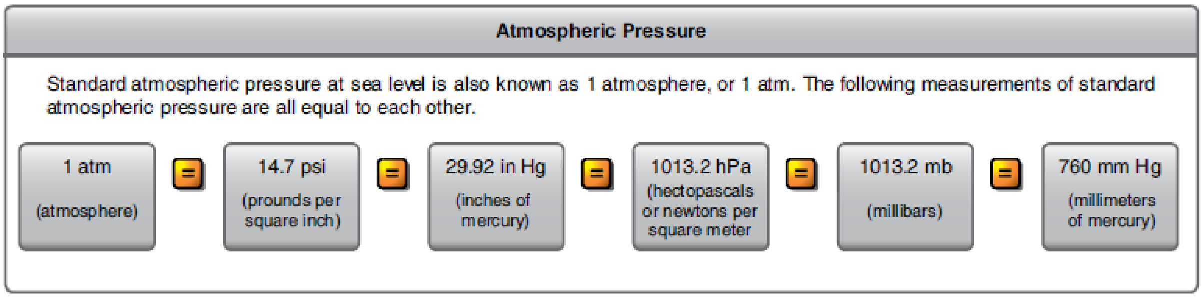
The weight exerted by a 1 square inch column of air stretching from sea level to the top of the atmosphere is what is measured when it is said that atmospheric pressure is equal to 14.7 pounds per square inch.

Atmospheric pressure is also known as barometric pressure and is measured with a barometer. *[Figure below]* Expressed in various ways, such as in inches of mercury or millimetres of mercury, these measurements come from observing the height of mercury in a column when air pressure is exerted on a reservoir of mercury into which the column is set. The column must be evacuated so air inside does not act against the mercury rising. A column of mercury 29.92 inches high weighs the same as a column of air that extends from sea level to the top of the atmosphere and has the same cross-section as the column of mercury.



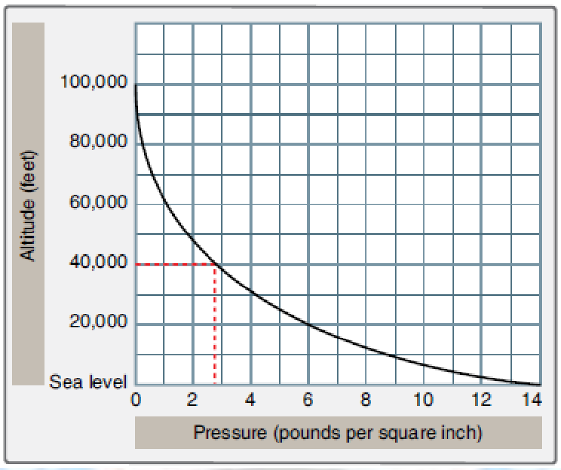
The weight of the atmosphere pushes down on the mercury in the reservoir of a barometer, which causes mercury to rise in the column. At sea level, mercury is forced up into the column approximately 29.92 inches. Therefore, it is said that barometric pressure is 29.92 inches of mercury at sea level.

Aviators often interchange references to atmospheric pressure between linear displacement (e.g., inches of mercury) and units of force (e.g., psi). Over the years, meteorology has shifted its use of linear displacement representation of atmospheric pressure to units of force. However, the unit of force nearly universally used today to represent atmospheric pressure in meteorology is the hectopascal (hPa). A hectopascal is a metric (SI) unit that expresses force in newtons per square meter. 1,013.2 hPa is equal to 14.7 psi.



Various equivalent representations of atmospheric pressure at sea level.

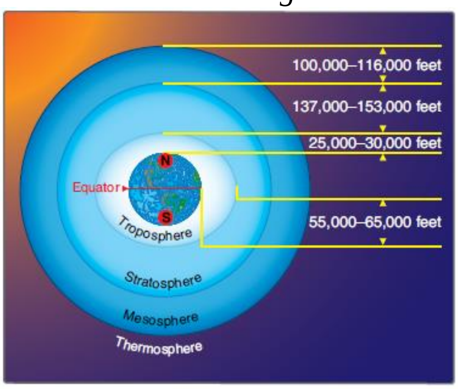
Atmospheric pressure decreases with increasing altitude. The simplest explanation for this is that the column of air that is weighed is shorter. How the pressure changes for a given altitude is shown in *Figure below*. The decrease in pressure is a rapid one and, at 50,000 feet, the atmospheric pressure has dropped to almost one-tenth of the sea level value.



Atmospheric pressure decreasing with altitude. At sea level the pressure is 14.7 psi, while at 40,000 feet, as the dotted lines show, the pressure is only 2.72 psi.

Temperature and Altitude

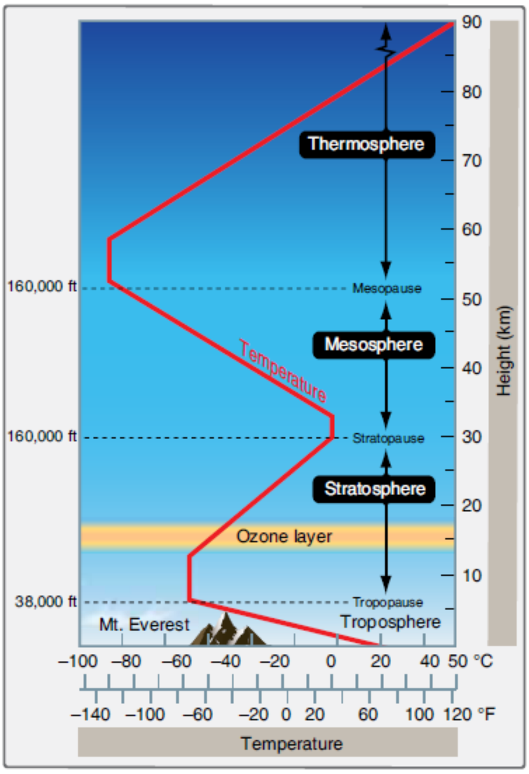
Temperature variations in the atmosphere are of concern to aviators. Weather systems produce changes in temperature near the earth's surface. Temperature also changes as altitude is increased. The troposphere is the lowest layer of the atmosphere. On average, it ranges from the earth's surface to about 38,000 feet above it. Over the poles, the troposphere extends to only 25,000–30,000 feet and, at the equator; it may extend to around 60,000 feet. This oblong nature of the troposphere is illustrated in *Figure below*.



The troposphere extends higher above the earth's surface at the equator than it does at the poles.

Most civilian aviation takes place in the troposphere in which temperature decreases as altitude increases. The rate of change is somewhat constant at about –2 °C or –3.5 °F for every 1,000 feet of increase in altitude. The upper boundary of the troposphere is the tropopause. It is characterized as a zone of relatively constant temperature of –57 °C or –69 °F.

Above the tropopause lies the stratosphere. Temperature increases with altitude in the stratosphere to near 0 °C before decreasing again in the mesosphere, which lies above it. The stratosphere contains the ozone layer that protects the earth's inhabitants from harmful UV rays. Some civilian flights and numerous military flights occur in the stratosphere.



The atmospheric layers with temperature changes depicted by the red line.

When an aircraft is flown at high altitude, it burns less fuel for a given airspeed than it does for the same speed at a lower altitude. This is due to decreased drag that results from the reduction in air density. Bad weather and turbulence can also be avoided by flying in the relatively smooth air above storms and convective activity that occur in the lower troposphere.

To take advantage of these efficiencies, aircraft are equipped with environmental systems to overcome extreme temperature and pressure levels. While supplemental oxygen and a means of staying warm suffice, aircraft pressurization and air conditioning systems have been developed to make high altitude flight more comfortable. *Figure 16-40* illustrates the temperatures and pressures at various altitudes in the atmosphere.

Altitude	Pressure			Temperature	
feet	psi	hPa	in Hg	°F	°C
0	14.69	1013.2	29.92	59.0	15
1,000	14.18	977.2	28.86	55.4	13
2,000	13.66	942.1	27.82	51.9	11
3,000	13.17	908.1	26.82	48.3	9.1
4,000	12.69	875.1	25.84	44.7	7.1
5,000	12.23	843.1	24.90	41.2	5.1
6,000	11.77	812.0	23.98	37.6	3.1
7,000	11.34	781.8	23.09	34.0	1.1
8,000	10.92	752.6	22.23	30.5	−0.8
9,000	10.51	724.3	21.39	26.9	−2.8
10,000	10.10	696.8	20.58	23.3	−4.8
12,000	9.34	644.4	19.03	16.2	−8.8
14,000	8.63	595.2	17.58	9.1	−12.7
16,000	7.96	549.2	16.22	1.9	−16.7
18,000	7.34	506.0	14.94	−5.2	−29.7
20,000	6.76	465.6	13.75	−12.3	−24.6
22,000	6.21	427.9	12.64	−19.5	−28.6
24,000	5.70	392.7	11.60	−26.6	−32.5
26,000	5.22	359.9	10.63	−33.7	−36.5
28,000	4.78	329.3	9.72	−40.9	−40.5
30,000	4.37	300.9	8.89	−48.0	−44.4
32,000	3.99	274.5	8.11	−55.1	−48.4
34,000	3.63	250.0	7.38	−62.2	−52.4
36,000	3.30	227.3	6.71	−69.4	−56.3
38,000	3.00	206.5	6.10	−69.4	−56.5
40,000	2.73	187.5	5.54	−69.4	−56.5
45,000	2.14	147.5	4.35	−69.4	−56.5
50,000	1.70	116.0	3.42	−69.4	−56.5

Cabin environmental systems establish conditions quite different from these found outside the aircraft.

Pressurization Terms

The following terms should be understood for the discussion of pressurization and cabin environmental systems that follows:

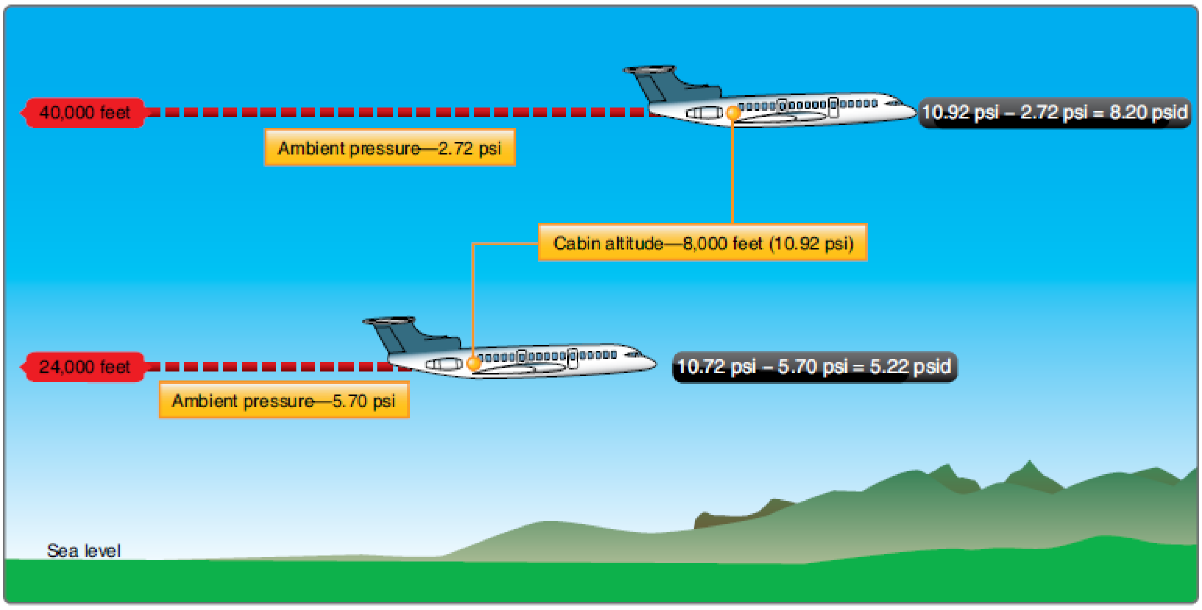
1. Cabin altitude—given the air pressure inside the cabin, the altitude on a standard day that has the same pressure as that in the cabin. Rather than saying the pressure inside the cabin is 10.92 psi, it can be said that the cabin altitude is 8,000 feet (MSL).
2. Cabin differential pressure—the difference between the air pressure inside the cabin and the air pressure outside the cabin. Cabin pressure (psi) – ambient pressure (psi) = cabin differential pressure (psid or Δ psi).
3. Cabin rate of climb—the rate of change of air pressure inside the cabin, expressed in feet per minute (fpm) of cabin altitude change.

Pressurization Issues

Pressurizing an aircraft cabin assists in making flight possible in the hostile environment of the upper atmosphere. The degree of pressurization and the operating altitude of any aircraft are limited by critical design factors. A cabin pressurization system must accomplish several functions if it is to ensure adequate passenger comfort and safety. It must be capable of maintaining a cabin pressure altitude of approximately 8,000 feet or lower regardless of the cruising altitude of the aircraft. This is to ensure that passengers and crew have enough oxygen present at sufficient pressure to facilitate full blood saturation. A pressurization system must also be designed to prevent rapid changes of cabin pressure, which can be uncomfortable or injurious to passengers and crew. Additionally, a pressurization system should circulate air from inside the cabin to the outside at a rate that quickly eliminates odors and to remove stale air. Cabin air must also be heated or cooled on pressurized aircraft. Typically, these functions are incorporated into the pressurization source.

To pressurize, a portion of the aircraft designed to contain air at a pressure higher than outside atmospheric pressure must be sealed. A wide variety of materials facilitate this.

Compressible seals around doors combine with various other seals, grommets, and sealants to essentially establish an air tight pressure vessel. This usually includes the cabin, flight compartment, and the baggage compartments. Air is then pumped into this area at a constant rate sufficient to raise the pressure slightly above that which is needed. Control is maintained by adjusting the rate at which the air is allowed to flow out of the aircraft. A key factor in pressurization is the ability of the fuselage to withstand the forces associated with the increase in pressure inside the structure versus the ambient pressure outside. This differential pressure can range from 3.5 psi for a single engine reciprocating aircraft, to approximately 9 psi on high performance jet aircraft. *[Figure below]* If the weight of the aircraft structure were of no concern, this would not be a problem. Making an aircraft strong for pressurization, yet also light, has been an engineering challenge met over numerous years beginning in the 1930s. The development of jet aircraft and their ability to exploit low drag flight at higher altitude made the problem even more pronounced. Today, the proliferation of composite materials in aircraft structure continues this engineering challenge.



Differential pressure (psid) is calculated by subtracting the ambient air pressure from the cabin air pressure.

In addition to being strong enough to withstand the pressure differential between the air inside and the air outside the cabin, metal fatigue from repeated pressurization and depressurization weakens the airframe. Some early pressurized aircraft structures failed due to this and resulted in fatal accidents. The FAA's aging aircraft program was instituted to increase inspection scrutiny of older airframes that may show signs of fatigue due to the pressurization cycle.

Aircraft of any size may be pressurized. Weight considerations when making the fuselage strong enough to endure pressurization usually limit pressurization to high performance light aircraft and larger aircraft. A few pressurized single-engine reciprocating aircraft exist, as well as many pressurized single-engine turboprop aircraft.

Sources of Pressurized Air

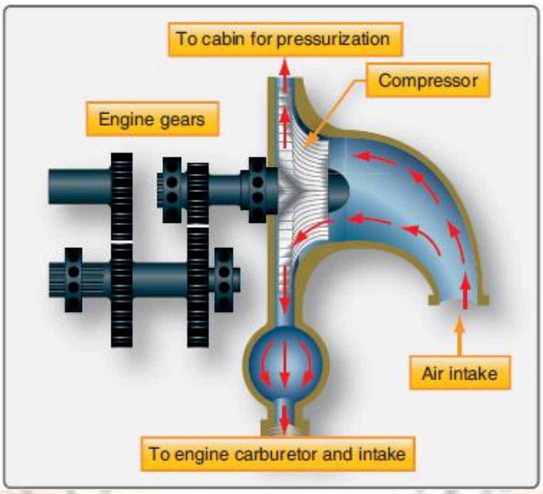
The source of air to pressurize an aircraft varies mainly with engine type. Reciprocating aircraft have pressurization sources different from those of turbine-powered aircraft. Note that the compression of air raises its temperature. A means for keeping pressurization air cool enough is built into most pressurization systems. It may be in the form of a heat exchanger, using cold ambient air to modify the temperature of the air from the pressurization source. A full air cycle air conditioning system with expansion turbine may also be used. The latter provides the advantage of temperature control on the ground and at low altitudes where ambient air temperature may be higher than comfortable for the passengers and crew.

Reciprocating Engine Aircraft

There are three typical sources of air used to pressurize reciprocating aircraft: supercharger, turbocharger, and engine-driven compressor. Superchargers and turbochargers are installed on reciprocating engines to permit better performance at high altitude by increasing the quantity and pressure of the air in the induction system. Some of the air produced by each of these can be routed into the cabin to pressurize it.

A supercharger is mechanically driven by the engine. Despite engine performance increases due to higher induction system pressure, some of the engine output is utilized by the supercharger. Furthermore, superchargers have limited capability to increase engine performance. If supplying both the intake and the cabin with air, the engine performance ceiling is lower than if the aircraft were not pressurized.

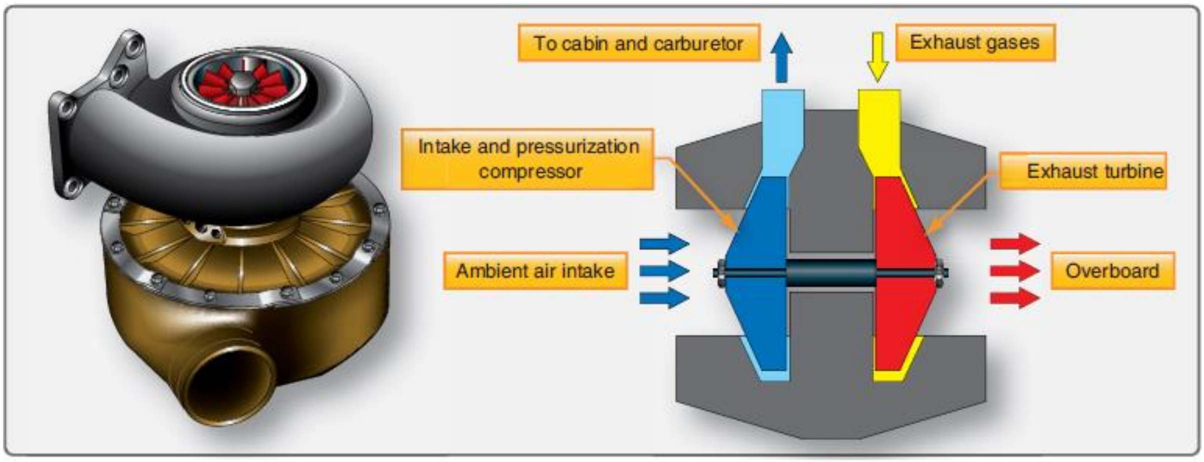
Superchargers must be located upstream of the fuel delivery to be used for pressurization. They are found on older reciprocating engine aircraft, including those with radial engines.



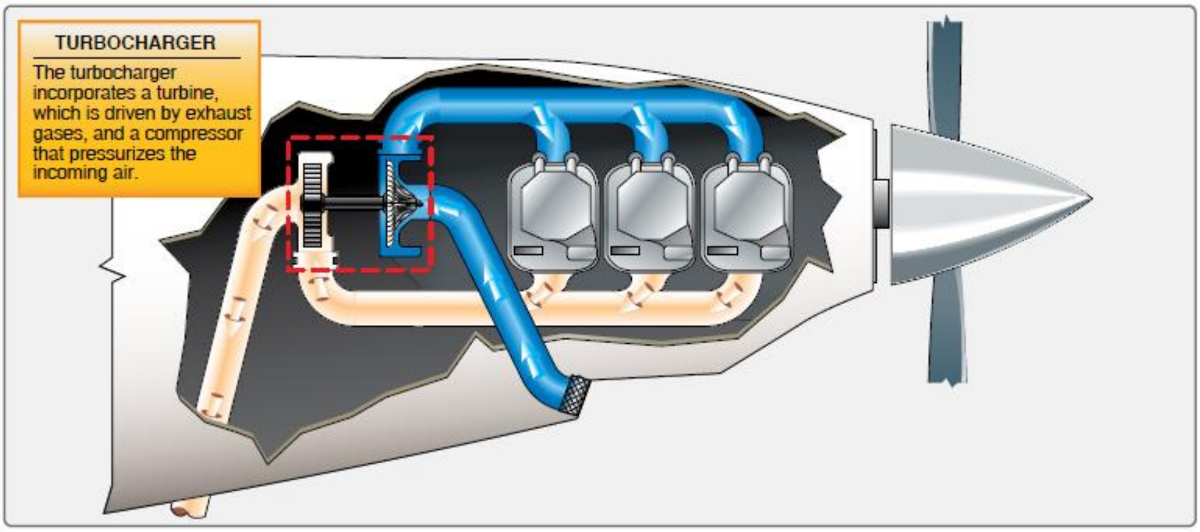
A reciprocating engine supercharger can be used as a source of pressurization if it is upstream of carburetion.

The radial engine supercharger cannot be used since fuel is introduced before the supercharger impeller compresses the air.

Turbochargers, sometimes known as turbo superchargers, are driven by engine exhaust gases. They are the most common source of pressurization on modern reciprocating engine aircraft. The turbocharger impeller shaft extends through the bearing housing to support a compression impeller in a separate housing. By using some of the turbocharger compressed air for cabin pressurization, less is available for the intake charge, resulting in lower overall engine performance. Nonetheless, the otherwise wasted exhaust gases are put to work in the turbocharger compressor, enabling high altitude flight with the benefits of low drag and weather avoidance in relative comfort and without the use of supplemental oxygen. *[Figures below]*



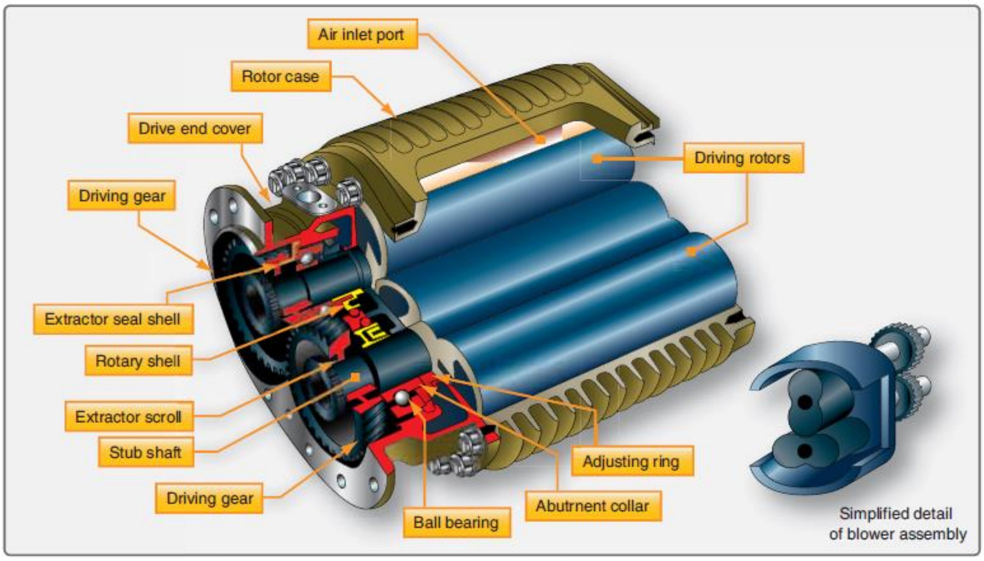
A turbocharger used for pressurizing cabin air and engine intake air on a reciprocating engine aircraft.



A turbocharger installation on a reciprocating aircraft engine (top left side).

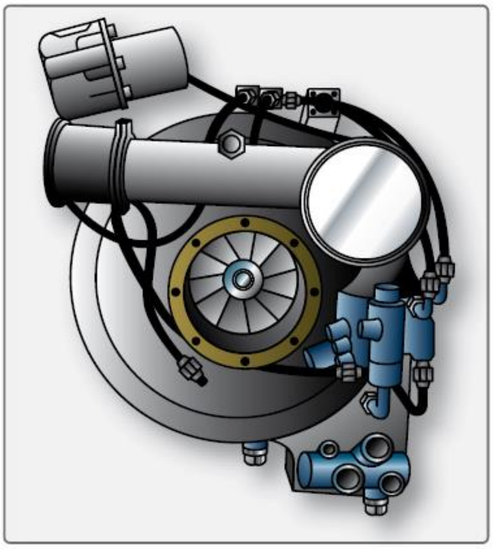
Both superchargers and turbochargers are oil lubricated. The supercharger is part of the fuel intake system and the turbocharger is part of the exhaust system. As such, there is a risk of contamination of cabin air from oil, fuel, or exhaust fumes should a malfunction occur, a shortcoming of these pressurization sources.
A third source of air for pressurizing the cabin in reciprocating aircraft is an engine driven compressor. Either belt driven or gear driven by the accessory drive, an independent, dedicated compressor for pressurization avoids some of the potential contamination issues of superchargers and turbochargers. The compressor device does, however, add significant weight. It also consumes engine output since it is engine driven.

The roots blower is used on older, large reciprocating engine aircraft. *[Figure below]* The two lobes in this compressor do not touch each other or the compressor housing. As they rotate, air enters the space between the lobes and is compressed and delivered to the cabin for pressurization.



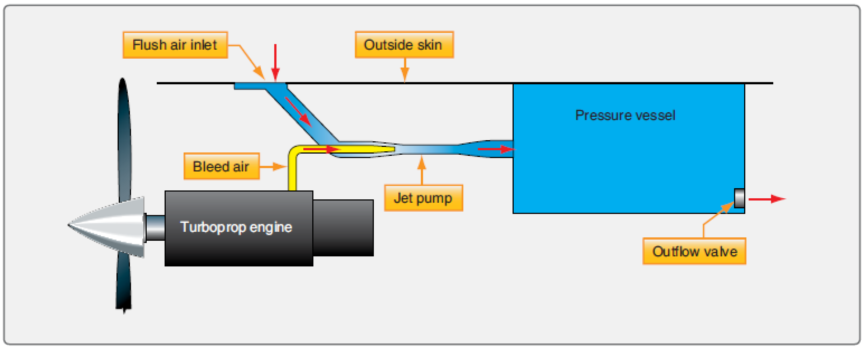
A roots blower found on older pressurized aircraft is gear driven by the engine. It pressurizes air as the rotors rotate very close to each other without touching.

Independent engine-driven centrifugal compressors can also be found on reciprocating engine aircraft. *[Figure below]* A variable ratio gear drive system is used to maintain a constant rate of airflow during changes of engine rpm.



A centrifugal cabin supercharger.

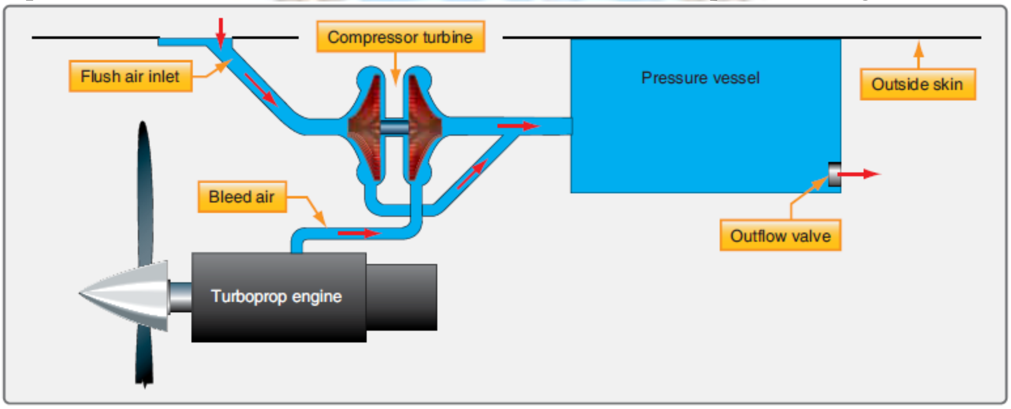
venturi by the bleed air flow, air is drawn in from outside the aircraft. It mixes with the bleed air and is delivered to the pressure vessel to pressurize it. An advantage of this type of pressurization is the lack of moving parts. *[Figure below]* A disadvantage is only a relatively small volume of space can be pressurized in this manner.



A jet pump flow multiplier ejects bleed air into a venturi which draws air for pressurization from outside the aircraft.

Another method of pressurizing an aircraft using turbine engine compressor bleed air is to have the bleed air drive a separate compressor that has an ambient air intake. A turbine turned by bleed air rotates a compressor impellor mounted on the same shaft. Outside air is drawn in and compressed.

It is mixed with the bleed air outflow from the turbine and is sent to the pressure vessel. Turboprop aircraft often use this device, known as a turbo compressor. *[Figure below]*



A turbo compressor used to pressurize cabins mostly in turboprop aircraft.

The most common method of pressurizing turbine-powered aircraft is with an air cycle air conditioning and pressurization system. Bleed air is used, and through an elaborate system including heat exchangers, a compressor, and an expansion turbine, cabin pressurization and the temperature of the pressurizing air are precisely controlled. This air cycle system is discussed in greater detail in the air conditioning section of this chapter. *[Figure below]*

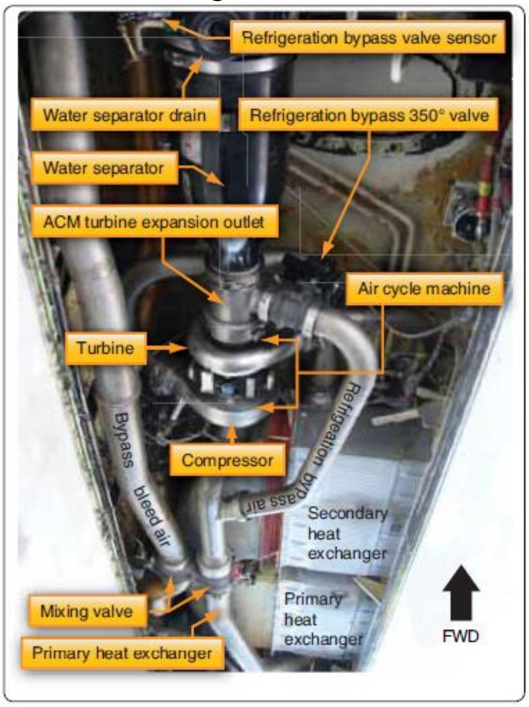
An air cycle air conditioning system used to pressurize the cabin of a business jet

AIR CONDITIONING SYSTEMS

There are two types of air conditioning systems commonly used on aircraft. Air cycle air conditioning is used on most turbine-powered aircraft. It makes use of engine bleed air or APU pneumatic air during the conditioning process. Vapour-cycle air conditioning systems are often used on reciprocating aircraft. This type system is similar to that found in homes and automobiles. Note that some turbine-powered aircraft also use vapour cycle air conditioning.

Air Cycle Air Conditioning

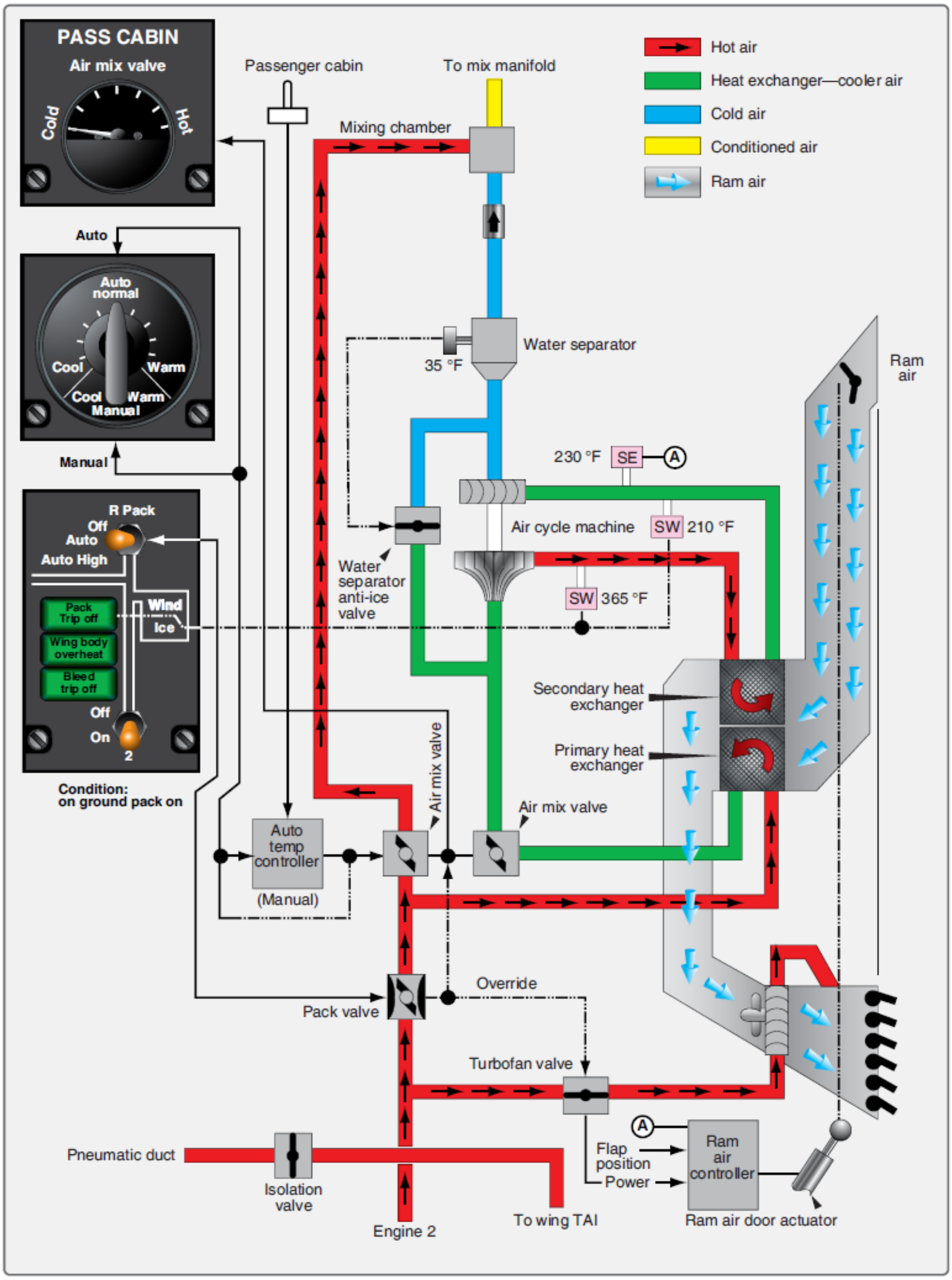
Air cycle air conditioning prepares engine bleed air to pressurize the aircraft cabin. The temperature and quantity of the air must be controlled to maintain a comfortable cabin environment at all altitudes and on the ground. The air cycle system is often called the air conditioning package or pack. It is usually located in the lower half of the fuselage or in the tail section of turbine-powered aircraft. *[Figure below]*



Boeing 737 air cycle system. The photo is taken looking up into the air conditioning bay located in the lower fuselage on each side of the aircraft.

System Operation

Even with the frigid temperatures experienced at high altitudes, bleed air is too hot to be used in the cabin without being cooled. It is let into the air cycle system and routed through a heat exchanger where ram air cools the bleed air.
This cooled bleed air is directed into an air cycle machine. There, it is compressed before flowing through a secondary heat exchange that cools the air again with ram air. The bleed air then flows back into the air cycle machine where it drives an expansion turbine and cools even further. Water is then removed and the air is mixed with bypassed bleed air for final temperature adjustment. It is sent to the cabin through the air distribution system. By examining the operation of each component in the air cycle process, a better understanding can be developed of how bleed air is conditioned for cabin use. Refer to *Figure below*, which diagrams the air cycle air conditioning system of the Boeing 737.



The air cycle air conditioning system on a Boeing 737.

Pneumatic System Supply

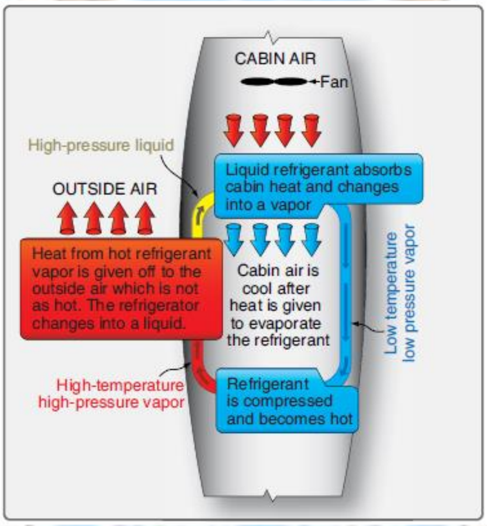
The air cycle air conditioning system is supplied with air by the aircraft pneumatic system. In turn, the pneumatic system is supplied by bleed air tap-offs on each engine compressor section or from the APU pneumatic supply. An external pneumatic air supply source may also be connected while the aircraft is stationary on the ground. In normal flight operations, a pneumatic manifold is supplied by the engine bleed air through the use of valves, regulators, and ducting. The air conditioning packs are supplied by this manifold as are other critical airframe systems, such as the anti-ice and hydraulic pressurization system.

Vapour Cycle Air Conditioning

The absence of a bleed air source on reciprocating engine aircraft makes the use of an air cycle system impractical for conditioning cabin air. Vapour cycle air conditioning is used on most non turbine aircraft that are equipped with air conditioning. However, it is not a source of pressurizing air as the air cycle system conditioned air is on turbine powered aircraft. The vapour cycle system only cools the cabin. If an aircraft equipped with a vapour cycle air conditioning system is pressurized, it uses one of the sources discussed in the pressurization section above. Vapour cycle air conditioning is a closed system used solely for the transfer of heat from inside the cabin to outside of the cabin. It can operate on the ground and in flight.

Theory of Refrigeration

Energy can be neither created nor destroyed; however, it can be transformed and moved. This is what occurs during vapour cycle air conditioning. Heat energy is moved from the cabin air into a liquid refrigerant. Due to the additional energy, the liquid changes into a vapour. The vapour is compressed and becomes very hot. It is removed from the cabin where the very hot vapour refrigerant transfers its heat energy to the outside air. In doing so, the refrigerant cools and condenses back into a liquid. The refrigerant returns to the cabin to repeat the cycle of energy transfer. *[Figure below]*

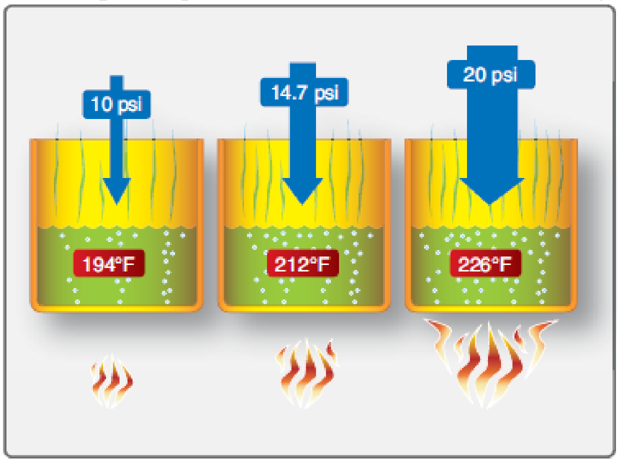


In vapour cycle air conditioning, heat is carried from the cabin to the outside air by a refrigerant which changes from a liquid to a vapour and back again.

Heat is an expression of energy, typically measured by temperature. The higher the temperature of a substance, the more energy it contains. Heat always flows from hot to cold.
These terms express the relative amount of energy present in two substances. They do not measure the absolute amount of heat present. Without a difference in energy levels, there is no transfer of energy (heat).
Adding heat to a substance does not always raise its temperature. When a substance changes state, such as when a liquid changes into a vapour, heat energy is absorbed. This is called latent heat. When a vapour condenses into a liquid, this heat energy is given off. The temperature of a substance remains constant during its change of state. All energy absorbed or given off, the latent heat is used for the change process. Once the change of state is complete, heat added to a substance raises the temperature of the substance. After a substance changes state into a vapour, the rise in temperature of the vapour caused by the addition of still more heat is called superheat.
The temperature at which a substance changes from a liquid into a vapour when heat is added is known as its boiling point. This is the same temperature at which a vapour condenses into a

liquid when heat is removed. The boiling point of any substance varies directly with pressure. When pressure on a liquid is increased, its boiling point increases, and when pressure on a liquid is decreased, its boiling point also decreases. For example, water boils at 212 °F at normal atmospheric temperature (14.7 psi). When pressure on liquid water is increased to 20 psi, it does not boil at 212 °F. More energy is required to overcome the increase in pressure. It boils at approximately 226.4 °F. The converse is also true.

Water can also boil at a much lower temperature simply by reducing the pressure upon it. With only 10 psi of pressure upon liquid water, it boils at 194 °F. *[Figure below]*



Boiling point of water changes as pressure changes.

Vapour pressure is the pressure of the vapour that exists above a liquid that is in an enclosed container at any given temperature. The vapour pressure developed by various substances is unique to each substance. A substance that is said to be volatile develops high vapour pressure at standard day temperature (59 °F). This is because the boiling point of the substance is much lower. The boiling point of tetrafluoroethane (R134a), the refrigerant used in most aircraft vapour cycle air conditioning systems, is approximately –15 °F. Its vapour pressure at 59 °F is about 71 psi. The vapour pressure of any substance varies directly with temperature.

Basic Vapour Cycle

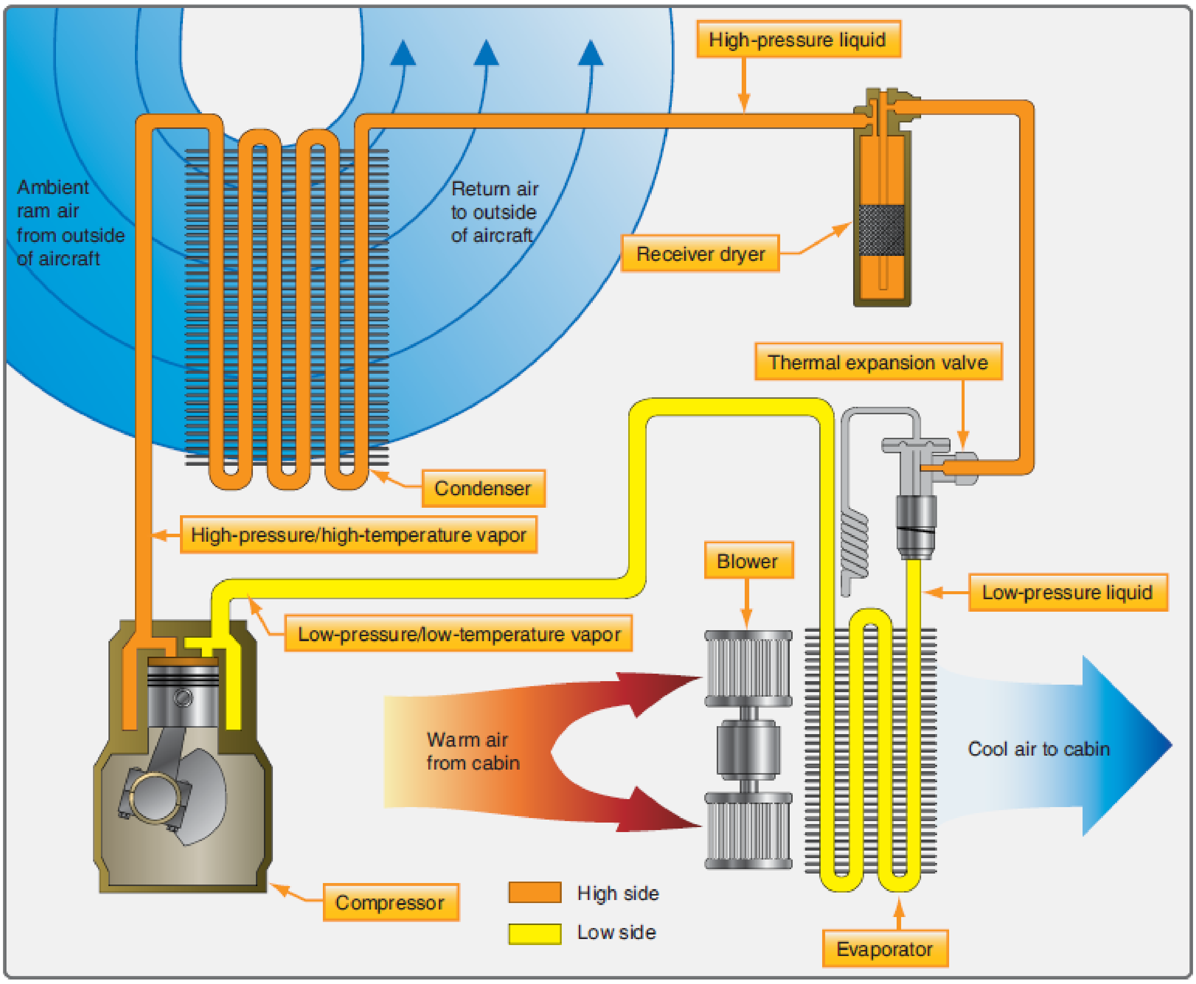
Vapour cycle air conditioning is a closed system in which a refrigerant is circulated through tubing and a variety of components. The purpose is to remove heat from the aircraft cabin. While circulating, the refrigerant changes state. By manipulating the latent heat required to do so, hot air is replaced with cool air in the aircraft cabin.

To begin, R134a is filtered and stored under pressure in a reservoir known as a receiver dryer. The refrigerant is in liquid form. It flows from the receiver dryer through tubing to an expansion valve. Inside the valve, a restriction in the form of a small orifice blocks most of the refrigerant. Since it is under pressure, some of the refrigerant is forced through the orifice. It emerges as a spray of tiny droplets in the tubing downstream of the valve. The tubing is coiled into a radiator type assembly known as an evaporator. A fan is positioned to blow cabin air over the surface of the evaporator. As it does, the heat in the cabin air is absorbed by the refrigerant, which uses it to change state from a liquid to a vapour. So much heat is absorbed that the cabin air blown by the fan across the evaporator cools significantly. This is the vapour cycle conditioned air that lowers the temperature in the cabin.

The gaseous refrigerant exiting the evaporator is drawn into a compressor. There, the pressure and the temperature of the refrigerant are increased. The high-pressure high-temperature gaseous refrigerant flows through tubing to a condenser. The condenser is like a radiator comprised of a great length of tubing with fins attached to promote heat transfer. Outside air is directed over the condenser. The temperature of the refrigerant inside is higher than the ambient air temperature, so heat is transferred from the refrigerant to the outside air.

The amount of heat given off is enough to cool the refrigerant and to condense it back to a high-pressure liquid. It flows through tubing and back into the receiver dryer, completing the vapour cycle.

There are two sides to the vapour cycle air conditioning system. One accepts heat and is known as the low side. The other gives up heat and is known as the high side. The low and high refer to the temperature and pressure of the refrigerant. As such, the compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. *[Figure below]* Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.



A basic vapour cycle air conditioning system. The compressor and the expansion valve are the two components that separate the low side from the high side of the cycle. This figure illustrates this division. Refrigerant on the low side is characterized as having low pressure and temperature. Refrigerant on the high side has high pressure and temperature.

ICE CONTROL SYSTEMS

Rain, snow, and ice are transportation's long-time enemies. Flying has added a new dimension, particularly with respect to ice. Under certain atmospheric conditions, ice can build rapidly on airfoils and air inlets. On days when there is visible moisture in the air, ice can form on aircraft leading edge surfaces at altitudes where freezing temperatures start. Water droplets in the air can be super cooled to below freezing without actually turning into ice unless they are disturbed in some manner. This unusual occurrence is partly due to the surface tension of the water droplet not allowing the droplet to expand and freeze. However, when aircraft surfaces disturb these droplets, they immediately turn to ice on the aircraft surfaces.

The two types of ice encountered during flight are clear and rime. Clear ice forms when the remaining liquid portion of the water drop flows out over the aircraft surface, gradually freezing as a smooth sheet of solid ice. Formation occurs when droplets are large, such as in rain or in cumuliform clouds. Clear ice is hard, heavy, and tenacious. Its removal by deicing equipment is especially difficult. Rime ice forms when water drops are small, such as those in stratified clouds or light drizzle. The liquid portion remaining after initial impact freezes rapidly before the drop has time to spread over the aircraft surface. The small frozen droplets trap air giving the ice a white appearance. Rime ice is lighter in weight than clear ice and its weight is of little significance.

However, its irregular shape and rough surface decrease the effectiveness of the aerodynamic efficiency of airfoils, reducing lift and increasing drag. Rime ice is brittle and more easily removed than clear ice.

Mixed clear and rime icing can form rapidly when water drops vary in size or when liquid drops intermingle with snow or ice particles. Ice particles become imbedded in clear ice, building a very rough accumulation sometimes in a mushroom shape on leading edges. Ice may be expected to form whenever there is visible moisture in the air and temperature is near or below freezing. An exception is carburetor icing, which can occur during warm weather with no visible moisture present.

Ice or frost forming on aircraft creates two basic hazards:

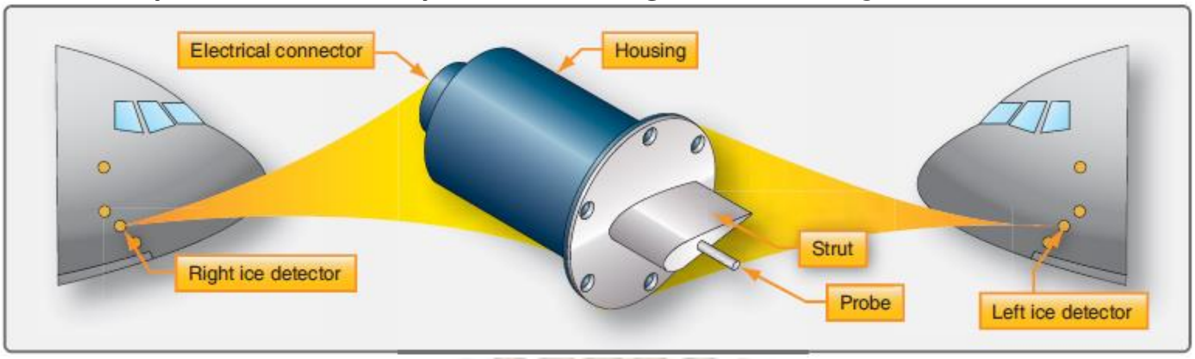
1. The resulting malformation of the airfoil that could decrease the amount of lift.
2. The additional weight and unequal formation of the ice that could cause unbalancing of the aircraft, making it hard to control.

Enough ice to cause an unsafe flight condition can form in a very short period of time, thus some method of ice prevention or removal is necessary. *Figure below* shows the effects of ice on a leading edge.

Formation of ice on aircraft leading edge.

ICE DETECTOR SYSTEM:

Ice can be detected visually, but most modern aircraft have one or more ice detector sensors that warn the flight crew of icing conditions. An annuciator light comes on to alert the flight crew. In some aircraft models, multiple ice detectors are used, and the ice detection system automatically turns on the WAI systems when icing is detected. *[Figure below]*



An ice detector alerts the flight crew of icing conditions and, on some aircraft, automatically activates ice protection systems. One or more detectors are located on the forward fuselage.

Ice Prevention

Several means to prevent or control ice formation are used in aircraft today:

1. Heating surfaces with hot air
2. Heating by electrical elements
3. Breaking up ice formations, usually by inflatable boots
4. Chemical application

Equipment is designed for anti-icing or for de-icing. Anti-icing equipment is turned on before entering icing conditions and is designed to prevent ice from forming. A surface may be anti-iced by keeping it dry, by heating to a temperature that evaporates water upon impingement, or by heating the surface just enough to prevent freezing, maintaining it running wet.

De-icing equipment is designed to remove ice after it begins to accumulate typically on the wings and stabilizer leading edges. Ice may be controlled on aircraft structure by the methods described in *Figure below.*

Location of ice	Method of control
Leading edge of the wing	Thermal pneumatic, thermal electric, chemical, and pneumatic (deice)
Leading edges of vertical and horizontal stabilizers	Thermal pneumatic, thermal electric, and pneumatic (deice)
Windshield, windows	Thermal pneumatic, thermal electric, and chemical
Heater and engine air inlets	Thermal pneumatic and thermal electric
Pitot and static air data sensors	Thermal electric
Propeller blade leading edge and spinner	Thermal electric and chemical
Carburetor(s)	Thermal pneumatic and chemical
Lavatory drains and portable water lines	Thermal electric

Typical ice control methods.

Stabilizer Anti-Icing Systems

The wing leading edges, or leading edge slats, and horizontal and vertical stabilizer leading edges of many aircraft make and models have anti-icing systems installed to prevent the formation of ice on these components. The most common anti-icing systems used are thermal pneumatic, thermal electric, and chemical. Most general aviation (GA) aircraft equipped to fly in icing conditions use pneumatic deicing boots, a chemical anti-ice system. High-performance aircraft may have "weeping wings." Large transport-category aircraft are equipped with advanced thermal pneumatic or thermal electric anti-icing systems that are controlled automatically to prevent the formation of ice.

Thermal Pneumatic Anti-icing

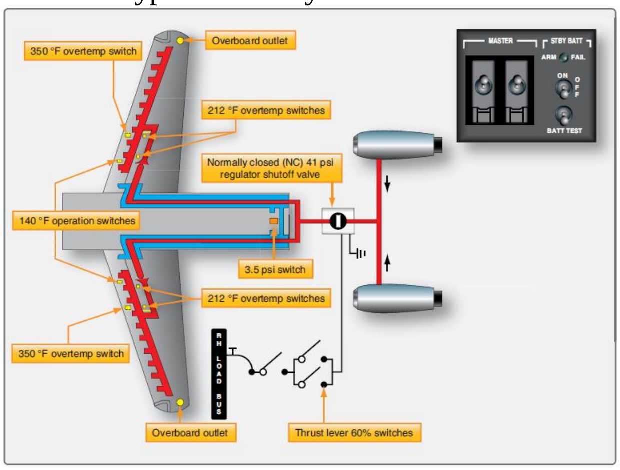
Thermal systems used for the purpose of preventing the formation of ice or for de-icing airfoil leading edges usually use heated air ducted span wise along the inside of the leading edge of the airfoil and distributed around its inner surface. These thermal pneumatic anti-icing systems are used for wings, leading edge slats, horizontal and vertical stabilizers, engine inlets, and more. There are several sources of heated air, including hot air bled from the turbine compressor, engine exhaust heat exchangers, and ram air heated by a combustion heater.

Wing Anti-Ice (WAI) System

Thermal wing anti-ice (WAI or TAI) systems for business jet and large-transport category aircraft typically use hot air bled from the engine compressor. *[Figure below]* Relatively large amounts of very hot air can be bled off the compressor, providing a satisfactory source of anti-icing heat.

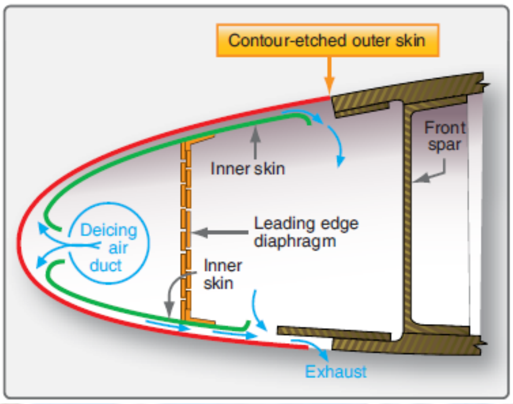
Aircraft with thermal WAI system.

The hot air is routed through ducting, manifolds, and valves to components that need to be anti-iced. *Figure below* shows a typical WAI system schematic for a business jet.



Thermal WAI system.

The bleed air is routed to each wing leading edge by an ejector in each wing inboard area. The ejector discharges the bleed air into piccolo tubes for distribution along the leading edge. Fresh ambient air is introduced into the wing leading edge by two flush-mounted ram air scoops in each wing leading edge, one at the wing root and one near the wingtip. The ejectors entrain ambient air, reduce the temperature of the bleed air, and increase the mass airflow in the piccolo tubes. The wing leading edge is constructed of two skin layers separated by a narrow passageway. *[Figure below]* The air directed against the leading edge can only escape through the passageway, after which it is vented overboard through a vent in the bottom of the wingtip.



Heated wing leading edge.

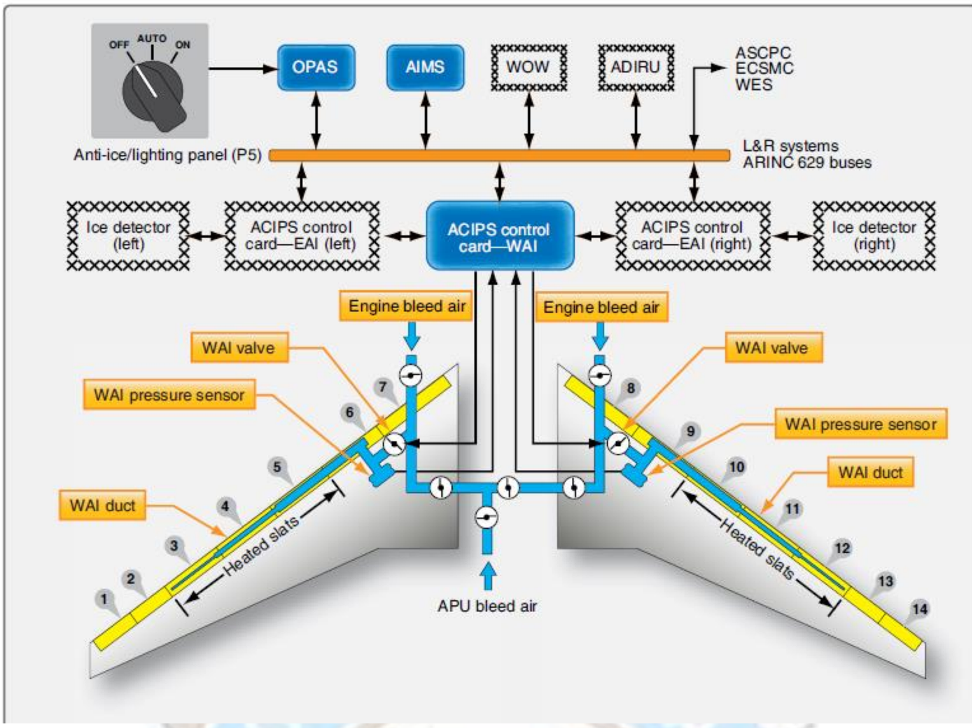
When the WAI switch is turned on, the pressure regulator is energized and the shutoff valve opens. When the wing leading edge temperature reaches approximately +140 °F, temperature switches turn on the operation light above the switch. If the temperature in the wing leading edge exceeds approximately +212 °F (outboard) or +350 °F (inboard), the red WING OV HT warning light on the annunciator panel illuminates. When installing a section of duct, make certain that the seal bears evenly against and is compressed by the adjacent joint's flange. When specified, the ducts should be pressure tested at the pressure recommended by the manufacturer of the aircraft concerned. Leak checks are made to detect defects in the duct that would permit the escape of heated air. The rate of leakage at a given pressure should not exceed that recommended in the aircraft maintenance manual.

Air leaks can often be detected audibly and are sometimes revealed by holes in the lagging or thermal insulation material. However, if difficulty arises in locating leaks, a soap-and water solution may be used. All ducting should be inspected for security, general condition, or distortion. Lagging or insulating blankets must be checked for security and must be free of flammable fluids, such as oil or hydraulic fluid.

Leading Edge Slat Anti-Ice System

Aircraft that utilize leading edge slats often use bleed air from the engine compressor to prevent the formation of frost on these surfaces. On a modern transport category aircraft, the pneumatic system supplies bleed air for this purpose. WAI valves control the air flow from the pneumatic system to WAI ducts. The WAI ducts carry the air to the slats. Holes in the bottom of each slat let the air out.

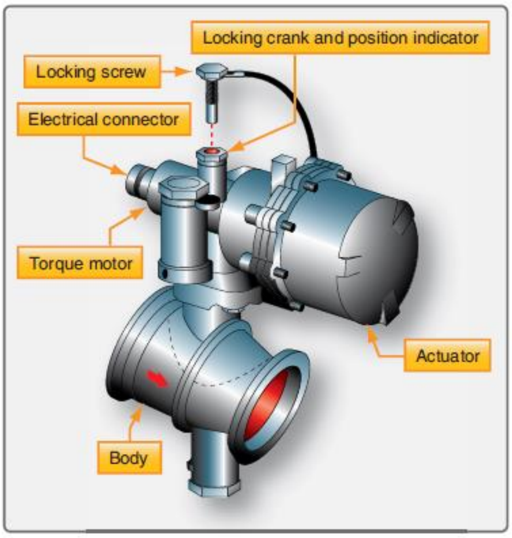
The airfoil and cowl ice protection system (ACIPS) computer card controls the WAI valves, and pressure sensors send duct air pressure data to the computer. The aircrew can select an auto or manual mode with the WAI selector. In the auto mode, the system turns on when the ice detection system detects ice. The off and on positions are used for manual control of the WAI system. The WAI system is only used in the air, except for ground tests. The weight on wheels system and/ or airspeed data disarms the system when the aircraft is on the ground. *[Figure below]*



Wing leading edge slat anti-ice system

WAI Valve

The WAI valve controls the flow of bleed air from the pneumatic system to the WAI ducts. The valve is electrically controlled and pneumatically actuated. The torque motor controls operation of the valve. With no electrical power to the torque motor, air pressure on one side of the actuator holds the valve closed. Electrical current through the torque motor allows air pressure to open the valve. As the torque motor current increases, the valve opening increases. *[Figure below]*



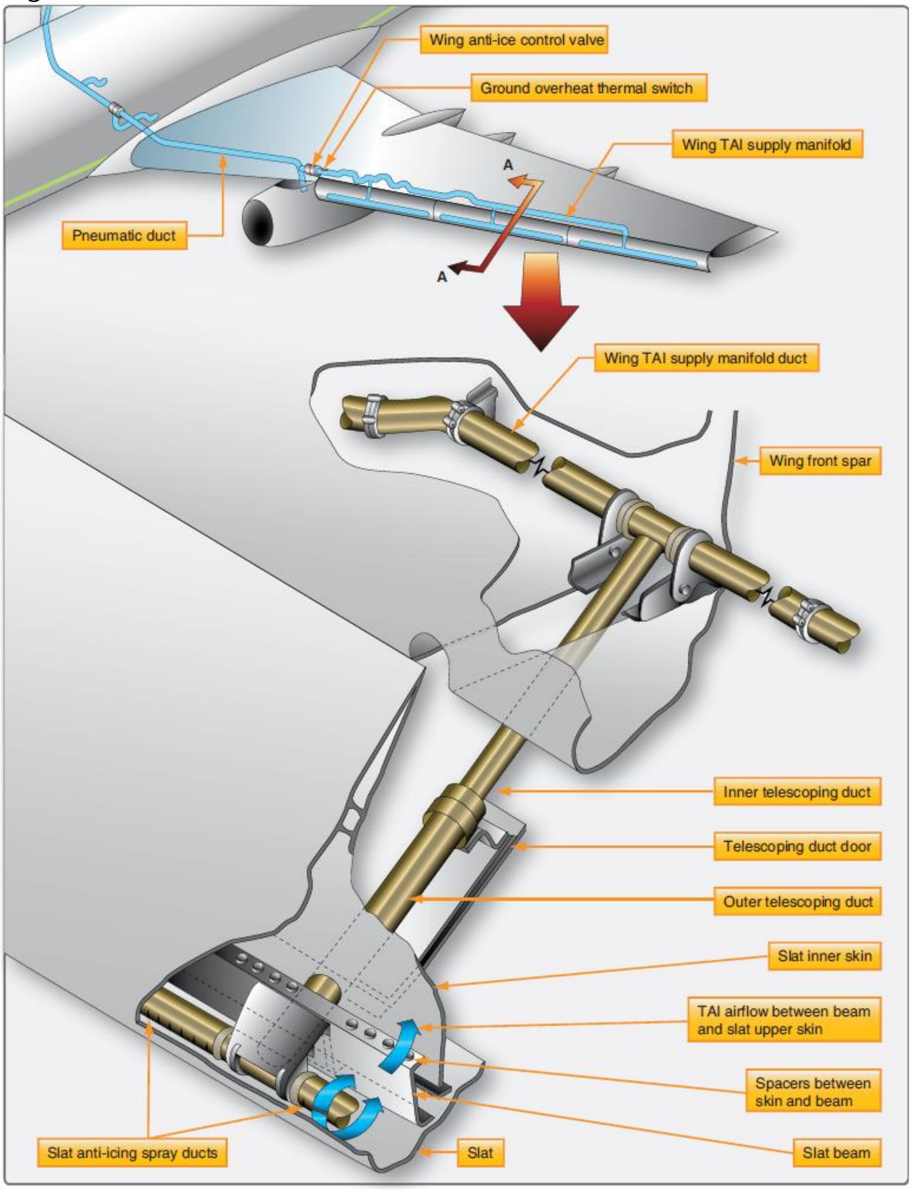
A wing anti-ice valve.

WAI Pressure Sensor

The WAI pressure sensor senses the air pressure in the WAI duct after the WAI valve. The ACIPS system card uses the pressure information to control the WAI system.

WAI Ducts
The WAI ducts move air from the pneumatic system through the wing leading edge to the leading edge slats.

Figure Wing leading edge slat anti-ice system shows that only leading edge slat sections 3, 4, and 5 on the left wing and 10, 11, and 12 on the right wing receive bleed air for WAI. Sections of the WAI ducting are perforated. The holes allow air to flow into the space inside the leading edge slats. The air leaves the slats through holes in the bottom of each slat. Some WAI ducts have connecting "T" ducts that telescope to direct air into the slats while extended. The telescoping section attached to the slat on one end, slides over the narrow diameter "T" section that is connected into the WAI duct. A seal prevents any loss of air. This arrangement allows warm air delivery to the slats while retracted, in transit, and fully deployed. *[Figure below]*

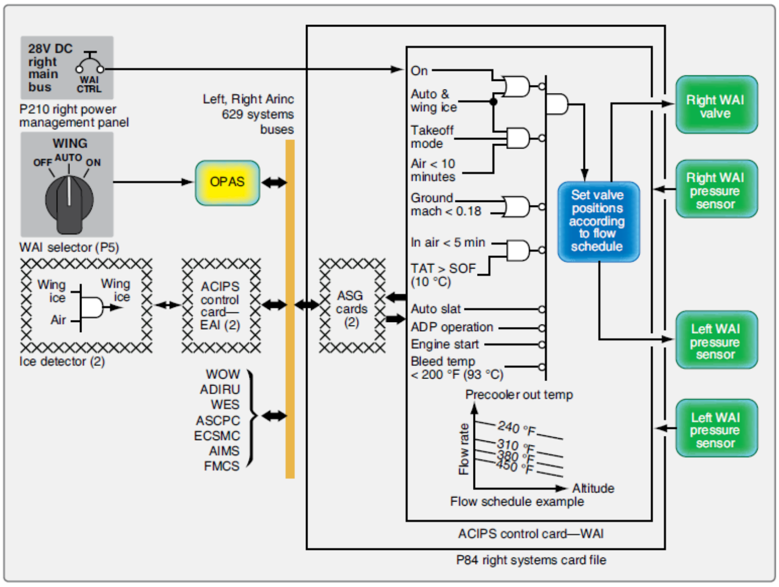


WAI ducting.

WAI Control System
Modern aircraft use several onboard computers to control aircraft systems. The WAI system is controlled by the ACIPS computer card. The ACIPS computer card controls both WAI

valves. The required positions of the WAI valves change as bleed air temperature and altitude change. The left and right valves operate at the same time to heat both wings equally. This keeps the airplane aerodynamically stable in icing conditions. The WAI pressure sensors supply feedback information to the WAI ACIPS computer card for WAI valve control and position indication. If either pressure sensor fails, the WAI ACIPS computer card sets the related WAI valve to either fully open or fully closed. If either valve fails closed, the WAI computer card keeps the other valve closed.

There is one selector for the WAI system. The selector has three positions: auto, on, and off. With the selector in auto and no operational mode inhibits, the WAI ACIPS computer card sends a signal to open the WAI valves when either ice detector detects ice. The valves close after a 3-minute delay when the ice detector no longer detects ice. The time delay prevents frequent on/off cycles during intermittent icing conditions. With the selector on and no operational mode inhibits, the WAI valves open. With the selector off, the WAI valves close. The operational mode for the WAI valves can be inhibited by many different sets of conditions. *[Figure below]*



WAI inhibit logic schematic.

The operational mode is inhibited if all of these conditions occur:

- Auto mode is selected
- Takeoff mode is selected
- Airplane has been in the air less than 10 minutes

With auto or on selected, the operational mode is inhibited if any of these conditions occur:

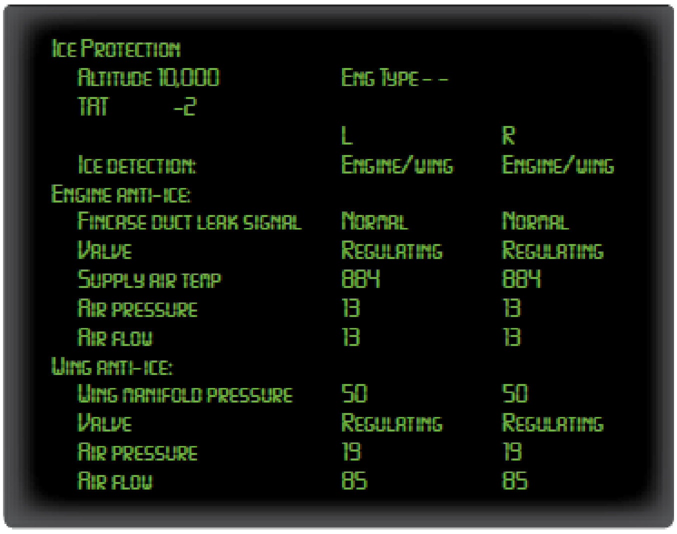
- Airplane on the ground (except during an initiated or periodic built-in test equipment (BITE) test)
- Total Air Temperature (TAT) is more than 50 °F (10 °C) and the time since takeoff is less than 5 minutes
- Auto slat operation
- Air-driven hydraulic pump operation
- Engine start
- Bleed air temperature less than 200 °F (93 °C).

The WAI valves stay closed as long as the operational mode inhibit is active. If the valves are already open, the operational mode inhibit causes the valves to close.

WAI Indication System

The aircrew can monitor the WAI system on the onboard computer maintenance page. *[Figure below]* The following information is shown:

- WING MANIFOLD PRESS—pneumatic duct pressure in PSIG
- VALVE—WAI valve open, closed, or regulating
- AIR PRESS—pressure downstream of the WAI valves in PSIG
- AIR FLOW—air flow through the WAI valves in pounds per minute.

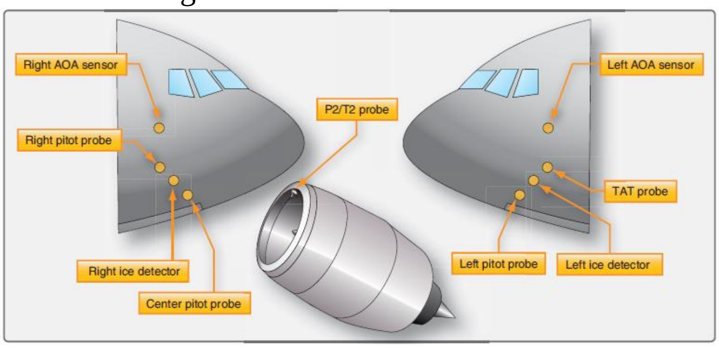


Ice protection onboard computer maintenance page.

Thermal Electric Anti-Icing

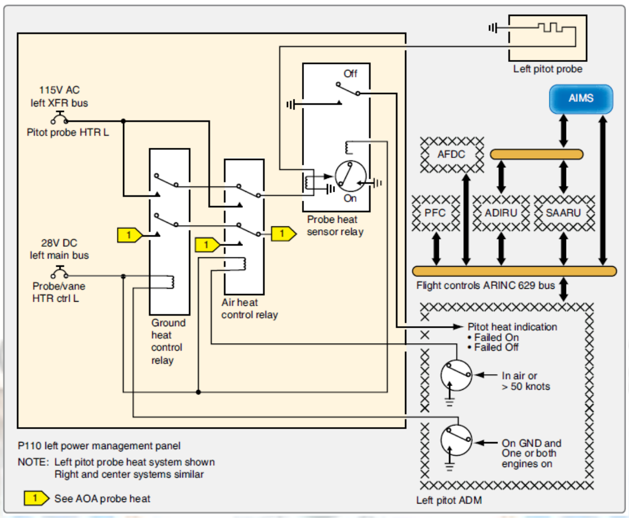
Electricity is used to heat various components on an aircraft so that ice does not form. This type of anti-ice is typically limited to small components due to high amperage draw. Effective thermal electric anti-ice is used on most air data probes, such as pitot tubes, static air ports, TAT and AOA probes, ice detectors, and engine P2/T2 sensors. Water lines, waste water drains, and some turboprop inlet cowls are also heated with electricity to prevent ice from forming. Transport category and high performance aircraft use thermal electric anti-icing in windshields. In devices that use thermal electric anti-ice, current flows through an integral conductive element that produces heat.

The temperature of the component is elevated above the freezing point of water so ice cannot form. Various schemes are used, such as an internal coil wire, externally wrapped blankets or tapes, as well as conductive films and heated gaskets. A basic discussion of probe heat follows. Windshield heat and portable water heat anti-ice are discussed later in this chapter. Propeller deices boots, which also are used for anti-ice, are also thermal electric and discussed in this chapter. Data probes that protrude into the ambient airstream are particularly susceptible to ice formation in flight.



Probes with thermal electric anti-icing on one commercial airliner.

Figure above illustrates the types and location probes that use thermal electric heat on one airliner. A pitot tube, for example, contains an internal electric element that is controlled by a switch in the cockpit. Use caution checking the function of the pitot heat when the aircraft is on the ground. The tube gets extremely hot since it must keep ice from forming at altitude in temperatures near -50 °F at speeds possibly over 500 miles per hour. An ammeter or load meter in the circuit can be used as a substitute to touching the probe, if so equipped.
Simple probe heat circuits exist on GA aircraft with a switch and a circuit breaker to activate and protect the device.
Advanced aircraft may have more complex circuitry in which control is by computer and flight condition of the aircraft is considered before thermal electric heaters are activated automatically.

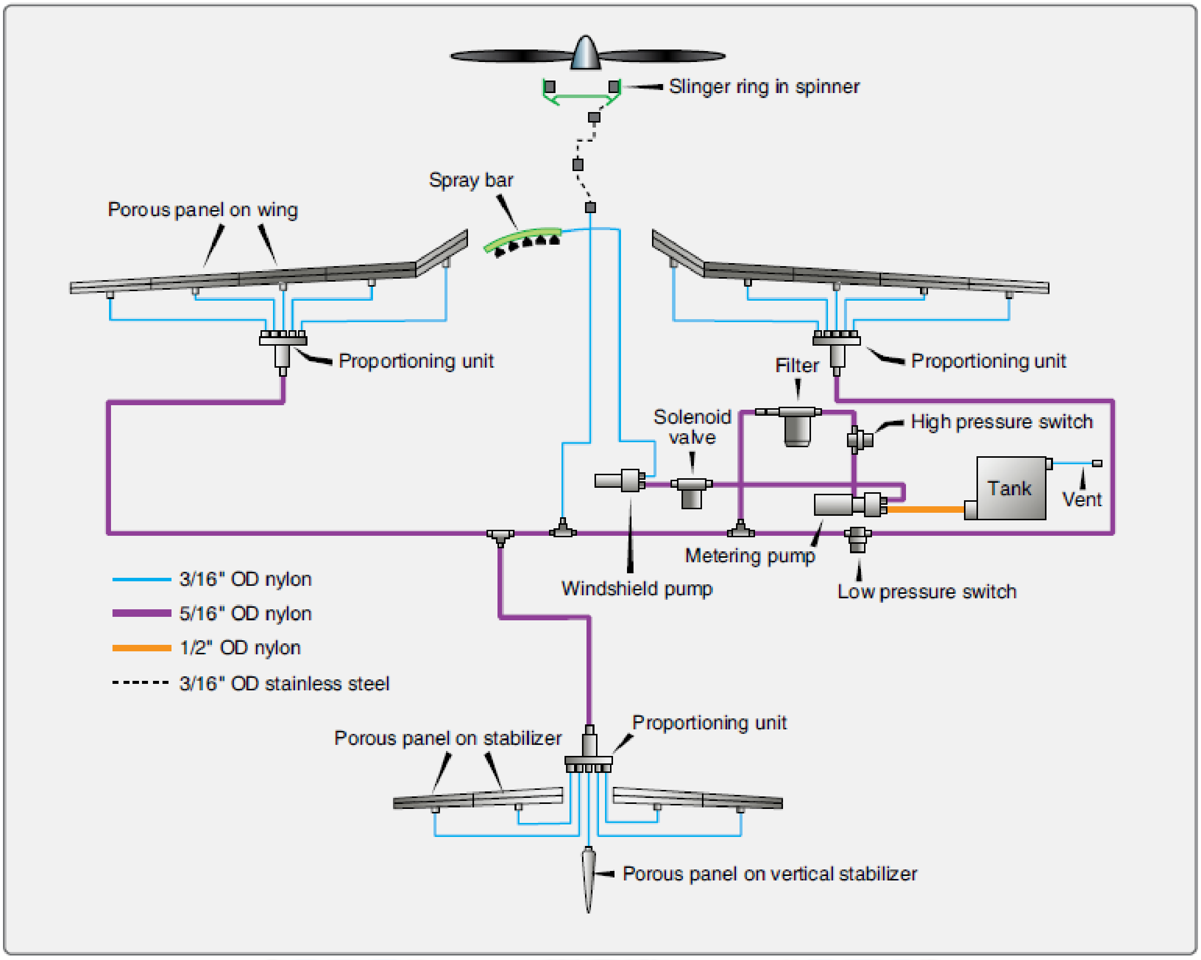


Pitot probe heat system.

Figure above shows such a circuit for a pitot tube. The primary flight computer (PFC) supplies signals for the air data card (ADC) to energize ground and air heat control relays to activate probe heat. Information concerning speed of the aircraft, whether it is in the air or on the ground, and if the engines are running are factors considered by the ADC logic. Similar control is use for other probe heaters.

Chemical Anti-Icing

Chemical anti-icing is used in some aircraft to anti-ice the leading edges of the wing, stabilizers, windshields, and propellers. The wing and stabilizer systems are often called weeping wing systems or are known by their trade name of TKS™ systems. Ice protection is based upon the freezing point depressant concept. An antifreeze solution is pumped from a reservoir through a mesh screen embedded in the leading edges of the wings and stabilizers. Activated by a switch in the cockpit, the liquid flows over the wing and tail surfaces, preventing the formation of ice as it flows.
The solution mixes with the super cooled water in the cloud, depresses its freezing point, and allows the mixture to flow off of the aircraft without freezing. The system is designed to anti-ice, but it is also capable of de-icing an aircraft as well. When ice has accumulated on the leading edges, the antifreeze solution chemically breaks down the bond between the ice and airframe. This allows aerodynamic forces to carry the ice away. Thus, the system clears the airframe of accumulated ice before transitioning to anti-ice protection. *Figure below* shows a chemical anti-ice system.



Chemical de-icing system.

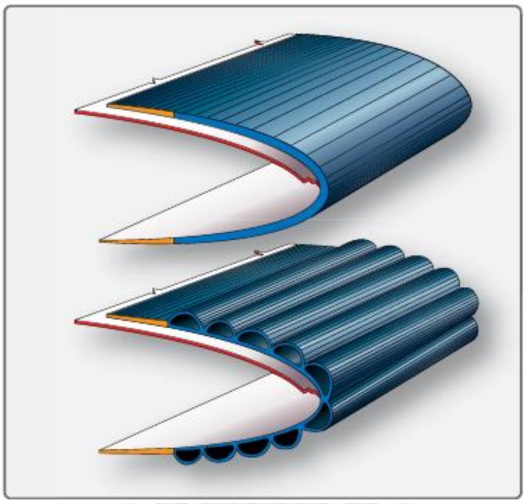
The TKS™ weeping wing system contains formed titanium panels that are laser drilled with over 800 tiny holes (.0025 inch diameter) per square inch. These are mated with non perforated stainless steel rear panels and bonded to wing and stabilizer leading edges. As fluid is delivered from a central reservoir and pump, it seeps through the holes. Aerodynamic forces cause the fluid to coat the upper and lower surfaces of the airfoil. The glycol based fluid prevents ice from adhering to the aircraft structure. Some aircraft with weeping wing systems are certified to fly into known icing conditions. Others use it as a hedge against unexpected ice encountered in flight. The systems are basically the same. Reservoir capacity permits 1- 2 hours of operation. TKSTM weeping wings are used primarily on reciprocating aircraft that lack a supply of warm bleed air for the installation of a thermal anti-ice system. However, the system is simple and effective leading to its use on some turbine powered corporate aircraft as well.

Pneumatic Deice Boot System for GA Aircraft

GA aircraft, especially twin-engine models, are commonly equipped with pneumatic deicer systems. Rubber boots are attached with glue to the leading edges of the wings and stabilizers. These boots have a series of inflatable tubes. During operation, the tubes are inflated and deflated in an alternating cycle.

[Figure below] This inflation and deflation causes the ice to crack and break off. The ice is then carried away by the airstream. Boots used in GA aircraft typically inflate and deflate along the length of the wing. In larger turbo prop aircraft, the boots are installed in sections along the wing with the different sections operating alternately and symmetrically about the

fuselage. This is done so that any disturbance to airflow caused by an inflated tube is kept to a minimum by inflating only short sections on each wing at a time.



Cross-section of a pneumatic de-icing boot uninflected (top) and inflated (bottom).

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 de-icing fluid. No attempt should be made to remove ice deposits or break an ice bond by force.

After completion of de-icing 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 up locks and micro switches checked.

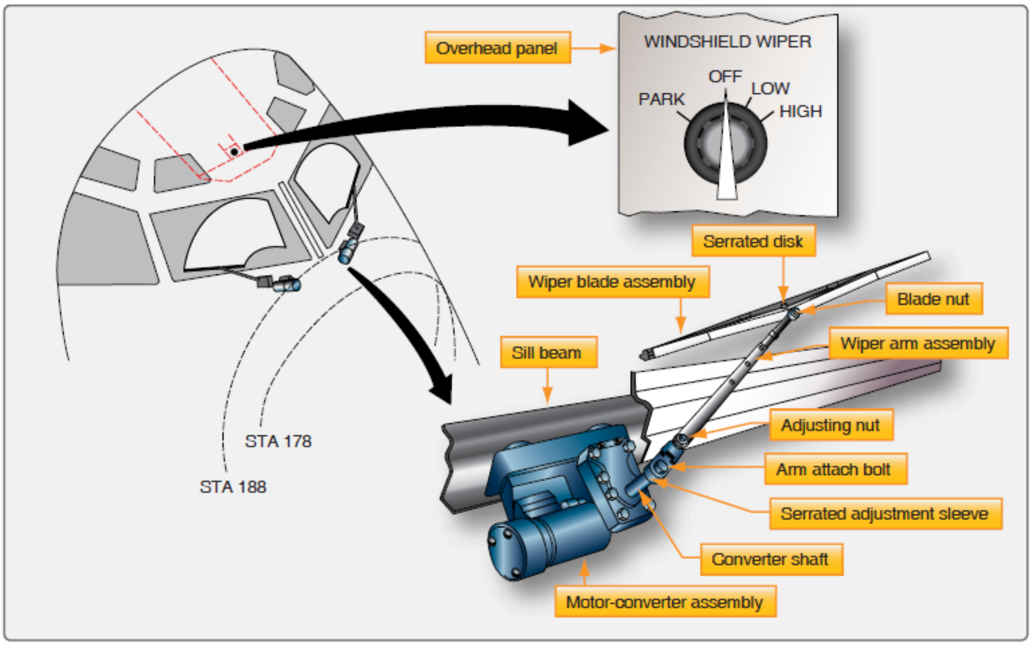
Snow or ice can enter turbine engine intakes and freeze in the compressor. If the compressor cannot be turned by hand for this reason, hot air should be blown through the engine until the rotating parts are free.

Rain Control Systems

There are several different ways to remove the rain from the windshields. Most aircraft use one or a combination of the following systems: windshield wipers, chemical rain repellent, pneumatic rain removal (jet blast), or windshields treated with a hydrophobic surface seal coating.

Windshield Wiper Systems

In an electrical windshield wiper system, the wiper blades are driven by an electric motor(s) that receive (s) power from the aircraft's electrical system. On some aircraft, the pilot's and co-pilot's windshield wipers are operated by separate systems to ensure that clear vision is maintained through one of the windows should one system fail. Each windshield wiper assembly consists of a wiper, wiper arm, and a wiper motor/converter. Almost all windshield wiper systems use electrical motors. Some older aircraft might be equipped with hydraulic wiper motors. *[Figure below]*



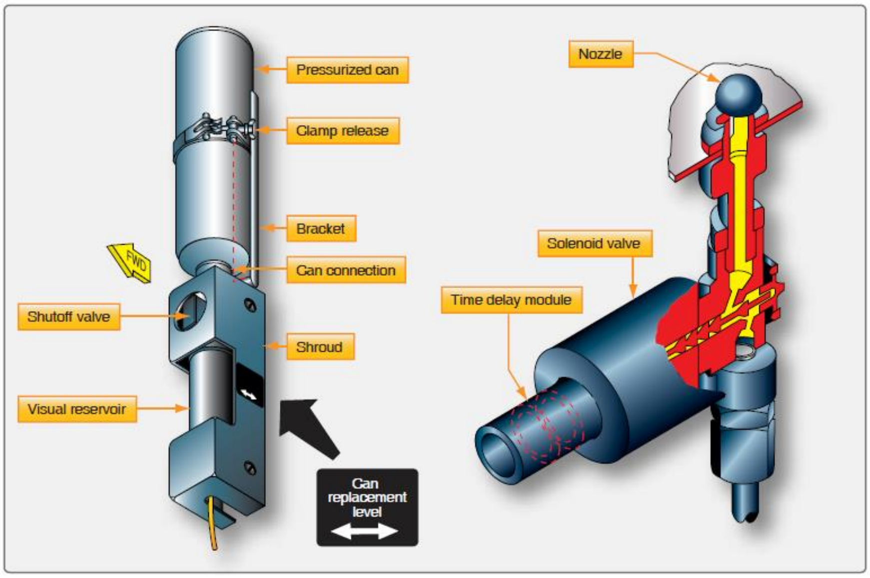
Windshield wiper assembly/installation on a transport category aircraft. The motor-converter is mounted under the aircraft skin.

Maintenance performed on windshield wiper systems consists of operational checks, adjustments and troubleshooting. An operational check should be performed whenever a system component is replaced or whenever the system is suspected of not working properly. During the check, make sure that the windshield area covered by the wipers is free of foreign matter and is kept wet with water. Adjustment of a windshield wiper system consists of adjusting the wiper blade tension, the angle at which the blade sweeps across the windshield, and proper parking of the wiper blades.

Chemical Rain Repellent

Water poured onto clean glass spreads out evenly. Even when the glass is held at a steep angle or subjected to air velocity, the glass remains wetted by a thin film of water. However, when glass is treated with certain chemicals, a transparent film is formed that causes the water to behave very much like mercury on glass. The water draws up into beads that cover only a portion of the glass and the area between beads is dry. The water is readily removed from the glass. This principle lends itself quite naturally to removing rain from aircraft windshields. The high-velocity slipstream continually removes the water beads, leaving a large part of the window dry.

A rain repellent system permits application of the chemical repellent by a switch or push button in the cockpit. The proper amount of repellent is applied regardless of how long the switch is held. On some systems, a solenoid valve controlled by a time delay module meters the repellent to a nozzle which sprays it on the outside of the windshield. Two such units exist — one each for the forward glass of the pilot and co-pilot. *[Figure below]*

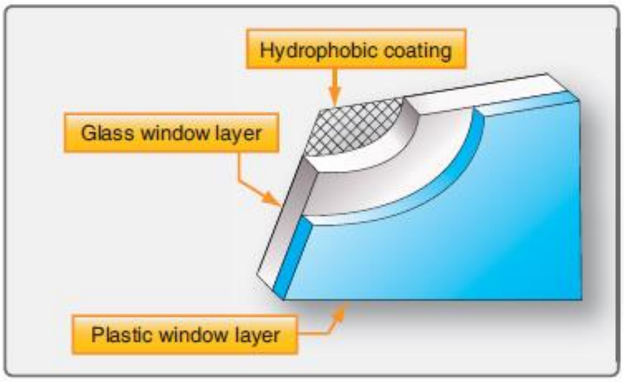


Cockpit rain repellant canister and reservoir.

This system should only be used in very wet conditions. The rain repellent system should not be operated on dry windows because heavy undiluted repellent restricts window visibility. Should the system be operated inadvertently, do not operate the windshield wipers or rain clearing system as this tends to increase smearing. Also, the rain repellent residues caused by application in dry weather or very light rain can cause staining or minor corrosion of the aircraft skin. To prevent this, any concentrated repellent or residue should be removed by a thorough fresh water rinse at the earliest opportunity. After application, the repellent film slowly deteriorates with continuing rain impingement. This makes periodic reapplication necessary. The length of time between applications depends upon rain intensity, the type of repellent used, and whether windshield wipers are used.

Windshield Surface Seal Coating

Some aircraft models use a surface seal coating, also called hydrophobic coating that is on the outside of the pilot's/ co-pilot's windshield. *[Figure below]* The word hydrophobic means to repel or not absorb water. The windshield hydrophobic coating is on the external surface of the windows (windshields). The coatings cause raindrops to bead up and roll off, allowing the flight crew to see through the windshield with very little distortion. The hydrophobic windshield coating reduces the need for wipers and gives the flight crew better visibility during heavy rain.

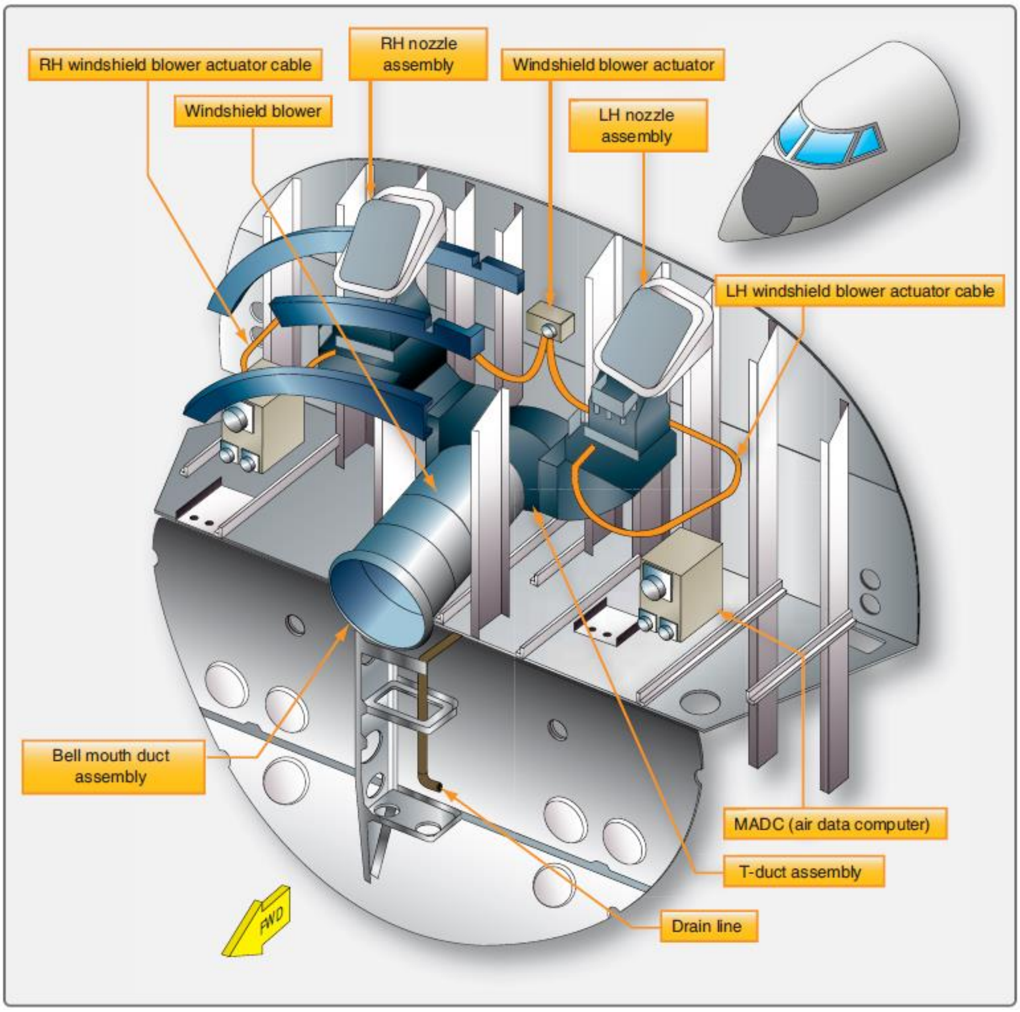


Hydrophobic coating on windshield.

Most new aircraft windshields are treated with surface seal coating. The manufacturer's coating process deeply penetrates the windshield surface providing hydrophobic action for quite some time. When effectiveness declines, products made to be applied in the field are used. These liquid treatments rubbed onto the surface of the windshield maintain the beading action of rain water. They must be applied periodically or as needed.

Pneumatic Rain Removal Systems

Windshield wipers characteristically have two basic problem areas. One is the tendency of the slipstream aerodynamic forces to reduce the wiper blade loading pressure on the window, causing ineffective wiping or streaking. The other is in achieving fast enough wiper oscillation to keep up with high rain impingement rates during heavy rain falls. As a result, most aircraft wiper systems fail to provide satisfactory vision in heavy rain.



Windshield rain and frost removal system.

The rain removal system shown in *Figure above* controls windshield icing and removes rain by directing a flow of heated air over the windshield. This heated air serves two purposes. First, the air breaks the rain drops into small particles that are then blown away. Secondly, the air heats the windshield to prevent the moisture from freezing. The air can be supplied by an electric blower or by bleed air.

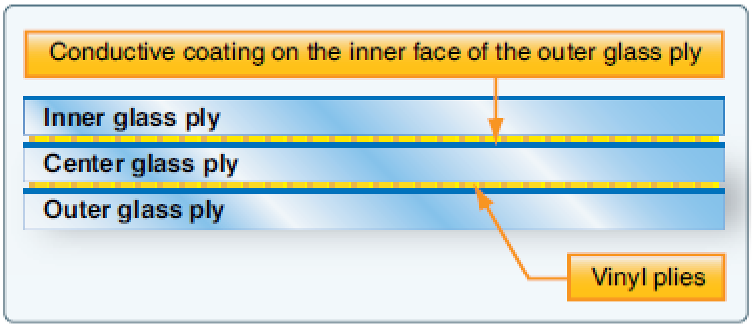
Windshield Frost, Fog, and Ice Control Systems

In order to keep windshield areas free of ice, frost, and fog, window anti-icing, de-icing, and defogging systems are used. These can be electric, pneumatic, or chemical depending on the type and complexity of the aircraft. A few of these systems are discussed in this section.

Electric

High performance and transport category aircraft windshields are typically made of laminated glass, polycarbonate, or similar ply material. Typically clear vinyl plies are also included to improve performance characteristics. The laminations create the strength and impact resistance of the windshield assembly. These are critical feature for windshields as they are subject to a wide range of temperatures and pressures. They must also withstand the force of a 4 pound bird strike at cruising speed to be certified.

The laminated construction facilitates the inclusion of electric heating elements into the glass layers, which are used to keep the windshield clear of ice, frost, and fog. The elements can be in the form of resistance wires or a transparent conductive material may be used as one of the window plies. To ensure enough heating is applied to the outside of the windshield, heating elements are placed on the inside of the outer glass ply. Windshields are typically bonded together by the application of pressure and heat without the use of cement.

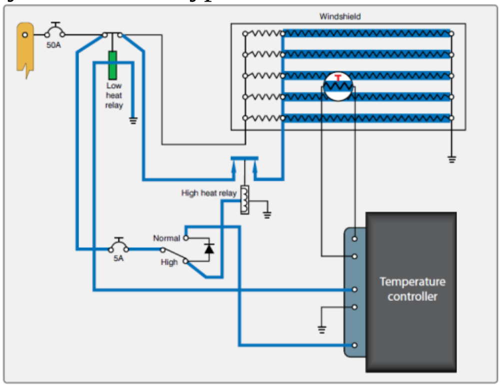


Cross-section of a transport category windshield.

Figure above illustrates the plies in one transport category aircraft windshield.

Whether resistance wires or a laminated conductive film is used, aircraft window heat systems have transformers to supply power and feedback mechanisms, such as thermistors, to provide a window heat control unit with information used to keep operating temperature within acceptable limits. Some systems are automatic while others are controlled by cockpit switches. Separate circuits for pilot and co-pilot are common to ensure visibility in case of a malfunction. Consult the manufacturer's maintenance information for details on the particular window heat system in question.

Some windshield heating systems can be operated at two heat levels. On these aircraft, NORMAL heating supplied heat to the broadest area of windshield. HIGH heating supplies a higher intensity of heat to a smaller but more essential viewing area. Typically, this window heating system is always on and set in the NORMAL position. *Figure below* illustrates a simplified windshield heat system of this type.

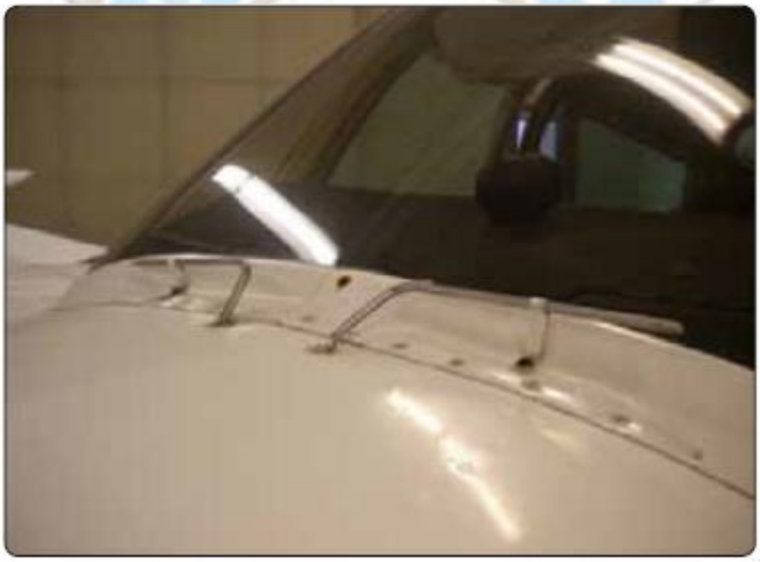


Electric windshield heat schematic.

Pneumatic

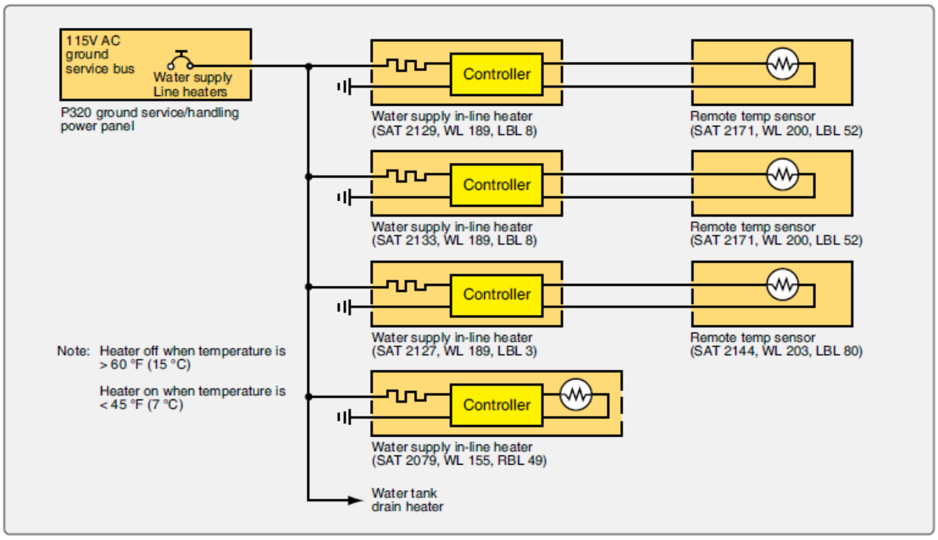
Some laminated windshields on older aircraft have a space between the plies that allows the flow of hot air to be directed between the glass to keep it warm and fog free. The source of air is bleed air or conditioned air from the environmental control system. Small aircraft may utilize ducted warm air, which is release to flow over the windshield inner surface to defrost and defog. These systems are similar to those used in automobiles. The source of air could be ambient (defog only), the aircraft's heating system, or a combustion heater. While these pneumatic windshield heat systems are effective for the aircraft on which they are installed, they are not approved for flying into known icing conditions and, as such, are not effective for anti-ice.
Large aircraft equipped with pneumatic jet blast rain repellent systems achieve some anti-icing effects from operating this system although electric windshield heat is usually used.

Chemical
As previously mentioned in this chapter, chemical anti-ice systems exist generally for small aircraft. This type of anti-ice is also used on windshields. Whether alone or part of a TKSTM system or similar, the liquid chemical is sprayed through a nozzle onto the outside of the windshield which prevents ice from forming. The chemical can also deice the windshield of ice that may have already formed. Systems such as these have a fluid reservoir, pump, control valve, filter, and relief valve. Other components may exist. *Figure below* shows a set of spray tubes for application of chemical anti-ice on an aircraft windshield.



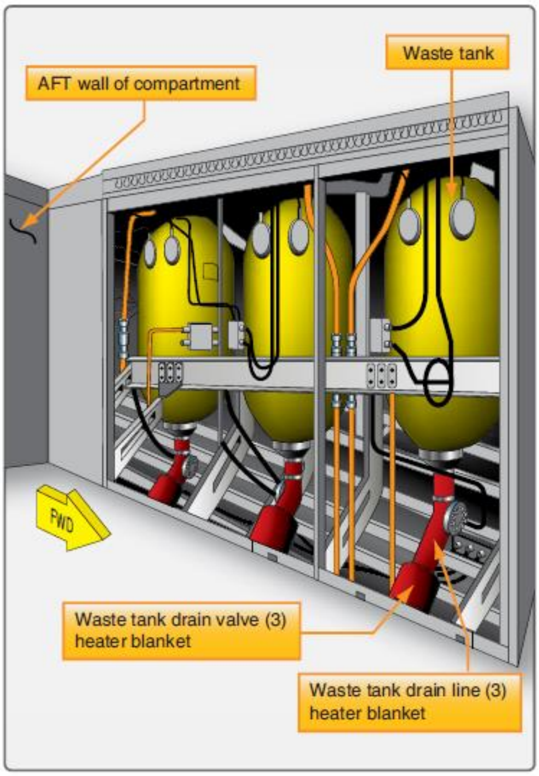
Chemical deicing spray tubes.

Portable Water Tank Ice Prevention
Transport type aircraft have water and waste systems on board, and electrical heaters are often used to prevent the formation of ice in the water lines of these systems. Water lines carry water from the portable tanks to the lavatories and galleys. The waste water tanks collect the gray water from the galleys and lavatories. Heater blankets, in-line heaters, or heater boots are often used to heat the water supply lines, water tank drain hoses, waste drain lines, waste tank rinse fittings, and drain masts. Thermostats in the water lines supply temperature data to the control unit that turns the electrical heaters on and off. When the temperature falls below freezing, the electrical heaters turn on and stay on until the temperature reaches a safe temperature.



Water supply line heater system.

Figure above is a schematic of a water supply line heater system, and *Figure below* shows the location of the waste water tanks and heater blanket.



Waste water tanks and heater blankets.

EJECTION SEATS:

Almost since the first days of flight man has been concerned with the safe escape from an aircraft which was no longer flyable. Early escape equipment consisted of a recovery parachute only. As aircraft performance rapidly increased during World War II, it became necessary to assist the crewmen in gaining clear safe separation from the aircraft. This was accomplished with an ejector seat which was powered by a propellant driven catapult - the first use of a propulsive element in aircrew escape. . Since then, this collection of componentry has evolved through several generations into today's relatively complex systems which are highly dependent upon propulsive elements. Ejection seats are one of the most complex pieces of equipment on any aircraft, and some consist of thousands of parts. The purpose of the ejection seat is simple: To lift the pilot straight out of the aircraft to a safe distance, then deploy a parachute to allow the pilot to land safely on the ground.

BASIC COMPONENTS

To understand how an ejection seat works, you must first be familiar with the basic components in any ejection system. Everything has to perform properly in a split second and in a specific sequence to save a pilot's life. If just one piece of critical equipment malfunctions, it could be fatal. Like any seat, the ejection seat's basic anatomy consists of the bucket, back and headrest. Everything else is built around these main components.

Here are key devices of an ejection seat:

- **Catapult**
- **Rocket**
- **Restraints**
- **Parachute**

This early propulsive element has been called a gun or catapult and, is in essence, a closed telescoping tube arrangement containing a propellant charge to forcibly extend the tubes, thereby imparting the necessary separation velocity to the "ejector seat" and its contents .The rocket is a propulsive device in the seat. The catapult remained as the initial booster to get the seat/man mass clear of the cockpit, while the rocket motor came on line, once clear of the cockpit, to act in a sustainer mode. The restraint system for the crue member is the protective devices to avoid injury while ejecting the seat. Harness straps can be tightened and body position can be adjusted to reduce injury from the forces encountered during ejection. Leg lifting devices and arm and leg restraints are provided to prevent limb flail injuries due to windblast forces. The limb restraints do not require the crew to hook up as they enter the aircraft and do not restrict limb movement during normal flight operations. Parachute helped the pilot to land safely on ground.

4. EJECTION-SEAT TERMS

Bucket - This is the lower part of the ejection seat that contains the survival equipment.
Canopy - This is the clear cover that encapsulates the cockpit of some planes; it is often seen on military fighter jets.
Catapult - Most ejections are initiated with this ballistic cartridge.
Drogue parachute - This small parachute is deployed prior to the main parachute; it designed to slow the ejection seat after exiting the aircraft.
Egress system - This refers to the entire ejection system, including seat ejection, canopy jettisoning and emergency life-support equipment.
Environmental sensor - This is an electronic device that tracks the airspeed and altitude of the seat.
Face curtain - Attached to the top of some seats, pilots pull this curtain down to cover his or her face from debris. This curtain also holds the pilot's head still during ejection.
Recovery sequencer - This is the electronic device that controls the sequence of events during ejection.
Rocket catapult - This is a combination of a ballistic catapult and an under seat rocket unit.
Underseat rocket - Some seats have a rocket attached underneath to provide additional lift after the catapult lifts the crewmember out of the cockpit.
Vernier rocket - Attached to a gyroscope, this rocket is mounted to the bottom of the seat and controls the seat's pitch.
Zero-zero ejection - This is an ejection on the ground when the aircraft is at zero altitude and zero airspeed.

PHYSICS OF EJECTING

Ejecting from an airplane is a violent sequence of events that places the human body under an extreme amount of force. The primary factors involved in an aircraft ejection are the force and acceleration of the crewmember. To understand the forces in the ejection we want to know the following.

Frames of Reference

- refers to the orientation of the object in relation to some reference. This way up/down, left/right, and front/back can be defined so others understand the position. In ejections, the following convention is used:

The primary vector acceleration axes are defined relative to the crewman's spinal axis (+Gz, positive spinal, eyeballs down; -Gz, negative spinal, eyeballs up; +Gx, positive fore-and-aft, eyeballs in; -Gx, negative fore-and-aft, eyeballs out; +Gy, positive lateral, eyeballs left; -Gy, negative lateral, eyeballs right).

Forces and G's - Newton's second law states that the force on a body is a function of the mass it contains and the acceleration it undergoes. It is represented in an equation as

Force = Mass * Acceleration [F=MA].

The acceleration is usually measured in terms of the G, or gravity, force equivalent. For each 32 feet/second^2 or 9.8 meter/second^2, one experiences 1 G of acceleration. A rocket assisted seat has a G rating of 5-10, while a pure catapult seat would be in the 10-20 G range.

G's and speed - To determine the speed of the seat at any point in time, one solves the Newton equation knowing the force applied and the mass of the seat/occupant system. The only other factors that are needed are the time for the force to be applied and the initial velocity present (if any). This all works together in the following equation:

Speed (final) = Acceleration * Time + Speed (initial)

[V(f) = AT + V(i)]

Initial velocity may involve the climb or sink rate of the aircraft, but most likely involves velocity resulting from a previous ejection force. For example, in most current seats, the ejection in a two step process where an explosive catapult removes the seat from the aircraft then a rocket sustainer gives final separation. So to solve this seat system, the Newton equation would be solved twice. Once with a V(i) of zero for the catapult and a second time where the initial velocity would be the speed at which the seat left the catapult.

Seat speed, aircraft speed, & aircraft size:

All the above parameters, force, mass, time, and seat sequencing, need to be considered when the system is applied to an operating aircraft. A seat speed needs to be high enough to give a reasonable separation distance between the occupant and the aircraft. At the same time, the operating time needs to be short enough to move the person out of danger and allow all actions to take place. But as speed goes up and time goes down, the G force may become excessive. Therefore distance and time have to be balanced to provide a system that will operate swiftly, provide adequate separation, and not impose an undue G load on the seat occupant. This relationship is given in the following equation:

Distance = 1/2 * Acceleration * Time^2 + Speed (initial) * Time

[D = 1/2AT^2 + V(i)T]

Pilot size and weight:

No discussion has been made about the occupant of the seat. This is important since the mass of the pilot will ultimately have an effect on the acceleration. There are three things determining the mass to be ejected and two of them are essentially constant. These are seat mass, equipment mass, and pilot/occupant mass. The seat mass is composed of the seat itself, any pyrotechnics that eject with it, the survival kit, and the parachute.

These weights can vary greatly. For the Martin Baker H-7 seat as installed in the F-4 phantom they were as follows, seat = 193 pounds (88 kg), survival kit = 40 pounds (18 kg), and parachute = 20 pounds (9 kg). Looking at the McDonnell Douglas ACES II seat, the seat weight drops to about 150 pounds (68 kg) with the other factors remaining essentially constant. For seats used in some aircraft, weight is even less as the survival kit may be deleted since the aircraft is only used for flight test or over land where rescue is immediately available.

Equipment mass is what the pilot brings on board. The clothing worn by the occupant does not count, however the G suit, torso harness, life preserver, and helmet would. Depending on the aircraft and the occupant that may be 30-50 more pounds (14-22 kg) of weight.

The pilot mass is the largest variable since the seat mass will be determined by the aircraft and the equipment mass determined by the mission. When preparing for the addition of women pilots, the United States Air Force revised its pilot weight data and found a 5th percentile pilot to be a weight of 103 pounds (47 kg) and a 95th percentile pilot to be 205 pounds (93 kg). This difference in mass will produce a significant difference in the forces involved

Pilot position and seat actuation:

As noted above, wind blast is a factor during an ejection. From the beginning, efforts were made to keep limbs and the head in place during the ejection event. The first step was using the inertia reel straps and having the pilot lock the harness prior to activation of the seat. As seats became more automatic, gas pressure from seat activation was used to retract and lock the reel. This helped to insure the hips and torso were tight against the seat.

The head and arms received attention next. Seats designed on both sides of the Atlantic settled on the face curtain as a means of seat activation and protection for the occupant. Hands grasped a set of handles mounted at the top and pulled down. The extended curtain helped hold the head back and gave some wind blast protection. The arms were also tight against the body and, with muscles under tension, less likely to be out of position. A similar idea was the use of the center pull handle. By grasping in a two hand grip, the hands and arms are again inside the body and protected from wind blast. The final option is the side firing levers. Some designers feel that moving the hands up to a face curtain or into the center for the handle wastes valuable time. Therefore side firing handles put the hands and arms in an anatomically stable position and also reduce reaction time when the need to eject arises.

The final appendages to consider are the legs and feet. Some seats, such as the Escapac and ACES II, attempt to passively control them through the use of high sides that keep the knees together and prevent the legs from abducting. Martin - Baker and Stencel have favored the use of a strap and garter assembly that attaches to the aircraft, passes through pulleys attached to the seat, and connects to the ankle of the occupant. As the seat moved up the rails, the cords tighten and pull the feet and legs into the bottom of the seat.

THE WORKING OR EJECTION SEQUENCES

A typical ejection sequence includes the following functions which occur generally in the order listed below:

Seat activation: Seats are activated through different methods. Some have pull handles on the sides or in the middle of the seat. Others are activated when a crew member pulls a face curtain down to cover and protect his or her face.

Canopy or hatch jettison: Prior to the ejection system launching, the canopy has to be jettisoned to allow the crewmember to escape the cockpit. There are at least three ways that the canopy or ceiling of the airplane can be blown to allow the crewmember to escape:

Lifting the canopy - Bolts that are filled with an explosive charge are detonated, detaching the canopy from the aircraft. Small rocket thrusters attached on the forward lip of the canopy push the transparency out of the way of the ejection path.

Shattering the canopy - To avoid the possibility of a crewmember colliding with a canopy during ejection, some egress systems are designed to shatter the canopy with an explosive. This is done by installing a detonating cord or an explosive charge around or across the canopy. When it explodes, the fragments of the canopy are moved out of the crewmember's path by the slipstream.

Explosive hatches - Planes without canopies will have an explosive hatch. Explosive bolts are used to blow the hatch during an ejection.

Seat ejection/crewmember extraction:

In modern ejection seat there is a two stage propulsion system for Seat ejection/ crewmember extraction. The catapult remained as the initial booster to get the seat/man mass clear of the cockpit, while the rocket motor came on line, once clear of the cockpit, to act in a sustainer mode. When combined into a single unit, this propulsive element was termed the rocket catapult.

Drogue parachute deployment:

This small parachute is deployed prior to the main parachute; it designed to slow the ejection seat after exiting the aircraft. Once out of the plane, a drogue gun in the seat fires a metal slug that pulls the drogue parachute, out of the top of the chair. This slows the person's rate of descent and stabilizes the seat's altitude and trajectory. After a specified amount of time, an altitude sensor causes the drogue parachute to pull the main parachute from the pilot's chute pack. At this point, a seat-man-separator motor fires and the seat falls away from the crewmember. The person then falls back to Earth as with any parachute landing.

Seat man separation:

Test flights and operational experience showed that some aspects could be safely automated. One of the main ones was the removal of the occupant from the seat. Multiple methods have been used ranging from simple to complex. The simplest is gravity. The lap belt and shoulder restraints are released and the seat will drop away of its own accord. In some cases this is assisted. The original Escape seat used a rubber bladder system and a bottle of nitrogen. When the time delay expired, a bell crank rotated pulling retaining pins from the straps and puncturing the bottle. High pressure gas inflated bladders in the bottom and back of the seat, pushing the occupant away.

There was a small probability of collision following the split. Therefore, in later versions of the seat, the gas assembly was replaced by a downward firing rocket at the top of the seat to insure a positive separation distance.

Recovery parachute deployment and inflation:

The altitude of parachute deployment is an important issue. Above 10 000 feet there is insufficient oxygen in the air (reduced altitude thins the air) to maintain consciousness. If the parachute opens too high, the occupant may become hypoxic and pass out. To alleviate this problem, many seats added a barostatic sensor to the parachute assembly. If below the preferred height, chute deployment would occur without delay. If above the appropriate height, a delay was initiated until the altitude conditions were met. One would think that the delay would not be needed since supplemental oxygen could be included as a part of the seat. However, masks can be ripped off by wind blast. Therefore altitude restrictions and opening the chute at the correct height is still important.

Parachute Descent and Landing:

This phase of the ejection sequence is critical to the outcome of the entire process of escape and yet 90 per cent of all non-fatal injuries associated with escape occur during landing. Although the techniques of landing by parachute are easily taught and simulated by jumps from training towers, the incidence of sprained or fractured ankles is estimated to be 50 per thousand descents. The correct procedures for parachute landing are taught aircrew during several phases of their training.

THE ACES II EJECTION SEAT

The Advanced Concept Ejection Seat (ACES) was designed to be rugged and lightweight compared to earlier systems. It also was designed to be easy to maintain and updatable.

It includes the following features:

- **Electronic Sequencing and timing**
- **Auto sensing of egress conditions**
- **Parachute reefing to control opening at all speed ranges**
- **Multi-Mode operation for optimum recovery of the crewman**

The ACES II is a third-generation seat, capable of ejecting a pilot from zero-zero conditions up to maximum altitude and airspeeds in the 250 knots (288 mph / 463 kph) range. The peak catapult acceleration is about 12gz. The ACES II has three main operating modes, one each for the low speed/low altitude, medium speed, and high speed/high altitude.

- **Mode 1: low altitude, low speed** - Mode 1 is for ejections at speeds of less than 250 knots (288 mph / 463 kph) and altitudes of less than 15,000 feet (4,572 meters). The drogue parachute doesn't deploy in mode 1.
- **Mode 2: low altitude, high speed** - Mode 2 is for ejections at speeds of more than 250 knots and altitudes of less than 15,000 feet.
- **Mode 3: high altitude, any speed** - Mode 3 is selected for any ejection at an altitude greater than 15,000 feet.

Deployment is delayed by the sequencer until the seat-man package reaches either Mode 2, or Mode 1 conditions, whichever comes first.

Seat modes are selected by the sequencer based on atmospheric conditions, and the modes vary depending on differences in the conditions such as apparent airspeed and apparent altitude.

Recovery Sequencing Subsystem

Seat functions are normally activated by the Recovery Sequencing Subsystem which consists of the environmental sensing unit, and the recovery sequencing unit, an electronic box located inside the seat rear on the right hand side. The environmental sensing unit consists of two altitude compensated dynamic pressure transducers, and two static pressure transducers. The dynamic pressure sensor (pitot tubes) are located on or near the headrest and read the air pressure as the seat exits the aircraft. The pressure differential between them and the ambient (static) sensors behind the seat is compared by the recovery sequencing unit to determine what operating mode the sequencer should select.

Ejection control handles

Firing of the seat is normally by pulling one of the ejection control handles mounted on the seat bucket sides. (On ACES seats fitted to F-16s and F-22s the ejection control handle is located in the center of the front of the seat bucket) The side pull handles are mechanically linked so that raising one will lift the other as well. Raising the handles actuates a pair of initiators via mechanical linkages.

Stapac Package

One particularly unique feature to the ACES II is the STAPAC package. STAPAC is a vernier rocket motor mounted under the seat near the rear. It is mounted on a tilt system controlled by a basic pitch-rate gyro system. This system is designed to help solve one of the great problems inherent to ejection seat systems. Center of mass/Center of gravity is extremely important in terms of keeping the thrust of the booster rocket from inducing a tumble. Rocket nozzles for the main boost of a seat are aligned to provide thrust through the nominal center of gravity of the seat-man package. The STAPAC provides a counter force to prevent extreme pitching in cases where the CG is off by up to +2 inches. The yellow flag is a safety pin preventing accidental firing of the STAPAC.

Survival kit

Another unusual feature is related to the survival kit. In most ejection seats the survival kit is a rigid fiberglass box that makes up the seat inside the seat bucket. The ACES II survival kit is a soft pack that is stored under a fiberglass seat lid that is hinged at the front. When the pilot separates from the seat, the straps that connect him to the survival kit lift the seat lid up and forward. The seat kit then slips free from the rear end.

Inertia Reel Harness Assembly

The Inertia Reel Harness Assembly is located in the center of the seat back just below the headrest. The inertia reel fulfills two functions: (1) it acts like the shoulder belt in a car, restraining the pilot against a 2gx forward (-x) motion. (2) upon ejection, it retracts the pilot to an upright posture to minimize the possibility of spinal damage due to spinal misalignment upon catapult ignition. On the left side of the seat bucket there is a handle which allows the crew member to manually lock the reel prior to intense maneuvers or landing to prevent possible injuries.

Drogue System

The Drogue System consists of a hemisflo chute, a small extraction chute, and the Drogue Mortar. The drogue mortar is fired in Mode 2 and Mode 3 to slow and stabilize the seat-man package. This is intended to prevent or limit the injuries to the crewmember as he/she is exposed to the windblast after exiting the aircraft. The mortar fires a 1.2 Lb slug of metal that draws the extraction chute out which by means of a lanyard deploys the drogue chute. The extraction chute is packed in a small wedge-shaped container on the upper left rear of the seat covered with metalized fabric. The lanyard is also covered in the metalized fabric. The drogue mortar is below this, and the drogue is packed in the metal covered box below this. The lid to the drogue is retained by a small plunger unit that is held in place by machining on the slug and released when the mortar fires.

Safety Lever

The seat is made safe by means of a Safety Lever on the left side of the seat bucket which prevents the seat from being fired when the lever is in the up/forward position. When it is down/back flat against the side of the bucket, it allows the seat to be fired.

Emergency Manual Chute Handle

The Emergency Manual Chute Handle is located on the right hand side of the seat bucket, and functions to fire the main chute mortar and initiate seat separation in case of failure of the electronic sequencer. Unlike other seats, the manual chute handle is inhibited in the aircraft and prevents the systems from functioning while the seat is still in the rails. In the event of ground egress, the crewman would have to unstrap the two shoulder harness connections, the two seat kit connections and the lap belt prior to egressing the aircraft. Given the 0-0 capability of the seat, in any case requiring extremely rapid egress, ejection would be a viable alternative.

Emergency oxygen system

The emergency oxygen system consists of an oxygen bottle attached to the seat back, an automatic activation lanyard, and a manual pull ring. As the seat rises up the rails, the lanyard activates the oxygen bottle and allows the crewman access to oxygen as long as he is still connected to the seat. During an in-flight emergency that does not require ejection; the oxygen bottle provides breathable air for enough time to return the aircraft to 10000 feet or below where the atmosphere is thick enough for the pilot to breath.

SCHOOL OF AERONAUTICS (NEEMRANA)

UNIT-V NOTES

FACULTY NAME: D.SUKUMAR. **CLASS: B.Tech AERONAUTICAL**

SUBJECT CODE: 5AN3 **SEMESTER: V**

SUBJECT NAME: AIRCRAFT SYSTEMS

GENERAL MAINTENANCE PRACTICES

Jacking, levelling and mooring, refuelling and defueling of aircraft, safety precautions. Hydraulic and fluid systems precautions against contamination. Identification colour coding, symbols and other markings to identify the fluid systems.

JACK IDENTIFICATION

All aircraft hydraulic jacks are either axle or airframe (tripod) jacks. These jacks use standard, authorized aircraft hydraulic fluid. They have a safety bypass valve that prevents damage when a load in excess of 10 percent over the rated capacity is applied. For example, the safety valve on a 10-ton jack will bypass fluid at 11 tons of pressure.

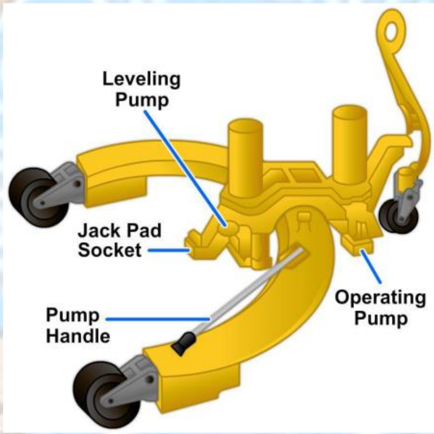
Axle Jacks

Axle jacks are used for raising one main landing gear or the nose gear of an aircraft for maintenance of tires, wheels, and struts. There are four different types of axle jacks and many different sizes (lifting capacity in tons). The smaller hydraulic axle jacks are normally squadron or unit permanent custody equipment. That means your outfit is responsible for making sure the jacks are load tested at the support equipment (SE) division of the FRC before being put into service, and annually thereafter. Special inspections include 13-week inspections at FRC SE, but a load test is not required every 13 weeks. A record of maintenance, inspections, technical directives, and load testing is kept on OPNAV Form 4790/51.
All model designations for axle jacks begin with the letter *A*, for axle, such as A10-1HC. The number following the *A* shows the jack capacity in tons, such as 10 for a 10-ton jack. This is followed by a dash (-) and the specific jack identification number. Then comes two letters that show the type of jack (HC = hand-carried, HS = horseshoe, and OR = outrigger). The three types of axle jacks are discussed below.

HAND-CARRIED — These axle jacks (*Figure below*) are portable, self-contained units, with single or double manually operated pumps. They have carrying handles, pump handles, reservoir vent valves, release valves, and safety valves. The different model sizes vary from 4 3/4 inches to 9 inches high (closed). Their weights vary from 26 to 120 pounds.

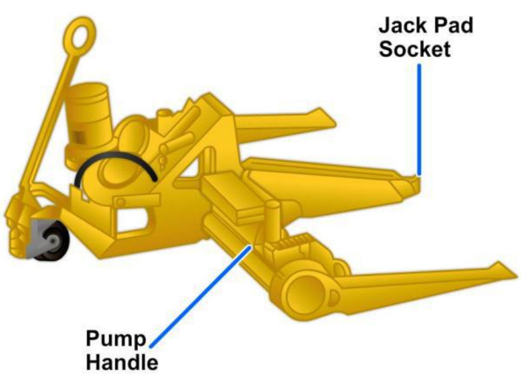
Hand-carried axle jack.

HORSESHOE — Horseshoe axle (*Figure below*), or crocodile jacks, consist of a lifting arm supported by two hydraulic cylinders. The cylinders move up over the stationary pistons when the manual pump operates. The A25-1HS is a large jack—5 feet long, 5 feet 8 inches wide, standing 2 feet 1 3/4 inches high, and weighing 900 pounds.



Horseshoe axle jack.

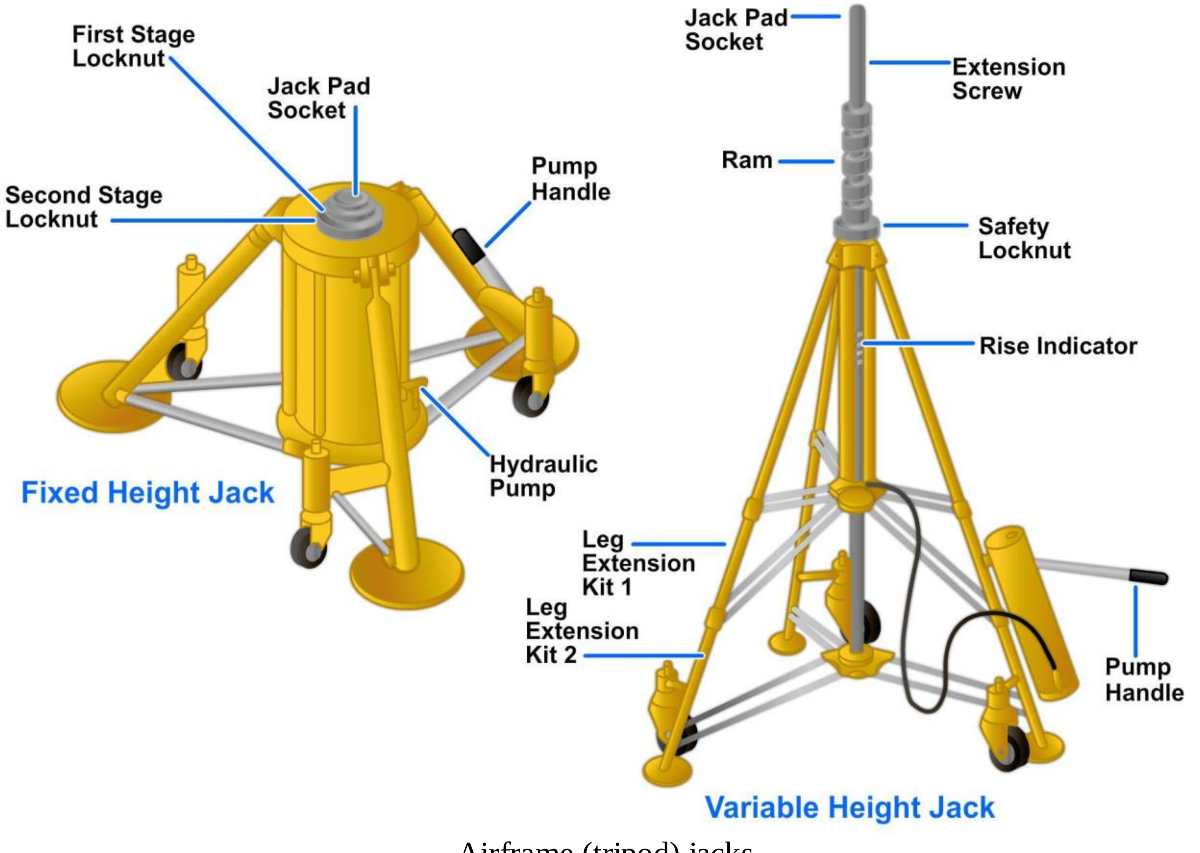
OUTRIGGER — This cantilever axle jack (*Figure below*) is a very large and heavy jack. It weighs 2,190 pounds and is 7 feet 3 inches long, 6 feet 8 inches wide, and 2 feet 3 inches high. A double (two-speed) pump mounts on the left-hand side of the frame to operate the hydraulic cylinder.



Outrigger axle jack.

Airframe (Tripod) Jacks

Airframe (tripod) jacks are used for lifting the entire aircraft off the ground or deck. Airframe jacks are commonly called tripod jacks. You may hear them called wing, nose, fuselage, or tail jacks. These names come from the jack placement on the aircraft. The points for jacking vary with the type of aircraft, and can be found in the MIM for each type of aircraft.
There are two different types of tripod jacks—fixed height and variable height. Both are mobile, self-contained, hydraulically operated units. They consist of three basic assemblies. These assemblies are the hydraulic cylinder, the tubular steel wheel tripod leg structure, and the hydraulic pump. The main difference between the two types is that the tripod structure on a variable height jack can be adjusted to different heights by adding leg extensions.
All model designations for tripod jacks begin with the letter *T*, for Tripod, such as T10-2FL or T20-1VH5. The number following the *T* indicates the jack capacity in tons, such as 10 for a 10-ton jack. This is followed by a dash (-) and the specific jack identification number. Then comes two letters indicating the type of tripod jack (*FH* = fixed height, or *VH* = variable height). The number that follows the *VH* in variable height jacks indicates the number of leg extension kits available for that jack. *Figure below* shows a T20-1VH5 jack with only two of five extension leg kits installed. Each leg extension kit increases the effective height of the basic jack by 18 inches. The airframe tripod jacks weight varies from 275 pounds to 837 pounds.



Airframe (tripod) jacks.

Several safety features are built into the tripod jacks. A locknut—also called a ring or collar—on the ram mechanically locks the ram in position. The locknut prevents the ram from settling in the event of hydraulic failure or inadvertent lowering. A safety bypass valve in the system bypasses fluid from the pump or ram when excessive pressure is built up.

Airframe (tripod) jacks are normally checked out from the SE division (FRC) when needed. Since transporting these heavy and cumbersome jacks is a problem, they often remain in custody of an organization for a prolonged period of time. The organization must be responsible for their care and cleanliness during periods when not in use. As with axle jacks, these jacks need to be load tested prior to being placed in service—and annually thereafter. Special inspections are performed every 13 weeks at FRC SE and recorded on the OPNAV Form 4790/51.
The MIM will show what type of aircraft jack to use at each position. During deployment, the jacks that are called for in the MIM may not be available. The *Index and Application Tables for Aircraft Jacks*, NAVAIR 19-70-46, contain a list of approved prime and alternate jacks for all Navy and Marine aircraft. It was prepared under the direction of the Commander, Naval Air System Command, by the Naval Air Engineering Center.

PREOPERATIONAL INSPECTION

The same basic safety precautions apply to all jacks. A good preoperational inspection should be conducted before use. NAVAIR 19-600-135-6-1 is the general pre-op MRC for all jacks. The jack must have been tested within the last 13 weeks and if the jack is dirty, it should be wiped down. Cracks or broken welds can't be seen under dirt. If the jack is covered with hydraulic fluid, it may be leaking and should be inspected more closely.

The reservoir should be checked and it should be full with the jack ram fully collapsed. If the reservoir is low, it should be checked for leaks somewhere. The reservoir should be filled with clean, fresh, hydraulic fluid and the filler plug vent valve checked to make sure it is not clogged. If the plug is blocked, it may get an air lock, and the jack may not operate correctly. Pressure could also build up in the reservoir and cause a rupture. The pump handle needs to be checked for bends and the pump rocker arm and link for elongated or out-of-round holes. These are signs that the jack may have been overloaded, and that the safety bypass valve is malfunctioning.

With the filler plug air vent valve open and the release valve closed, the ram should be pumped up and checked for leaks and full extension. When the ram reaches full extension, the pumping pressure will increase. It is important not to continue to pump or it may cause damage to the internal ram stops because there is no load on the jack.

The ram and screw should be lowered out the extension screw, but not forcibly overextended past the internal stops. It should be checked that it is clean and oiled. If it is dirty, it should be wiped clean and coated with a light film of MIL-PRF-7870 oil.

On jacks equipped with wheels, the wheels and springs suspension assemblies must be checked to make sure they are in good condition. Towing or dragging these jacks around with broken wheels will damage the frame or reservoir.

Since many leaks in jacks will only appear when the jack is under a load, possible leaks can be found when jacking the aircraft. If a leak or other defect is found during the preoperational inspection, use of the jack should be discontinued. The jack should be downed, red-lined, tagged as bad, reported, and turned into the SE division (FRC) for repairs. A defective jack should never be left where someone else may use it.

HANDLING AND MOVEMENT

Handling airframe jacks can be hazardous. The jacks are heavy—anywhere from 110 to 900 pounds—and the wheels are free-swiveling and small. Directional stability is poor, and pushing one into position around an aircraft is no simple chore. A jack moved or positioned by one person is hazardous. If the jack is dirty and covered with grease or fluid, it's even more hazardous. The jack footplates and wheels at the base of the tripod stick out, and are notorious "foot-crunchers" and "shin-knockers." It's not hard to damage an aircraft tire, wheel brake assembly, hydraulic lines, landing gear door, or any other part of an aircraft if someone is careless and rams it with a jack.

Movement of jacks aboard ship during any pitch or roll of the deck is extremely hazardous. Even with a calm sea, a smart turn into the wind by the ship while you're moving an airframe jack can be disastrous. Movement of jacks from hangar to hangar, through hangar bays, and across hangar tracks and ramp seams can easily damage a jack and put it out of commission—just when someone needs it!

Transportation of jacks over longer distances ashore, such as from the SE pool to a hangar on the other side of the field, can be a real problem. If the SE division (FRC) has locally fabricated a special "jack transporter" trailer, you're in luck. If any other type of trailer, truck, or flatbed is used, sufficient manpower must be available to get the jacks on and off the vehicle safely. Jacks are heavy and cumbersome to handle. Loading and unloading is hazardous even when there are enough people.

Usually, a locally fabricated sling and some sort of hoist are necessary. Forklifts should never be used to handle or lift jacks. The tripod cross braces are not strong enough, and this will damage the jack. The chances of dropping it are also high. Forklifts must NOT be used to handle jacks.

The wheels on a tripod jack are not made for towing the jack. They are small, allow only a couple of inches of clearance, and are spring loaded. Bouncing over uneven surfaces will usually cause the jack footplates to hit the ground, and that can spin the jack around, tip it over, or damage the tripod structure. Airframe jacks don't have tow bars, the wheels can't be locked in position so they track, and there are no brakes. NEVER try to tow airframe jacks.

Free-swiveling casters and no brakes also mean that jacks can move by themselves if not properly secured. A loose, 900-pound tripod jack on a pitching hangar deck could be disastrous. Jacks can also be moved by jet or prop blast. Therefore, any jack that isn't tied down can be a hazard. Since there are no tie-down rings on the jacks, care must be taken in attaching the tie-down chains or ropes to prevent damage to the jack. This is particularly true aboard ship where the jacks are likely to be "working" against the tie-downs in rough seas.

General Hazards

The extension screws on jacks have a maximum extension range. This range is stenciled on the jack. An internal stop prevents overextending the screw. If the screw is forcibly overextended—which isn't hard to do—not only could damage be done to the internal stop mechanism, but the jack may be rendered unsafe and hazardous to use. An overextended screw is very likely to bend or break off from any side motion.

Each extension screw on a jack is equipped with a jack pad socket. The aircraft jack pad fits into this socket and into a fitting or socket in the aircraft. The sockets and pads are designed to take vertical loads but not much horizontal pressure. The pads can shear or slip from either the jack or aircraft socket if enough side load is applied.

Side loads normally result when the jacks are not raised at the same rate. This causes the aircraft to tilt or pitch. When that happens, the distance between the jacking points becomes closer in the ground plane—like the ends of a ruler will cover less distance across a desk top as you raise one end. With the weight of the aircraft holding the jacks in one place that "shrink" in distance between the jack points creates a tremendous side load on the jacks, and eventually they will break or slip. The same thing happens if all the jacks aren't lowered at the same rate to keep the aircraft level or at the same attitude it was in when jacking started.

Lowering the jack can be very hazardous. The rate of descent of a jack depends on how far the release valve is opened. Control can be very tricky when trying to coordinate three jacks at once. Usually, it takes only a small amount of rotation on the valve to get a fast rate of descent. If the valve was tightened hard before jacking, it will take force to open it. Care must be taken so extra force doesn't cause the valve to open more than expected. The valves may vary in different jacks, so it is best to get an idea of how an individual release valve reacts during the preop check. But remember it comes down a lot quicker with a 30-ton load than with a 5-ton load.

There is a safeguard to prevent the jack from lowering too fast—the safety locknut. The safety locknuts on jacks are a very important safeguard in preventing the aircraft from falling off the jacks in the event of jack failure. However, using them during raising, and particularly during lowering operations, is hazardous to hands and fingers. To be effective, the locknut must be kept about one-half thread above the top surface of the jack (the top of the ram cylinder or second ram, depending upon the model of jack). It is important to carefully keep fingers and hands clear of the area between the locknut and cylinder head so they won't be pinched or crushed. This will be easier while the jack is being raised and the locknut rotated down. Variable height jack rams have spiral grooves, which allow the locknut to rotate down the ram by its own weight. However, this means that while lowering the jack, the locknut must be held up as it is rotated up the ram. This makes it more dangerous. Depending upon the height of the jack, it normally takes two people to operate the jack and the safety nut. Do NOT try to do it by yourself.

Jacking Restrictions

There are many restrictions to jacking for each type aircraft. If any of these restrictions are violated, there is a good chance that there will be an accident, damage to the aircraft, or injury. The restrictions generally concern aircraft gross weight and configuration. Some of the considerations are fuel dispersion in fuselage and wing tanks, engines in or out, and tail hook up or down.

Details on restrictions and procedures are in the MIMs. These should be learned and followed exactly. Many squadrons will have their own local standing instructions for jacking aircraft, which contain additional safety precautions and restrictions to be followed.

JACKING PROCEDURES

The jacking procedures vary for each aircraft type and configuration. The procedures that follow are examples of what could be encountered. Fairly exacting steps are given to provide clarity. Remember, these steps are for representative type aircraft, and are not necessarily accurate for all. When actually jacking aircraft, the exact procedures described in the MIMs must be followed.

The location of the aircraft will determine what is needed for equipment. Jacking procedures on a ship require tie-down procedures to prevent aircraft from shifting on jacks. When tie-down chains are to be used, they should be positioned in accordance with the MIM, so as not to interfere with the landing gear during the drop check of the gear. Jacking procedures on land do not require tie-downs, except in high-wind conditions.

Aboard ship, squadron maintenance controls will request, through the carrier air group (CAG), permission to place an aircraft on jacks. The MIM should be checked for jacking restrictions, warnings, and cautions. The support equipment required by the MIM should be obtained, ensuring all preoperational inspections have been completed. All protective covers and ground safety devices should be installed, as required by the MIM. The surrounding area around the aircraft must be roped off during the entire aircraft jacking operation, and signs posted stating **"DANGER: AIRCRAFT ON JACKS."** The area below and around the aircraft must be cleared of all equipment not required for the jacking operation. Jack adapters must be installed, as well as aircraft mooring adapters and tie-down chains as required by the MIM. *Figure 5-27* shows an example of carrier tie-down for aircraft jacking. Wing and nose jacks must be positioned and extended until seated on wing jack and tie-down adapters.

Raising Aircraft

Jack pressure should be applied on each jack without lifting the aircraft, and checked to see that the base of each jack is evenly seated. The base position of the jack should be corrected, as required, for firm base seating. For shipboard operations, all jacks must be tie-down before jacking aircraft with a minimum of three tie-down chains per jack. The jack must be tied down at the spring-loaded wheel caster mounts, allowing the jacks to make small movements with the aircraft jack points. The aircraft parking brake must be released and main landing gear chocks removed. The aircraft should be jacked evenly and tie-down chains extended while jacking. Extension of tie-down chains must be coordinated in a way that preload on each tie-down chain is partially removed before jacking. Partial preload is maintained with jacking of aircraft by rotation of the chain tensioning grip.

NOTE

Some aircraft require the extension of the center screw to provide for clearance of the gear doors.

⚠ CAUTION ⚠

Use extreme care to raise wing jacks in coordinated, small, equal amounts. Preload on the tie-down chain is too high when tensioning grip cannot be rotated manually.

As each jack is being extended, the lock collar must be screwed down. The aircraft should be jacked until its wheels clear the deck, and the lock collar set hand tight. Each tie-down chain must be set to preload by manually rotating and tightening tensioning grip.

JACKING UP OF AN AIRCRAFT

To jack (LIFT UP) the aircraft from its steady position

OCCASION

When aircraft is need to be inspected for damage to change type and during rigging check from OGCA jacking of an aircraft has to be carried out

REQUIREMENTS

- Man power=3+1
- Man hours=3 hrs
- Documents of aircraft maintenance manual

TOOLS,EQUIPMENT REQUIRED

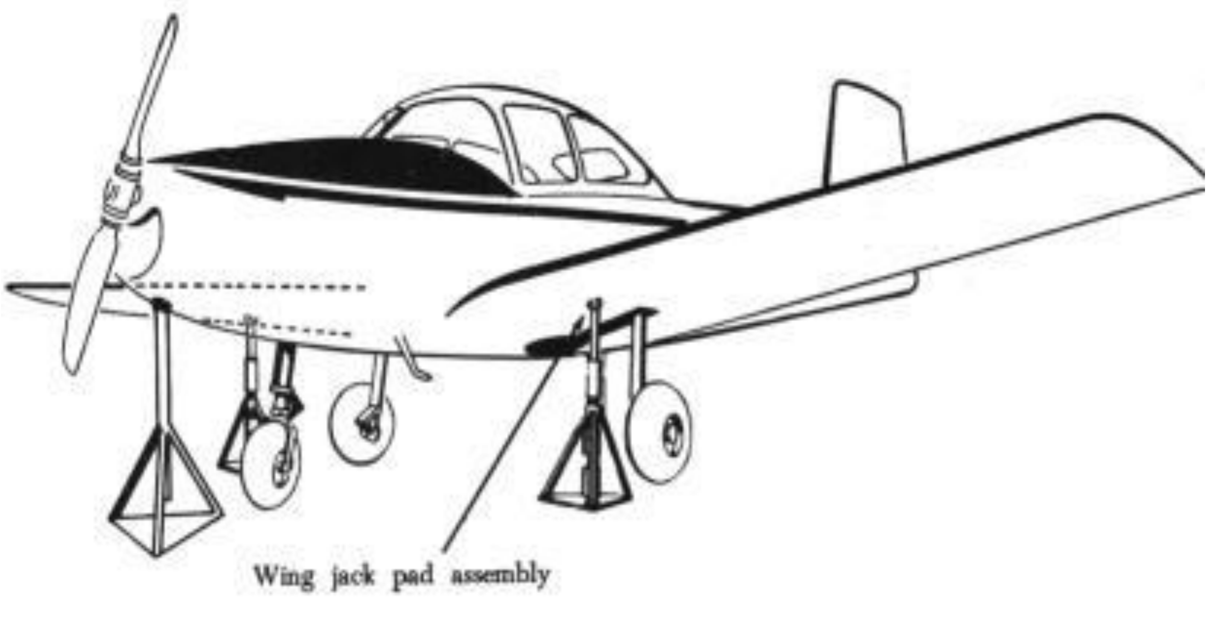
- Jacking pad
- Necessary jacks, bottle jack1, wheel chocks

PRECAUTIONS

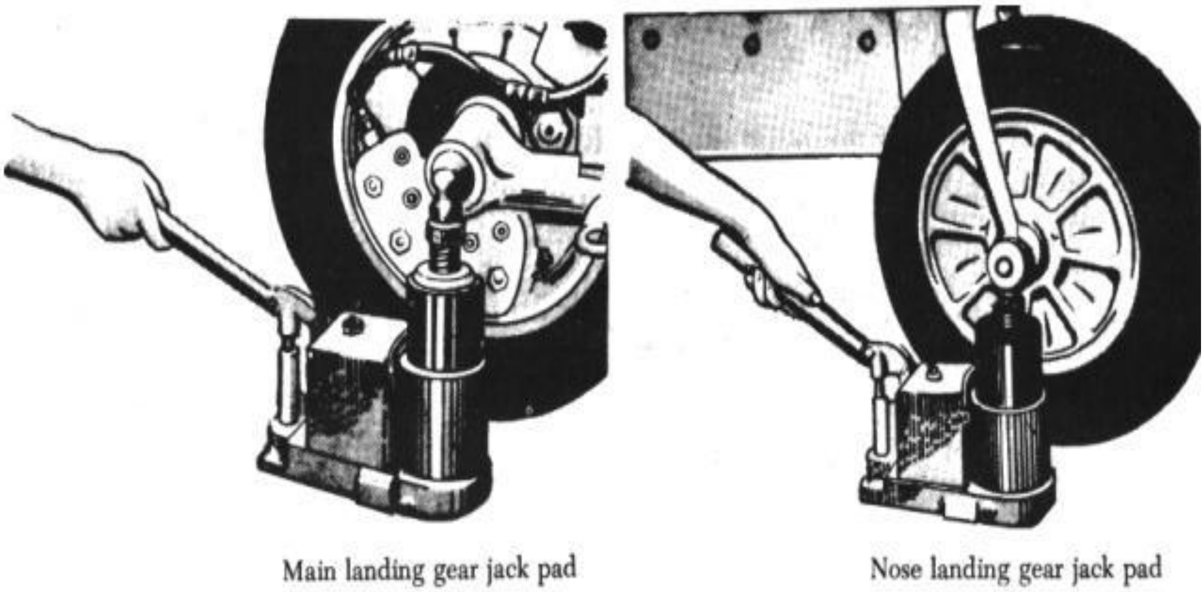
- Refer aircraft maintenance manual , ensure the capacity and semi circularity of jack
- The jacking area should be oil free
- The jacking point should of which 2 at wings and one at maximum c.g location
- There should be no person inside the aircraft while jacking
- Central surfaces should be locked
- The ballasted weight should be removed before jacking
- Jack handle should not damage structure of weight
- Clearance of propeller should be ensured before jacking

PROCEDURE

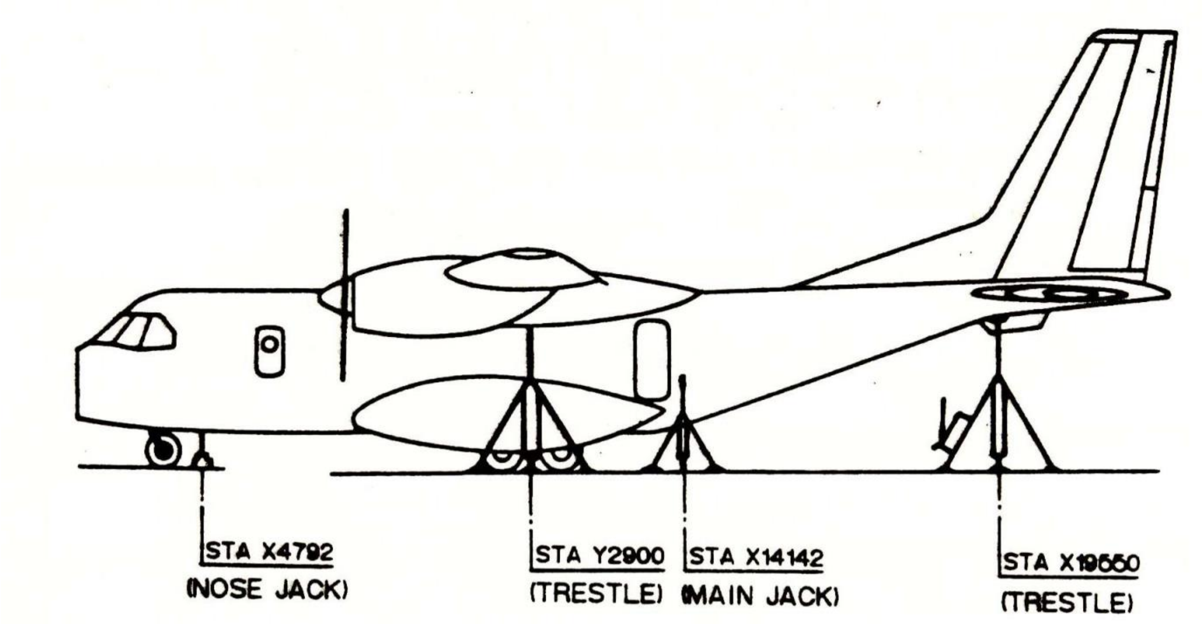
- It differs from various aircraft and refer respective aircraft maintenance manual
- Remove the mooring
- Identify the jacking points of the aircraft by placing it in level
- After finding the jacking points place the jacks at the points.
- Place a person at the jacking point to look after the raised jacks
- All the jacks should be simultaneously raised.
- After jacking, jack locks should be checked for stability and tightened.
- The necessary inspection has to be carried out.
- If the aircraft is likely to be checked for more than 24 hrs, place the adjustable truss at specified station
- Place the displace board aircraft jacks near the aircraft.



Jacking of a Complete Aircraft



Jacking One Wheel



Jacking of a Complete Aircraft

LEVELLING OF PUSHPAK AIRCRAFT

To level the aircraft for inspection purpose

LEVELING

- Leveling is the process of placing an aircraft in its rigging position by means of hydraulic or screw jacks
- The rigging position is the position of the aircraft at which longitudinal and lateral axis are parallel to ground.
- Leveling means leveling the aircraft in the horizontal position for rigging. There are three types of leveling. They are as follows

- Straight edge method
- Grid plate method
- Engineers transmit method

OCCASION

During replacement or renewal of major components, rigging checks, symmetry checks and as when DGCA require leveling process is carried out.

REQUIREMENTS

- Man hours = 3 hrs
- Man power= 3+1
- Documents= Aircraft maintenance manual

TOOLS REQUIREMENT

- Tripod screw/hydraulic jack
- Spirit level [adjustable/fixed]
- Leveling boards
- Tail trestles[fixed/adjustable]

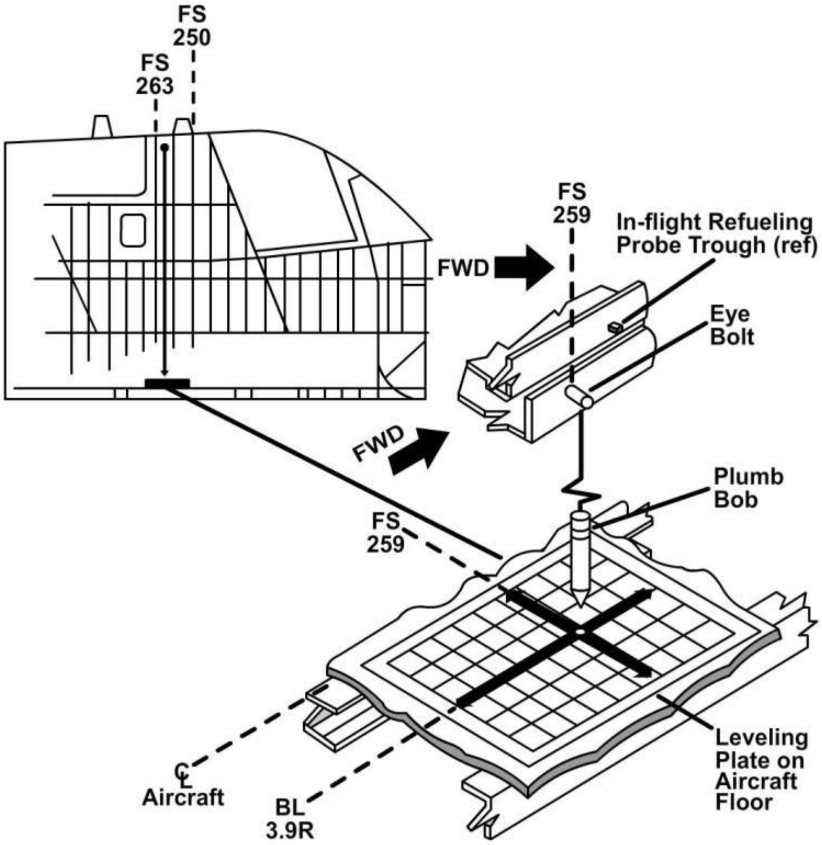
PRECAUTION

- Observe on safety precautions for jack up
- Check the accuracy of spirit level
- Always finish leveling procedure once by checking the [longitudinal level without any adjustment]

PROCEDURE

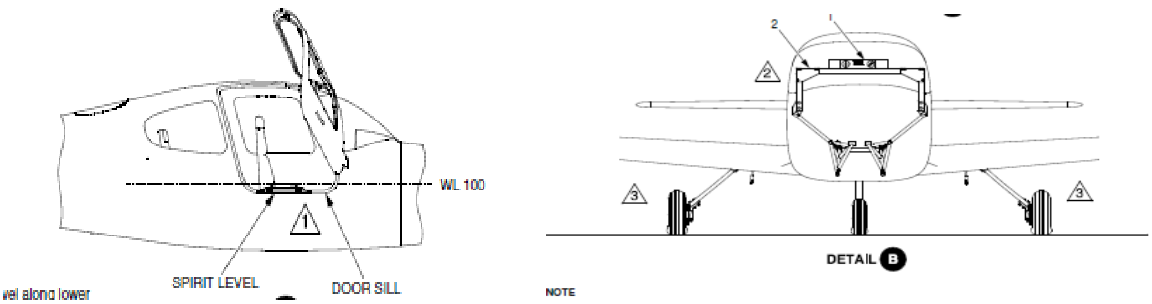
- Place the main jack below the undercarriage near the fuselage
- Place the trestle of the specified station by lifting the tail unit
- Place the longitudinal leveling board at both side of cockpit
- Place the lateral leveling board at rear of the slats
- Place the spirit level over it and adjust main jack till the bubble of spirit level is brought in centre
- Recheck the longitudinal level
- If the bubble is in the centre in both the spirit level, the aircraft is considered to be brought into level condition
- If not, then repeat the operation from step 3 to 7

An aircraft levelling technique is shown in *Figure*.

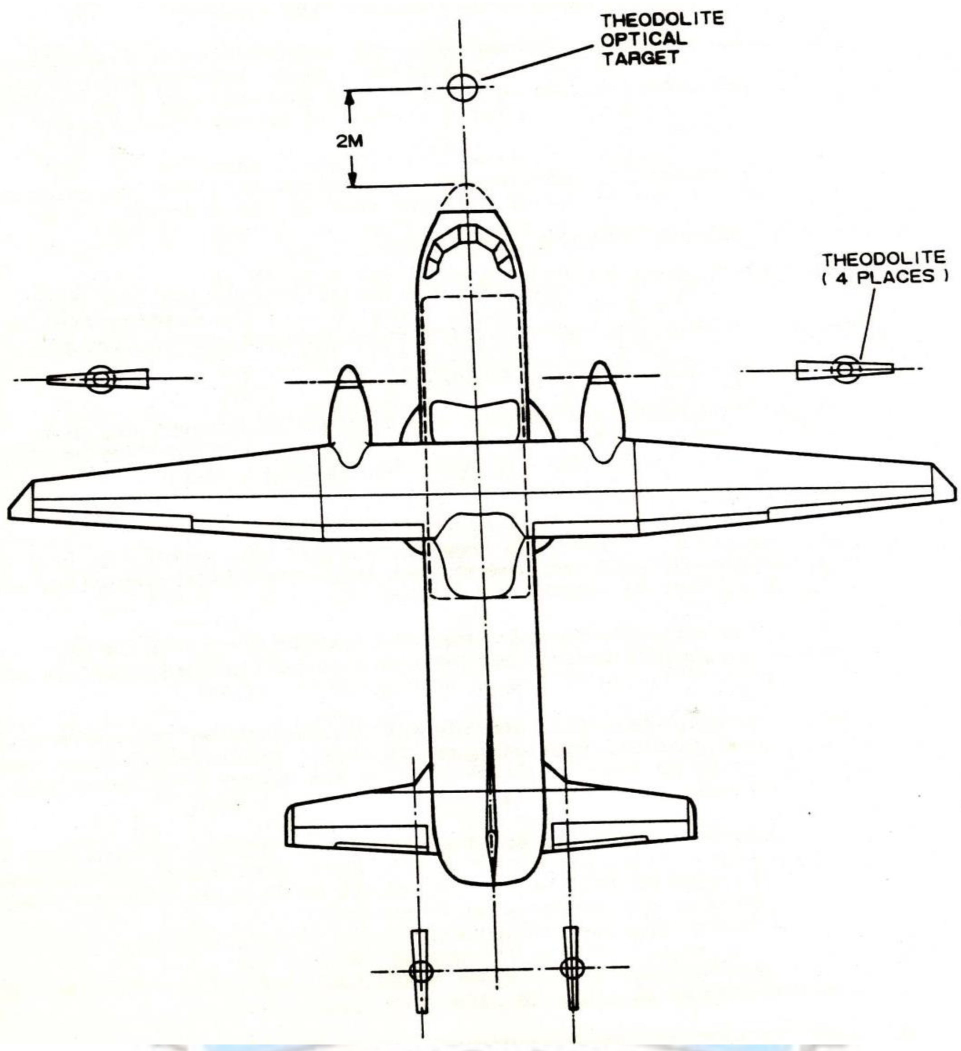


Aircraft levelling

Aircraft should be jacked at wing and nose jack point as described earlier. The plumb bob and string should be attached to the eye bolt at FS 259 (fuselage station) and positioned directly over the levelling plate on floor of aircraft. The aircraft should be levelled laterally (left to right) by adjusting wing jacks until the plumb bob tip is directly above the centre line in the levelling plate. The aircraft should be levelled longitudinally (forward and aft) by adjusting the nose jack until the plumb bob tip is directly above FS 259 line on the levelling plate. This procedure varies greatly with different types of aircraft. The applicable MIM must be used to perform a levelling procedure.



Aircraft levelling



Jacking of a Complete Aircraft

Thus the aircraft is leveled and is made ready for further checks.

Mooring:

The following is a list of equipment need to park and/or moor (tie down) the airplane.
- 4 wheel chocks
- 3 screw-in mooring rings (left and right wing, and tail)
- 3 ropes (nylon or other non-shrinking/non-stretching synthetic material)

If wheel brakes are hot from prolonged taxi, allow brakes to cool before setting parking brake.

Controls may be secured with ailerons neutral and horizontal stabilizers leading edge down by pulling the control stick aft as far as possible and fastening seat belt snugly around it.

SHORT-TERM PARKING

Perform this procedure for short-term parking of the airplane.

1. Taxi or tow airplane to desired parking position.
2. Align nose of airplane into the wind.
3. Ensure nose wheel is centered.
4. In windy or gusty weather, moor (tie down) the airplane, see Section 10-20 Mooring (Tying Down) on page 11 of this chapter.
5. Set the parking brake. If wheel brakes are hot from prolonged taxi, allow brakes to cool before setting parking brake.
6. Place chocks in front of and behind main wheels.
7. Release the parking brake.
8. Secure flight controls in neutral position; retract flaps.
Controls may be secured with ailerons neutral and horizontal stabilizers leading edge down by pulling the control stick aft as far as possible and fastening seat belt snugly around it.
9. Close and lock the doors.

LONG-TERM PARKING

Perform this procedure for long-term parking of the airplane.
1. Perform the steps for short-term: parking.
2. Moor (tie down) the airplane, is shown below
3. Install external rudder lock if available.

ALL GUST LOCKS MUST BE REMOVED FROM THE AIRCRAFT PRIOR TO TAXI AND FLIGHT. CARE SHOULD BE TAKEN NOT TO DEFORM OR DAMAGE THE STRUCTURE DURING INSTALLATION AND REMOVAL OF THESE LOCKS. ALL DEFOMRATION, DAMAGE AND INTERFERENCE MUST BE REVIEWED BY A QUALIFIED MECHANIC OR TECHNICIAN PRIOR TO FLIGHT.
4. Install pitot/static, canopy, and propeller covers as applicable.
5. Refer to engine, electrical, and fuel system chapters of this manual for information on required servicing for long-term storage.

The airplane has three mooring points: one under each wing, and one under the tail. Mooring rings are provided to secure tie down ropes into the mooring points. Park the airplane; see the procedures for short and long term parking of the airplane.

Attach tie-down ropes to ground tie-downs and aircraft mooring rings. Leave sufficient play or looseness in the ropes to prevent inadvertent loading of the structure. Also, if using a rope, tie a bowline knot to allow tension freedom.

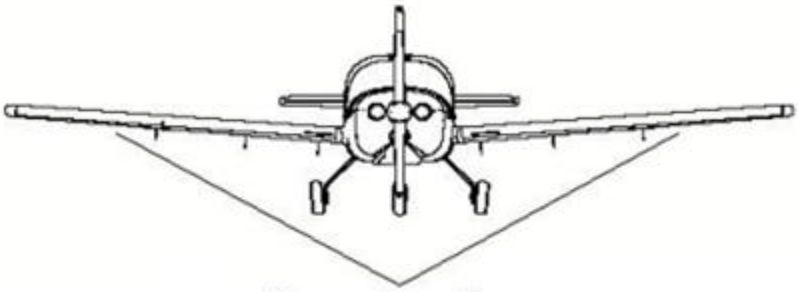


Figure 10-1 Mooring Points on the Wings

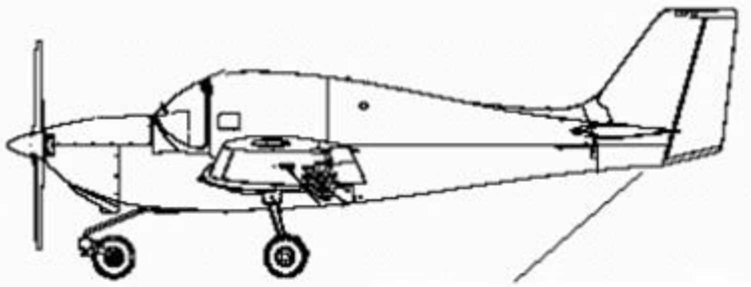


Figure 10-2 Mooring Point on the Tail

Proper tie-down procedure is the best precaution against damage to the aircraft by gusty or strong winds. To tie-down the aircraft securely, proceed as follows:

1. Head the aircraft into the wind

2. Place chocks fore and aft of each main wheel.

When chocking the wheels, ensure that the chocks used are not too large to come in contact with the wheel fairings. The use of chocks that are too large may damage the fairings.

3. Drive stakes into the ground approximately three feet outboard of each wing tip and to either side of tail wheel.

4. Install one tie-down ring in each wing tip rib.

5. Tie a sufficiently strong rope to each wing tie-down ring and anchor to the ground stakes. Allow a little slack in each tiedown rope.
6. Tie the center of the rope to the tail wheel fork and anchor the rope ends to the ground stakes at either side of the tail wheel.
7. Ensure that the canopy is closed waterproof and locked.

AIRCRAFT RIGGING

The term “rigging” has been around a lot longer than airplanes have. It’s one of the many carry-over terms from the sailing world that aided aviation during its infancy, and still holds them close together. After all, we use “nautical miles” for distance, “knots” for speed, and both pursuits have an uncanny way of emptying one’s wallet.
Just as in sailing, trimming and tuning the way that we harness the wind is the key to performance and efficiency. Chances are that your aircraft’s performance is somewhat less than the numbers in your operations manual. While it’s questionable whether any of our planes actually ever flew quite as fast as the original advertisements boasted, there is a lot that you can do to get close.

Airframe Alignment

Due to the handmade nature of general aviation aircraft, a certain degree of variation in the manufacturing process is inevitable. Manufacturers employ jigs and fixtures to get each part as close as possible to the ideal blueprint design.
However, most designs also employ methods of fine-tuning the airframe such as spacers and shims to ensure that the proper dihedral is in the wings, angle of incidence is correct on all flying surfaces, and the airframe is as straight as possible.

General aviation aircraft tend to lead long lives, and those lives can include all sorts of accidents, incidents, hangar rash, and other activities that can change the alignment of the airframe. In some cases, checking the alignment of the airframe is fairly straightforward; in others it can require specialized tools. However, there are a few simple checks that you can do to verify the basics.

Begin the process by levelling the aircraft. Every aircraft has a level point at which the aircraft must first be levelled laterally. In many aircraft, the levelling point is between the two control yokes. This makes it easy to balance a bubble level across the yokes or the control shafts. Ideally, this process is conducted on a level surface, but as long as the parking spot isn’t too bad, you should be able to get the aircraft level by simply adjusting the air pressure in the tires. (Don’t forget to re-inflate the tires before flying.). While you’re in the cockpit, the first thing to do is to ensure that the aircraft instruments are reading what the aircraft is actually doing.

The turn and bank indicator and the attitude indicator should be showing the aircraft to be perfectly level. If they're not, each instrument can be adjusted by loosening the front mounting screws and gently rotating the instrument to the correct position. I've heard of more than a few cases where pilots thought the aircraft was flying with a wing down, only to discover that the instruments were in need of adjustment.

The next step is to ensure that the fixed surfaces of the aircraft are in alignment. Using a tape or string that does not stretch measure the distance from each wingtip to a point on the centerline of the tail cone. The same technique can be used to check the horizontal stabilizer by measuring to a central point at the front of the aircraft. Do not use the front of the vertical stabilizer or the spinner as a measuring point because many aircraft are designed with asymmetric mountings to help reduce P-factor. The left and right measurements should be equal. If they're not, the aircraft may have been improperly repaired following an accident.

If your shop floor is perfectly flat, you may be able to measure the wing dihedral, but you'll need to have access to the proper rigging tools to check the wing and tail angle of incidence. In most cases, you'll find everything in order, but it always pays to check the fixed surfaces first, before spending time and money on the control surfaces.

Engine Alignment

As we stated earlier, many aircraft designs set the engine thrust line at an angle to help reduce P-factor. In most aircraft, this alignment is built into the engine mount design. However, if corrections are required, washer spacers are inserted, as necessary, between the rubber dampers (LORD mounts) and the engine case.

Most mounts consist of two solid rubber "biscuits" that encase a gelfilled core. When they are in good condition, they do an excellent job of isolating the engine from the steel engine mount. However, as they age, they begin to harden and sag under the weight of the engine. In addition, it's quite possible that the engine alignment may not have been properly done at the last engine change. The bottom line is that if your prop isn't pulling the plane in the direction you want to go, chances are that you're not getting to your destination as efficiently as possible.

Adjusting your engine's alignment is not a difficult task. The first step is to determine whether you have an alignment problem. On most aircraft, this can be easily accomplished by examining the alignment of the spinner to the nose bowl. Even small variations left, right, up, or down can cause problems.

Adjusting the alignment is fairly straight forward. The mounts are loosened and spacers are inserted, as needed, between the rubber dampers and the engine case until the alignment is correct.

Control Surface Rigging

Control surface rigging checks are probably the most neglected maintenance procedure on general aviation aircraft.

If you don't believe me, pick up your maintenance logbooks and look for an entry that says something like this:

Control surface rigging checked and adjusted per manufacturer's instructions.

It's a well-known fact that drag reduction is the best way to increase aircraft performance. When we think traditionally about drag reduction, things like fairings and removing steps and antennas come to mind. However, improperly rigged control surfaces top the list for reasons two aircraft of the same model can have very different performance numbers.

A properly rigged aircraft should be able to fly level and hands-off so long as the loading is balanced. If yours doesn't, that's a sure sign to check the rigging of the control surfaces. Other signs of rigging problems can include fixed trim tabs that are significantly bent to allow the aircraft to fly level, or the need to use regular aileron and rudder trim in straight and level flight.

However, even if these symptoms are not present, it doesn't hurt to go through a complete rigging check. It's extremely unlikely that your aircraft is already properly rigged, and I have yet to hear of an aircraft that didn't require adjustments following a rigging check.

The rigging process for every aircraft varies by manufacturer. A good starting point is to check and set the cable tensions.

A calibrated cable tensiometer is a must for this task, and the adjustment process can be quite complex on some aircraft. Every action has some reaction. For example, adjusting the cable tension at one point may cause the control surfaces to become misaligned with respect to each other. This is why it is extremely important to follow the manufacturer's rigging instructions carefully.

Flaps and ailerons are probably the most common source of misalignment.

Not only does each surface need to be set for the proper travel and alignment with the yoke, but each side must be aligned with its counterpart on the opposite side. Surprisingly, flaps are a very common cause of banking problems, and they can also have a significant effect on climb and cruise performance.

Drooping flaps can induce a lot of drag. Depending on the aircraft, the flap-adjustment procedure may require applying upward pressure on the flaps to take out any play and properly check the alignment.

Aircraft designs, such as the Maule, reflex the flaps upward to reduce wing drag during cruise flight. This is also a technique used by some air racers. Reflexing the flaps effectively reduces the chord of the wing and, therefore, reduces drag in cruise. However, be warned that setting the flaps outside of the manufacturer's specifications is illegal on certificated aircraft and makes you an unwitting test pilot regardless of the aircraft category.

Once all of the control surfaces are properly rigged, you should straighten any fixed trim tabs so that you will have a clean starting point from which to work.

Then you can proceed to the flight-testing and trim-tab adjustment phase.

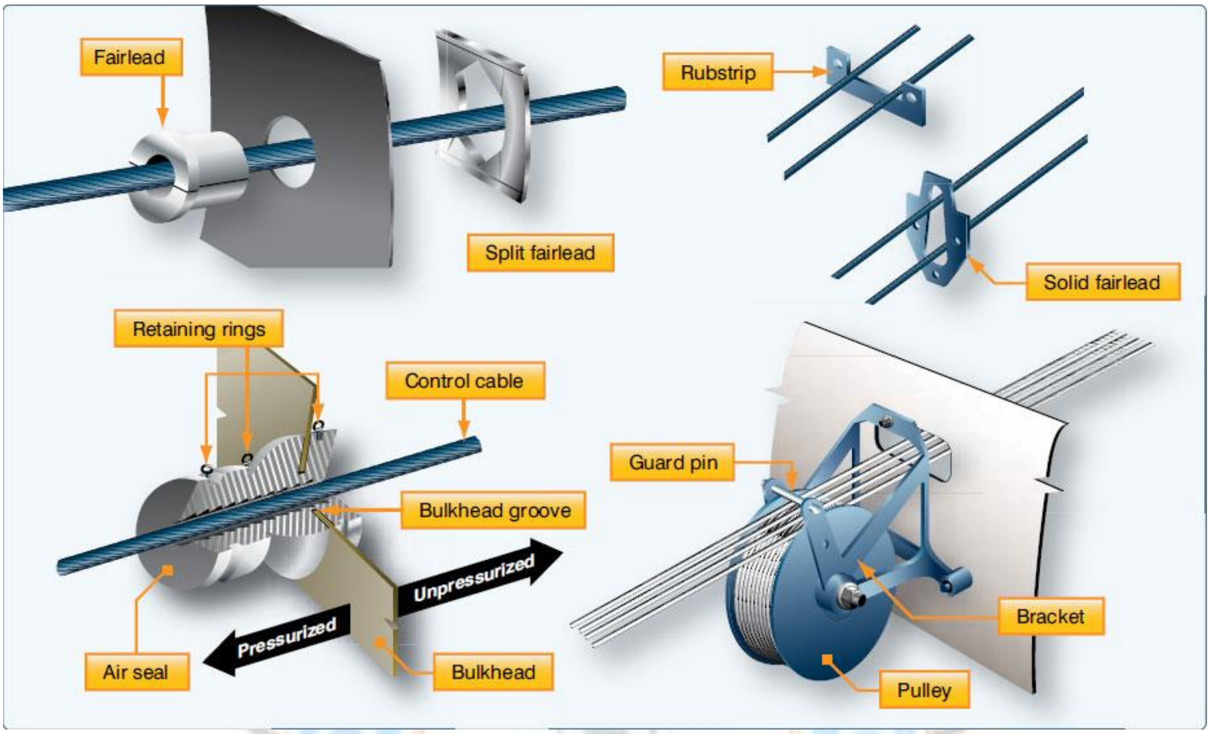
Flight Test

When flight testing, be sure to pick a calm day and begin by setting up a stable cruise speed. The aircraft should be loaded as it would be on your typical flights. Trim the elevator first so that the aircraft does not tend to pitch up or down when flying hands-off. Next, take your feet off the rudder pedals and check the ball to see if the aircraft is yawing left or right. If the aircraft has adjustable rudder trim, trim out any undesired yaw. If not, you will need to land to adjust the fixed-rudder trim tab and repeat the process.

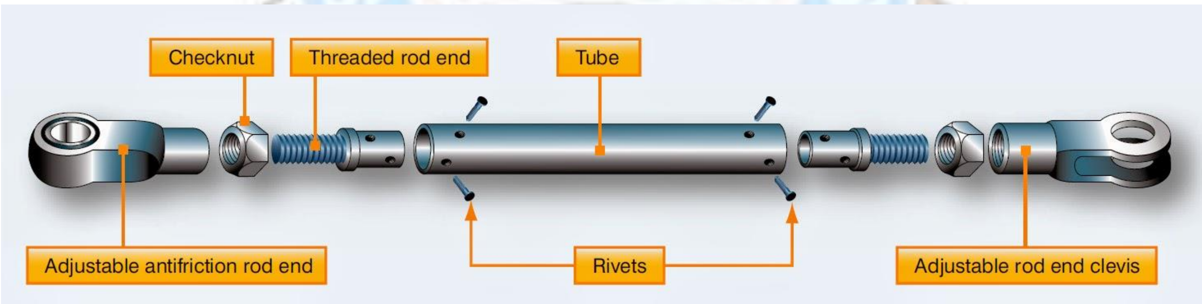
With the rudder trim properly set, you can proceed to the aileron trim. Again, set the aircraft for stable, level flight with a centered ball in the turn and bank. If the aircraft has adjustable aileron trim, you can complete the process in the air. But, for most aircraft, you'll need to land and adjust the aileron trim tabs.

Once the aircraft is perfectly trimmed, make a note of the position of the trim tabs. Only minor inputs should have been necessary to achieve coordinated flight. If the tabs need to be excessively bent to achieve level flight, it's quite possible that something else is going on with the aircraft and further investigation is warranted.

A well-rigged aircraft is a pleasure to fly. With a little effort and the right set of tools, you can eliminate the constant crosswind you've been fighting, gain a knot or two, and renew your love affair with your favourite bird!



AIRCRAFT RIGGING



Fuelling Procedures

Any published procedures by the fuelling company and any manufacturer's manual instructions on fuelling must be strictly followed.

Precautions

The operator or the overseer should ensure that the following precautions are observed during the fuelling of any aircraft—

(a) Except for the provisions of subsection 8.5, aircraft engines should be stopped, with the ignition and starter switches placed on the "OFF" or "SAFE" position, before fuelling starts. Fuelling with engines running (hot fuelling) should not be conducted unless otherwise approved by the CAA. If such a procedure is approved, the location and/or timing of the fuelling process are to be agreed in writing between the aircraft operator, the fuelling company, and the airport authority if appropriate.

(b) No smoking, or the use of a naked flame, should be permitted on the apron or within 15 metres of the aircraft, the fuelling system or equipment at any time. This safety distance is extended to 50 metres during any fuelling process. If any naked flame device has to be used in these circumstances (outside these recommended distances), its use should be strictly controlled in accordance with locally approved safety procedures.
(c) "No Smoking" signs or symbols should be displayed in prominent positions near the aircraft and fuelling vehicles throughout the fuelling operation. These symbols may be painted onto the sides of the fuelling vehicles.

General procedures

Personnel responsible for fuelling aircraft should take into account the following general procedures—
(a) Ascertain fuelling requirements – quantity and grade required.
(b) General aircraft servicing such as baggage handling and catering services and any other associated services may be carried out during fuelling operations. However, if obvious defects develop in motorised units operating within 6 metres of fuelling operations, the faulty units should be stopped immediately during fuelling operations.
(c) Operational problems can arise through the unsuitable location of the aircraft, due to misalignment of the aircraft in the parking bay, or by inappropriately located hydrant pits. In these cases steps should be taken to arrange for the aircraft to be realigned or relocated.
(d) Fuelling personnel should not operate aircraft fuel system controls. The aircraft operator is responsible for determining the volume of fuel to be loaded and to instruct fuelling personnel accordingly. The operator is also responsible for manipulating aircraft tank valves and switches, drip and dip sticks and to finally check the security of tank fill caps, covers and components. If requested, the fuel company may advise on the density (specific gravity) of the fuel being delivered to enable any associated calculations to be made.

Hydrant systems – underwing

In addition to the 'general procedures' in subsection, the following sequence is recommended when the hydrant pit cover is removed—

(a) The grade of fuel from the hydrant pit and dispenser should be checked before the connection is made to the pit; and
(b) The visibility of the hydrant pit and dispenser should be improved by the use of a high visibility flag, safety cones or other acceptable method, during daylight hours; and
(c) The hydrant pit and dispenser should be suitably illuminated – usually via local tarmac lighting, when dark or at night; and
(d) Follow the sequence set out below in respect of hydrant dispensers or servicers—
(e) If grounding is required, follow the procedure set out below,

The fuelling company's published procedures on bonding or grounding must be strictly followed.
The aircraft and fuelling equipment should be electrically bonded together throughout the fuelling operation to ensure that no difference in electrical potential exists between the units.
Bonding or grounding requirements and electrical continuity checks should be in accordance with
New Zealand electrical code of practice NZECP 24 "Safety of Electricity in Hazardous Places".

Bonding or grounding leads should be examined for security of connections and damage prior to use. Clips should be intact and undamaged.

Bonding between the fuelling vehicle and aircraft should be completed before any hoses are connected or tank filler caps opened. Bonding should be maintained until all hoses have been finally disconnected or tank filler caps replaced.

Grounding of aircraft is generally not recommended. However, if authorities do require grounding, and earthing points exist for this purpose, the fuelling equipment and aircraft should be grounded by means of a "Y" grounding cable and not through the fuelling vehicle, following agreement of the local procedures by the airline, fuel company and airport authority. Hydrant pits or hydrant pit internals should not be used as grounding connections. Where grounding is carried out, it should be completed before connecting hoses or opening filler caps.

When overwing fuelling, make sure to follow the correct procedure for inserting the nozzle into the tank filler. If the filler caps have been previously removed to dip check the tank contents, the caps should be replaced and any vapour allowed dispersing before starting any fuelling operation. The fuelling procedure may vary with aircraft type, but the following additional steps are recommended—

(a) Equalise the electrical potential by touching the nozzle to the metal wing surface, taking care to protect the wing from damage; and

(b) Open the fill point cover flap; and

(c) Attach the nozzle bonding jack or clip, where fitted, to the bonding point or cover flap, with the filler cap still closed; and

(d) Open the filler cap; and

(e) Insert the fuelling nozzle - avoid damaging the aperture, or 'bottoming' the nozzle which could possibly damage the internal structure and/or protective coatings; and

(f) Start fuelling.

(ii) Bond the hydrant dispenser to the aircraft; and

(iii) If required, attach a lanyard to the pit valve, and extend the lanyard away from the fuelling position and the aircraft; and

(iv) Remove any dirt or moisture on the pit valve adaptor and hydrant coupler; and

(v) Connect the hydrant coupler to the hydrant pit valve, and the delivery hose(s) to the aircraft. Each joint operation should have only one sequence which will be agreed by all participants and incorporated into a written fuelling procedure; and

(vi) Open the hydrant coupler and adaptor if it is manually operated; and

(vii) Activate the dead man control to start delivery; and

(viii) Follow the above sequence in reverse when fuelling ends.

(e) Whenever the dispenser is left unattended (e.g. for signing the fuel receipt) the hydrant pit valve or hydrant coupler should be closed; and

(f) Dust caps should be fitted to the pit valve adaptor and dispenser couplings at all times when not in use.

Fuellers – underwing

In addition to the general procedures in subsection 6.2, the following sequence is recommended—

(a) If grounding is required, follow the procedure set out in subsection 4.2; and

(b) Bond the fueller to the aircraft; and

(c) Connect all delivery hoses to the aircraft; and

(d) Activate the deadman control to start delivery; and

(e) At the conclusion of fuelling, the reverse sequence should be followed.

Overwing fuelling

In addition to the procedures for underwing fuelling, the following further measures are required to ensure that the correct grade of fuel is delivered when using an overwing (trigger) nozzle—

(a) Personnel responsible for fuelling should never assume what the fuel grade is. Confirm the grade between you and the customer. Whenever possible, have in writing what the grade of fuel that should be provided; and

(b) Before fuelling starts, fuelling personnel should check that the grade requested is the same as the grade marked on the aircraft, adjacent to the tank filler cap, and the same as the grade marked on the overwing fuelling nozzle; and

(c) For avgas overwing fuellings, nozzles with a maximum external diameter of 40mm should be used; and

(d) For Jet A-1 overwing fuellings, nozzles with a minimum external diameter of 67mm should be used.

The following additional precautions are applicable for overwing fuelling—

(a) Loose articles should not be carried in caps, jackets or shirt pockets as these might fall into aircraft tanks.

(b) Hoses should be routed over the leading edge of the wing (and not the trailing edge) in such a manner that avoids the possibility of damage to the aircraft. Ladders and wing mats should be used as appropriate to avoid damage to the aircraft. Care should be taken in positioning ladders to avoid damage to the aircraft caused by settling whilst product is being loaded. Wing mats should be positioned so that the fuel grade identification remains visible at all times.

(c) Overwing nozzles should be held open manually and should never be wedged open.

Refuelling from drums

Take care to correctly identify the type and quality (fuel does go stale) of the fuel before refuelling from drums. Ensure that the pump is fitted with a clean and serviceable filter (one that will filter particulate matter, as well as absorbing water). Corrosion products (rust), water and dirt can all be a problem when fuel is stored in drums.

When opening a drum—

(a) Stand the drum upright but tilted slightly, and chock it with the high side positioned at 12 o'clock, the bung at 3 o'clock, and the vent at 9 o'clock. This minimises water or dirty fuel on the outside of the drum from reaching the openings.

(b) Allow the drum to stand undisturbed for at least 10 minutes prior to fuelling to let any internal contaminants settle out.

(c) Proper bonding is critical. Connect the bonding lead from the drum to the aircraft before opening any fuel caps, and leave it in place until all fuel caps have been replaced.

(d) Open the pumping bung and vent.

(e) Ensure that the pump standpipe cannot reach the lowest point in the drum - any small amount of water or dirt will thus remain in the drum. The last few litres of fuel should not be needed badly enough to risk using it.

Some fuelling practices are likely causes of contamination, particularly when carried out on helicopters whilst the main rotor is turning, as under this condition particle of foreign material (dust and grass) are likely to be introduced into the fuel system through the tank filler.

The practice of using bleed air from the compressor of an aircraft turbine for the purpose of pressurising the fuel drum can only be considered safe if the following points are observed—

(a) Any plumbing and other permanent attachments to the aircraft designed and fitted to achieve such pressurisation, must be properly authorised as such by an approved modification; and

(b) There should be a means of filtering all contaminants, removing moisture and regulating the pressure of the compressor bleed air prior to its entry to the drum; and

(c) The bleed air pressure to the drum should be reduced by an acceptable means to below 2.5 psi.

When refuelling from drums it is most important that the fuel delivery line incorporates a filter of five microns or less with the ability to separate both water and other contaminants. Fuel suppliers can provide or recommend suitable filters for this purpose. Such filters will normally meet Energy Institute Standard EI 1583 or EI 1583 as an alternative (formerly American Petroleum Institute Specification API 1581/1973).

Take care not to exceed the allowable maximum differential pressure across the filter element so that the excessive pressure does not render the filter ineffective. It must also be noted that the filter will only separate out water which is in suspension - straight water will pass through the filter. It is therefore important to ensure that the stand pipe is positioned clear of water deposits which may be presented in the bottom of drums.

Fuel suppliers are well aware of the problems of refuelling from drums in remote areas and have indicated their willingness to assist operators in the adoption of safe refuelling practices. Technical information in the form of bulletins and leaflets is readily available from most suppliers.

Refuelling from jerry cans

Use only jerrycans specifically manufactured as fuel containers. The traditional metal jerrycans are preferable to the plastic versions available on the market. Plastic jerrycans intended for use with fuels will have been manufactured to a recognised standard. In New Zealand, this is

Australian/New Zealand standard 2906:2001 and this identification are embossed permanently on the side of the container.

Do not use plastic containers not designed for fuel, as their deficiencies may pose hazards such as—

(a) A tendency to accumulate a static charge (refer subsection 5.2); and

(b) Fuel could degrade the container material; and

(c) Inadequate structural strength and impact resistance; and

(d) Lack of a proper fuel grade label and other required markings; and

(e) Insufficient resistance to ultraviolet radiation and heat; and

(f) Cap gaskets inadequately retained.

In particular, the cap gaskets have been identified as an actual hazard. The standard requires that these be physically restrained in the cap by a retaining ring, or other means of preventing accidental loss. Obviously, the gasket itself should also be fuel resistant.

Apart from simply falling out of the cap and preventing proper sealing, two ways in which the gasket can be hazardous are—

(a) Embrittlement and subsequent disintegration. The fragments can then be tipped into the aircraft fuel tank along with the fuel, and, over time, can either clog the tank outlet or the fuel system filter(s); and

(b) Progressive degradation /disintegration by turning to ‘mush’ (possibly more likely in jet fuel), also resulting in filter clogging.

Maintenance and servicing of aircraft during fuelling operation

During the fuelling operation, the pilot-in-command or overseer, as appropriate, should only permit maintenance, testing, servicing or cabin replenishment within the fuelling area subject to the following conditions—
(a) Ground power units should not be started, connected, their switches operated, or disconnected during fuelling. These actions must be completed either before refuelling or after the refuelling process is completed.
(b) The operation of aircraft combustion heaters, integral cabin heaters, wing, tail and surface heaters should not be permitted.
(c) The operation of aircraft radar transmitters should not be permitted.
(d) Maintenance, repair, or testing of the aircraft radio, radar and electrical equipment should not be permitted when the aircraft is being fuelled with class 3.1A fuel, except that switches necessary for the fuelling operation and lighting may be used.
(e) Functional checks may be carried out on aircraft radio, radar receivers and electrical equipment when class 3.1C fuelling is being carried out, but maintenance should be limited to the exchange of complete units.
(f) Maintenance, testing and functional checks other than those already detailed in paragraphs (b), (c), (d) and (e) may be carried out when class 3.1A or class 3.1C fuelling is being carried out, except that work which may create sources of ignition, especially in the vicinity of aircraft fuel tanks or fuelling equipment, may not be carried out.
(g) Electric hand lamps or flashlights used in the immediate vicinity of the fuelling operation should be of a flame proof or safe design.

The operators, pilots-in-command or overseer of any aircraft in the vicinity of fuelling operations should ensure that aircraft transmitters are not operated within 25 metres of fuelling equipment or aircraft fuel vents.
The operators of ground radar transmitters should ensure that transmitters are not operated within 30 metres of fuelling equipment or aircraft fuel vents.

Defueling Procedures
Any published procedures by the fuelling company and any manufacturers’ manual instructions must be strictly followed.

Defueling procedure
It may be necessary either to off-load fuel from an aircraft after completing fuelling for subsequent aircraft fuel load adjustment, or to completely off-load all fuel, usually at the airline overhaul base, to permit maintenance work to be carried out.
Both operations are designated defueling and the procedures to be followed during defueling are similar to those which apply to fuelling.
To protect the quality of the fuel in the fuelling equipment from being contaminated by the fuel offloaded from the aircraft, the following procedures should be adopted before defueling begins—
(a) The grade of fuel contained in the aircraft tank should be established by—
(i) Taking samples for a visual check and, if jet fuel, water check by chemical detector; and
(ii) Identifying the grade of fuel uplifted on the two previous supplied fuelling.
Note: *The aircraft operator representative should be able to supply this information*.

(b) If there is any reason to suspect the quality of the fuel, any fuel off-loaded should be segregated and subjected to a certificate of analysis test that must be successful before returning the fuel to operating storage or another aircraft.
(c) If the quality of fuel is not suspect, or it has passed the applicable tests, it may be delivered to an aircraft of the same airline/operator or to another airline/operator with or written permission.
(d) If the aircraft contains a mixture of Jet A-1 with Jet A or Jet B or Jet Fuel of East European origin or fuel of unknown origin or specification, the fuel should be disposed of, unless the airline/operator concerned agrees that the fuel can be returned to the aircraft. The product which has been defueled for load adjustment purposes should, whenever possible, be returned to an aircraft of the same airline.
(e) Defueled fuel may be received into segregated storage until redelivery to the aircraft concerned or to an aircraft of the same airline. Defueled stock can only be returned to airport operating storage after appropriate tests as above have been made on the fuel and results show it is acceptable for aviation use.
(f) When a fueller has contained fuel of suspect quality, it should be drained and inspected internally for cleanliness and absence of any remaining fuel. All drain points should be purged to clear pipe work and components (filters, pumps, etc.) of the suspect fuel. The filter elements must be replaced. The fueller should then be filled to capacity and 1,000 litres should be delivered at maximum flow rate through each hose back into a storage tank containing at least 20,000 litres of the fuel grade.
(g) Fuel containing FSII additive shall not be redelivered via filter monitor elements due to the possibility of filter media migration.

Fuelling Procedures under Certain Situations

Fuelling while aircraft mounted auxiliary power units (APU) are in operation

An APU exhaust discharging outside fuelling zone4—
(a) Fuelling unit should be located as far from the APU exhaust as possible; and
(b) The APU may be started and stopped during the fuelling operation without notification; and
(c) If fuel spills, the APU should be stopped immediately and remain stationary until spillage is removed and there is no danger from inflammable vapours.
An APU exhaust discharging into fuelling zone—
(a) The APU should be started before the covers of the fuelling connections and hydrant caps are removed or any fuelling connections made.
(b) If the APU is stopped during the fuelling operation; it should not be started until the flow of fuel has stopped.
(c) When the APU discharges from the side of the aircraft, if possible, the fuelling unit should be positioned on the opposite side of the aircraft to the discharge. If this is not possible, the fuelling unit should be positioned out of, and at the maximum practicable distance from, the exhaust stream.
(d) If fuel spills, stop the APU immediately and remain stationary until spillage is removed and there is no danger from inflammable vapours.
(e) Where the APU exhaust is directly across the upper surface of the aircraft wing, do not carry out overwing fuelling while APU is running.
An APU in engine nacelle on fuelling side of aircraft—
(a) The fuelling company should develop their own specific procedures with regard to fuelling this type of aircraft.

Fuelling while ground power units (GPU) are in operation

Position the GPU and associated cabling at least 6 metres away from fuelling vehicles and clear of wing tank vents.
Do not start, connect, switch on, or disconnect the GPU during the refuelling process. These actions must be completed either before refuelling or after the refuelling process is completed.
If fuel spills, the GPU should be stopped immediately and should remain stationary with all electrical circuits and switches left untouched until the spillage is removed and there is no danger from inflammable vapours.

Fuelling with air conditioning units in operation

Fuelling operations may be carried out subject to the same conditions as those applicable to general aircraft servicing, with the exception that, if fuel spills, the unit should be switched off. This is to prevent the possibility of flammable vapours being drawn into the aircraft passenger compartment.

Fuelling with one aircraft engine running

Fuelling of an aircraft, which has one propulsion engine running, is a non-routine, emergency operation and requires very strict safety precautions5.
The following procedure applies specifically to underwing fuelling—
(a) Fuelling with one engine running should not be performed unless the operator's authorised representative requesting this kind of operation accepts, in writing, complete responsibility for the operation; and
(b) A qualified representative from the operator should then supervise the fuelling operation; and
(c) Due to its non-routine nature, the operation should be reviewed ahead of time by the operator and the fuelling company representatives; and
(d) The aircraft should be positioned at a distance of at least 50 metres away from the passenger loading area of the terminal and any other building or other aircraft; and
(e) The aircraft should be headed into the wind; and
(f) Where one-man fuelling would normally be carried out, an additional supervisor or senior fuelling hand should also be presented; and
(g) Fuelling is not to be started until all passengers have vacated the aircraft and are kept at a distance of at least 50 metres; and
(h) All personnel involved in the fuelling operation should be clear of the running engine, and all other personnel not directly needed for the fuelling operation should maintain a safe distance of at least 50 metres from the aircraft; and
(i) Properly manned mobile fire-fighting equipment, with the engine running, should be standing by the aircraft; and
(j) Fuel will be loaded on the side opposite to that of the running engine with the fuelling equipment positioned a maximum (sensible) distance from the running engine; and
(k) When additional fuel is required on the other side of the aircraft the operation should be carried out in the following order—

(i) Remove the fuelling equipment from the side where the fuelling has just been completed; and
(ii) Reposition the fuelling equipment at least 50m from the engine to be started; and
(iii) Operator aircraft personnel to start the engine on the side which has just been fuelled; and
(iv) Operator aircraft personnel to shut down the engine of the side to be fuelled; and

(v) Position fuelling equipment adjacent to the wing to be fuelled at a maximum (sensible) distance from the running engine; and
(vi) Load fuel.

Operation of aircraft engines and APU within the fuelling area

The pilot-in-command and/or overseer as designated by the aircraft operator should ensure that no hazard is presented to fuelling equipment, its operation or to fuelling personnel during the starting of engines or taxiing of aircraft, especially due to the efflux from turbine engines. In the case of the fuelling equipment or personnel to the rear of, and within a 15° arc either side of the exhaust outlet axis, the engines should not be operated unless the engine is at a minimum distance (listed in Appendix 2).

As aerodromes or airports serve a large variety of aircraft types, depending on prevalent aircraft engine type, the minimum distances may be increased or decreased if agreed by the affected parties.

The operation of aircraft engines including aircraft-borne APUs within the fuelling area is not permitted, except when the engines (or APUs) are tail-mounted and the fuel to be uplifted is class 3.1C, or the express approval of the relevant fuelling agency and aircraft operator has been granted.

In addition, if the aircraft-borne APU is not tail-mounted, it may be operated within the fuelling area when the fuel to be uplifted is class 3.1C providing the APU is started before the filler caps are removed and fuelling connections made.

If an aircraft-borne APU is stopped for any reason during fuelling, it should not be restarted until the fuel has stopped flowing, the refuelling vehicle is disconnected and moved away, and there is no risk of igniting fuel vapours.

Operators are responsible for the following—

(a) Ensuring that personnel concerned with the starting of aircraft engines near fuelling operations are fully conversant with correct operation of the aircraft's fire extinguishing system; and

(b) Ensuring that during the starting of aircraft engines, an approved fire extinguisher is available for immediate use; and

(c) Ensuring that during the starting of aircraft engines using class 3.1A fuel with passengers aboard the aircraft, equilibrium of the aircraft is maintained. Maintaining the equilibrium is ideal especially if an emergency arises and passengers need to leave by one exit. A manned passenger loading ramp should be readily available in an emergency.

Fuelling/defueling with on board/embarking/disembarking passengers

Fuelling or defueling involving passengers may be carried out following the accepted procedures in an aircraft operator's exposition. Refer to Civil Aviation Rules 121.91, 125.73, and 135.73 provided the conditions listed below are satisfied—

(a) Such fuelling or defueling is permitted by the local airport regulations and is requested by the aircraft operator, preferably in writing.

(b) The aircraft operator accepts sole responsibility for ensuring that—

(i) The local airport regulations relating to fuelling or defueling are carried out.

(ii) Instructions are issued to its employees for the safety of all passengers during fuelling or defueling and that these instructions are strictly observed.

(iii) Passengers joining or leaving the aircraft are moved under the supervision of a responsible person employed by the operator over a safe route, and are not allowed to smoke, linger, use mobile phones, cameras, or any other no intrinsically safe devices, and are kept at a maximum distance from the fuelling operation.

(c) 6Fuelling or defueling should stop immediately in a hazardous situation, such as spillage, or if the procedures set out in this advisory circular are not followed correctly which could result in a dangerous incident.
(d) The following special safety measures should be observed when passengers are to remain on board during aircraft fuelling—
(i) Where passenger loading stairways are used they should be positioned at each passenger door normally used at that airport and these doors should be kept open, except these doors may be closed during inclement weather, but they should be kept unlocked and free to open, with the stairways remaining in position. Where aerobridges are used, only those doors served by the aerobridges at that location need be opened.
(ii) Access to exit doors and gangways in the aircraft should be kept unobstructed and any doors between passenger compartments kept open.
(iii) One cabin attendant or a suitably trained person should be presented at each passenger main exit door in use and additionally in each other occupied compartment.
(iv) Cabin attendants should advise passengers that fuelling will take place and that proper precautions are being taken to ensure their safety. The attendant will ensure that the "No Smoking" sign is displayed in each compartment, all exits are clearly indicated by a reflective marker or lights, and all exit lights are illuminated or armed.
(v) If an abnormal concentration of fuel vapour is detected in the cabin, or any other condition that may constitute a hazard occurs, the cabin attendant should advise the fuelling personnel immediately.
Cabin attendants are to assist the evacuation of passengers in the event of fire or when any other hazard exists and when necessary should utilise appropriate emergency evacuation slides on their own initiative.
(vii) The equilibrium of the aircraft should be maintained if all passengers leave by one exit; and
(viii) For a marine aircraft not moored to a pontoon or jetty, adequate means of water transport should be stationed at the cabin exit door.
(e) When passengers are to embark or disembark during fuelling the following special additional safety measures should be observed—
(i) Passengers should be warned not to smoke.
(ii) Passengers should be routed by a roped off or clearly marked track, clear of the fuelling equipment, or supervised by a responsible person employed by the operator on their journey to and from the aircraft.
(iii) Suitable measures should be taken to prevent spark hazard from passengers' shoes within the fuelling area.

Auxiliary plant, vehicles and electrical equipment

Internal combustion engines used in association with auxiliary plant and vehicles powered by internal combustion engines should not be operated within the fuelling area unless—
(a) When refuelling with class 3.1A fuel or 3.1C fuel, the spark plugs of these engines have been encased in an approved screening device and effective flame traps are fitted on air intakes and exhaust systems; and
(b) The equipment is subject to regular inspection and maintenance, or the entire exhaust system (excluding exhaust valve gear) inspected at not greater than 90 day intervals and the integrity of the complete system verified.
Do not start, connect, switch on, or disconnect a GPU during refuelling. These actions must be completed before or after refuelling is completed.

Where an electric motor, portable electrical appliance or ground supply unit is operated within the fuelling area, all electrical apparatus on the unit should be flame proofed in accordance with New Zealand electrical code of practice NZECP 24 "Safety of Electricity in Hazardous Places".
Operators should make sure that vehicles and fuelling equipment are maintained to satisfactory safety standards.
Do not start ground equipment engines during fuelling until the flow of fuel has ceased and there is no risk of igniting fuel vapours.
Ground equipment engines should not be operated within 3 metres horizontal radius of an aircraft fuel venting system. The area also includes all that space encompassed vertically below the horizontal exclusion zone.

Fuelling on aircraft having fuel tanks with inert gas system (nitrogen generation system)
Modern generation transport category airplanes may be fitted with fuel tanks having a nitrogen generating system. This nitrogen generating equipment is dangerous as nitrogen is colourless and odourless. The generated nitrogen decreases the oxygen in the air remaining within the tank, safeguarding against the likelihood of an explosive mixture. However, the resultant gaseous mixture when vented is unhealthy and may cause hypoxia, dizziness, nausea, and in extreme cases unconsciousness and possible death.
While fuelling or defueling aircraft which have fuel tanks fitted with nitrogen generating equipment, make sure that any warning instructions associated with such systems (typically in the main wheel well, centre fuel tank and air conditioning bay) are read and obeyed by fuelling operators. The aircraft operator should be approached to assist in identifying any hazards and procedures to be followed when dealing with such systems.
An aircraft operator is responsible for educating and training fuellers regarding features of the aircraft used by the operator relating to fuelling/defueling operations and special precautions to be taken during fuelling operations.

LUBRICATION

Perhaps the only connection you have had with lubrication was taking the car to the garage for greasing and oil change. If your car has ever burned out a bearing, you have learned the importance of lubricants. The proper lubrication of high-speed aircraft is very important. You should be familiar with the various types of lubricants, their specific use, and the method and frequency of application.
Lubricants are used to reduce friction, to cool, to prevent wear, and to protect metallic parts against corrosion. In the aircraft, lubrication is necessary to minimize friction between moving parts. Only the presence of a layer or film of lubricant between metal surfaces keeps the metals from touching. As a result, friction is reduced between moving parts. Prolonged operating life is ensured when the lubricant keeps metal surfaces from direct contact with each other. If the film disappears, you end up with burned out or frozen bearings, scored cylinder walls, leaky packings, and a host of other troubles. Appropriate use of proper lubricants minimizes possible damage to equipment.

LUBRICANTS

You can get lubricants in three forms. They are fluids, semisolids, and solids. Additives improve the physical properties or performance of a lubricant. We all know that oils are fluids, and greases are semisolids. You probably think of graphite, molybdenum disulfide, talc, and boron nitride as additives. In fact, they are solid lubricants. A solid lubricant's

molecular structure is such that its platelets will readily slide over each other. Solid lubricants can be suspended in oils and greases.
There are many different types of approved lubricants in use for naval aircraft. Because the lubricants used will vary with types of aircraft and equipment, it is impractical to cover each type. Some of the more common types are described in *Table below.*

TITLE AND SPECIFICATION	RECOMMENDED TEMPERATURE RANGE	GENERAL COMPOSITION	INTENDED USE
MIL-PRF-23827C [Grease, Aircraft, Synthetic, Extreme Pressure]	-100 to 250 °F	Thickening agent, low-temperature synthetic oils, or mixture EP additive	Actuator screws, gears, controls, rolling-element bearings, general instrument use
MIL-PRF-21164D [Grease, Aircraft, Synthetic, Molybdenum Disulfide]	-100 to 250 °F	Similar to MIL-PRF-23827 plus molybdenum disulfide	Sliding steel on steel, heavily loaded hinges, rolling element bearing where specified
MIL-PRF-81322G [Grease, Aircraft, General Purpose, Wide Temperature Range]	-65 to 350 °F	Thickening agent and synthetic hydrocarbon. Has cleanliness requirements	O-rings, certain splines, ball and roller bearing assemblies, primarily wheel bearings in internal brake assemblies, and where compatibility with rubber is required
MIL-PRF-4343 [Grease, Pneumatic System]	-65 to 200 °F	Thickening agent and blend of silicone and diester	Rubber to metal lubrication: pneumatic and oxygen systems
MIL-G-25537C [Grease, Helicopter Oscillating Bearing]	-65 to 160 °F	Thickening agent and mineral oil	Lubrication of bearings having oscillating motion of small amplitude
MIL-G-6032D [Grease, Plug Valve, Gasoline and Oil Resistant]	32 to 200 °F	Thickening agent, vegetable oils, glycerols, and/or polyesters	Pump bearings, valves and fittings where specified for fuel resistance
MIL-PRF-2617F [Grease, Aircraft Fuel and Oil Resistant]	-30 to 400 °F	Thickening agent and fluorocarbon or fluorosilicone	Tapered plug and oxygen system valves; certain fuel system components; antiseize
MIL-G-25013E [Grease, Ball and Roller Bearing, Extreme High Temp]	-100 to 450 °F	Thickening agent and silicone fluid	Ball and roller bearing lubrication

Methods of Application
Different types of lubricants may be applied by any one of several methods. Common methods are by grease gun, by oil/squirt cans, by hand, and by brush.

GREASE GUNS — There are numerous types and sizes of grease guns available for different equipment applications. The lever and one-handed lever guns are two of the most common types in use. The grease gun may be equipped with a flexible hose instead of a rigid extension. Different nozzles can be attached to the grease guns for different types of fittings. See *Figure below*

OIL/SQUIRT CAN — Oil/squirt cans are used for general lubrication. Always use the specified oil for the part being lubricated. Before using oil cans, always check to make sure the oil can contains the proper lubricant.

HAND — this method of lubrication is generally used for packing wheel bearings. It involves using grease in the palm of your hand to pack the bearings.

BRUSH — this method of lubrication is used when it is necessary to cover a large area, or for coating tracks or guides with a lubricant.

Lubrication Fittings
There are several different types of grease fittings. They are the hydraulic (Zerk fitting), the buttonhead pin, and the flush type of fittings. (See *Figure below*) The two most commonly used fittings in naval aviation are the hydraulic- and flush-type fittings. These fittings are found on many parts of the aircraft.

HYDRAULIC FITTINGS — this type protrudes from the surface into which it is screwed, and it has a rounded end that the mating nozzle of the grease gun grips. A spring-loaded ball acts as a check valve. *Figure below* shows a cross-sectional view of a straight hydraulic fitting and an angled hydraulic fitting made for lubricating parts that are hard to reach.

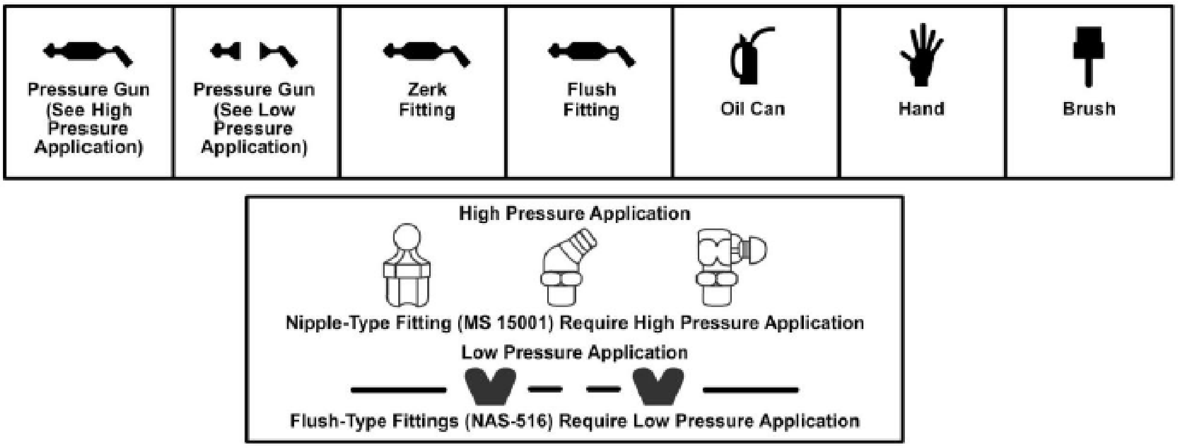
FLUSH FITTINGS — This type of fitting sits flush with the surface into which it is placed. It will not interfere with moving parts.

LUBRICATION SELECTION

How do you know what grease or oil to select for a particular application? Lubrication instructions are issued for all equipment requiring lubrication. You will find that the MIM or Maintenance Requirements Cards (MRCs) provide you with lubrication information. In the event that the exact lubricant is not available and a substitution is not listed, request substitution through the chain of command.

LUBRICATION CHARTS

The lubrication requirements for each model of aircraft are given in the "General Information and Servicing" section of the MIM. In the MIM you will find the necessary support equipment and consumable material requirements. A table/chart similar to the one shown in *Figure below* lists all of the various types of lubricants used in lubricating the whole aircraft. Additional information, such as application symbols, specification numbers, and symbols are provided in this table.



SURFACE TREATMENT		
IDENTIFICATION LETTERS	SPECIFICATION	TYPE OF LUBRICANT/COMPOUND
BRW	MIL-PRF-81322G	Grease Aircraft, General Purpose, Wide Temperature.
GIA	MIL-PRF-23827C	Grease Aircraft And Instrument, Gear And Actuator Screw.
GMD	MIL-PRF-21164D	Grease, Molybdenum Disulfide (For Low And High Temperature).
OAI	MIL-PRF-6085D	Lubricating Oil; Aircraft Instrument, Low Volatility.
OHA	MIL-PRF-83282D	Hydraulic Fluid, Fire Resistant Synthetic Hydrocarbon Base, Aircraft.
	MIL-PRF-6083F	Hydraulic Fluid, Petroleum Base, Preservative.
PL-SPECIAL	MIL-PRF-32033	Lubricating Oil, General Purpose, Preservative (Water Displacing, Low Temperature).
GOS	MIL-PRF-10324A or Silogram APG 75 (Alternate)	Lubricating Oil, Gear, Sub-Zero.
†(NONE)	MIL-PRF-16173E	Corrosion Preventive Compound, Solvent Cutback, Cold Application.
††(NONE)	MIL-PRF-81309	Corrosion Preventive Compound, Water Displacing, Ultra Thin Film.

Lubrication, Transportation, and Storage Requirements

Examine and lubricate all slings once a month in accordance with NAVAIR 17-1-114. When transporting slings, they should be carried at all times. Dragging slings over floors, runways, decks, and obstructions can cut or severely abrade the material. This malpractice results in an unserviceable sling. Whenever possible, slings should be stored indoors in a clean, dry, well-ventilated area so as to be protected from moisture, salt atmosphere, and acids of all types. In addition, slings constructed with nylon or other fabric materials should be stored in such a way as to prevent contact with sharp objects, high temperatures, and sunlight. Fabric materials deteriorate rapidly from prolonged exposure to sunlight or excessive heat, severely reducing strength and service life. Where practicable, slings should be securely fastened to overhead storage racks to prevent accidental damage. Avoid laying slings on ash or concrete floors.

Hoisting Restrictions

There are many restrictions to hoisting for each type of aircraft. Most hoisting restrictions are the same as for jacking aircraft. If you violate any of these restrictions, there is a good chance that you will have an accident, damage the aircraft, or injure someone. The restrictions generally concern aircraft gross weight and configuration. Some of the considerations are access (stress) panels on or off, external stores on or off, and wings folded or spread.
There are many factors that can affect the safety of the aircraft and personnel during hoisting operation. For details on restrictions and for the proper installation of any sling, consult the applicable MIM. Don't forget that many squadrons have their own local standing instructions

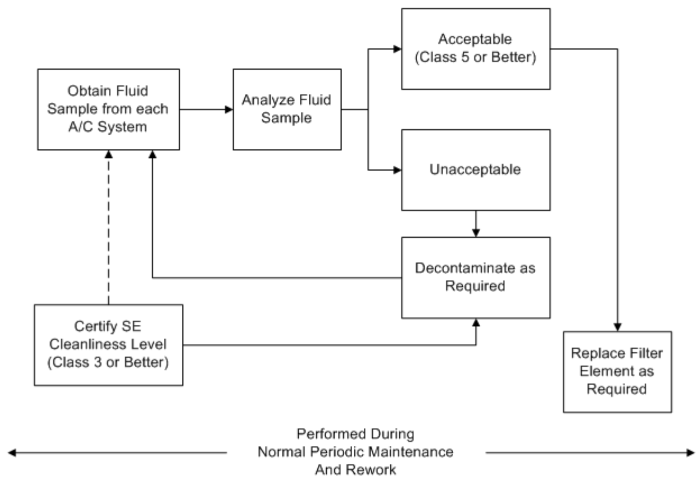
for hoisting aircraft that contain additional safety precautions and restrictions. You must know these precautions and restrictions as well.
Prior to carrier operation, aircraft hoist points are inspected for serviceability and easy access in an emergency. For details on how to accomplish this inspection on your aircraft, consult the applicable MIM.

HYDRAULIC CONTAMINATION CONTROL PROGRAM

Hydraulic contamination in Navy and Marine Corps aircraft and related support equipment (SE) is a major cause of hydraulic system and component failure. Every technician who performs hydraulic maintenance should be aware of the causes and effects of hydraulic contamination. Correct practices and procedures should be followed to prevent contamination. Supervisory and quality assurance personnel must know and ensure compliance with accepted standards. Each maintenance level needs to accept their applicable responsibility. Supervisory personnel at each level of maintenance should indoctrinate and train personnel and implement procedures that apply to that level of maintenance.
The Hydraulic Contamination Control Program is defined in the COMNAVAIRFORINST 4790.2 (series). Within the scope of this program, training must be consistent with the objectives of an effective aircraft hydraulic contamination control program. At all maintenance levels, personnel must be trained in matters pertaining to hydraulic systems contamination control using the Hydraulic Contamination Control Training Device 4B38A or Videotape Number 802577DN. The Hydraulic Contamination Control Program requires that the correct procedures be followed during fluid sampling, maintenance procedures, and practices.

FLUID SAMPLING

Contamination measurement standards and acceptability limits define and control hydraulic contamination levels. The maximum acceptable hydraulic fluid particulate level is Navy Standard Class 5 for naval aircraft and Navy Standard Class 3 for related SE. The contamination level of a particular system is determined by analysis of a fluid sample drawn from the system. Analysis is accomplished at all levels of maintenance through the use of the HACH Ultra Analytics Portable Oil Diagnostic System (PODS). Hydraulic system fluid sampling is accomplished on a periodic basis according to the applicable maintenance instruction manual (MIM), maintenance requirement cards (MRC), and rework specification. *Figure below* shows the requirements for periodic fluid surveillance.



Periodic fluid surveillance requirements.

Analysis of hydraulic systems should be performed if extensive maintenance and/or crash/battle damage occurs. Analysis should be performed when a metal-generating component fails, an erratic flight control function or a hydraulic pressure drop is noted, or there are repeated and/or extensive system malfunctions. Analysis is performed when there is a loss of system fluid, or when the system is subjected to excessive temperature. Analysis is also performed when an aircraft is removed from storage in accordance with NAVAIR 15-05-500. An analysis of the hydraulic system should also be performed any time hydraulic contamination is suspected.

MAINTENANCE PROCEDURES

The general contamination control procedures and testing of hydraulic systems, subsystems, components, and fluids are requirements for each maintenance level. Hydraulic fluid contamination controls ensure the cleanliness and purity of fluid in the hydraulic system. Fluid sampling and analysis is performed periodically. Checks are made sufficiently before the scheduled aircraft induction date so that if fluid decontamination is required, it may be accomplished at that time. The condition of the fluid depends, to a large degree, on the condition of the components in the system. If a system requires frequent component replacement and servicing, the condition of the fluid deteriorates proportionately.

Replacement of aircraft hydraulic system filter elements takes place on a scheduled or conditional basis, depending upon the requirements of the specific system. A differential pressure flow check and bubble point test are performed to properly evaluate the condition of a cleanable filter element. These two checks are done to verify that the element is good before it is installed in a system or component. Many filter elements look identical, but not all of them are compatible with flow requirements of the system.

If the hydraulic system fluid is lost to the point that the hydraulic pumps run dry or cavitate, the defective pumps should be changed, the filter elements checked, and the system decontaminated as required. The applicable MIM should be checked for corrective action to be taken regarding decontamination of the system. If this action is not taken, the complete system could be contaminated. Hydraulic systems and components are serviced by using approved fluid dispensing equipment only. Unfiltered hydraulic fluid should NEVER be introduced into systems or components.

All portable hydraulic test stands must receive the required periodic maintenance checks. Each unit must be approved and the applicable MIM should be readily accessible and up to date. When the portable hydraulic test stand is not in use, it should be protected against contaminants such as dust and water. It is important to ensure that correct hoses are used on each stand, and that they are approved for the type of fluid being used. Hoses should be properly capped when they are not being used. Hoses must be serialized and must remain with the equipment. The hoses must be coiled, kept free of kinks, and properly stowed. They should be in satisfactory condition and checked periodically. Any hose that exhibits fluid seepage from the outer cover or separation between the inner tube and the outer cover should be replaced. Portable hydraulic test stands that show indications of contamination or that have loaded (clogged) filters should be removed from service immediately and returned to the supporting activity for maintenance.

Only approved lubricants for O-ring seals should be used; incorrect lubricants will contaminate a system. Many lubricants look alike, but few are compatible with hydraulic fluids. The only approved O-ring seal lubricants are hydraulic fluid MIL-PRF-5606H, hydraulic fluid MIL-PRF-83282C, hydraulic fluid MIL-PRF-46170D, or a thin film of grease, MIL-PRF-81322F.

MAINTENANCE PRACTICES

Good housekeeping and maintenance practices help eliminate problems caused by contamination. Care must be taken when working on a hydraulic system in the open, especially under adverse weather conditions. Caution should be used when working on hydraulic equipment near grinding, blasting, machining, or other contaminant-generating operations. Often, harmful grit cannot be seen. Hydraulic systems should not be broken into unless absolutely necessary (this includes cannibalization). Proper tools should be used for the job. It is important to use only authorized hydraulic fluid, O-rings, lubricants, or filter elements. When dispensing hydraulic fluid, only an authorized fluid service unit should be used. The hydraulic fluid must be clean before it is installed. All empty hydraulic fluid cans and used hydraulic fluid must be disposed of in accordance with Navy and local hazardous material (HAZMAT) instructions. All hydraulic fluid should be in a closed container at all times.

All hydraulic test stand reservoirs should be kept above three-quarters full. All hydraulic lines, tubing, hoses, fittings, and components should be sealed with approved metal closures. Plastic plugs or caps should not be used because they are possible contamination sources. Quick-disconnect dust covers should be installed and unused caps and plugs should be stored in a clean container.

Exterior contaminants should be removed by using approved wiping cloths. Lint-free wiping cloths should be used on surfaces along the fluid path. If possible, the replacement component should be kept on hand for immediate installation upon removal of defective component. Filters should be replaced immediately after removal. If possible, the filter bowl should be filled with proper hydraulic fluid before it is installed to minimize the induction of air into the system. The differential pressure indicators should not be reset if the associated filter element is loaded and in need of replacement. When cleanable filter elements are removed from hydraulic systems, they should be put in individual polyethylene bags and forwarded to the intermediate- or depot-level maintenance activity for cleaning. Cleanable filter elements should NOT be cleaned by washing them in a container and blowing them out with shop air. Cleanable filter elements must be cleaned and tested according to applicable procedures before they are reused. All connections should be cleaned and the pressure and return lines of the stand should be interconnected. The hydraulic fluid should be circulated through the test stand filters before connecting portable hydraulic test stands to aircraft.

NOTE

Do not use chlorinated solvents to clean connectors. Use dry-cleaning solvent MIL-PRF-680 or filtered hydraulic fluid.

O-rings, tubing hoses, fittings, and components should be stored in clean packaging. Individual packages of O-rings or backup rings should not be opened or punctured until just before they are used. *Used* or *unidentifiable O-rings* should not be used. Seals or backup rings should be replaced with new items when they have been disturbed. The correct O-ring should always be used when O-rings are installed over threaded fittings to prevent threads from damaging the O-ring.

If packages of tubing, hoses, fittings, or components are opened when received or found opened, their contents should be decontaminated. The system should be decontaminated if it is suspected the system is contaminated with anything (including water). The working area where hydraulic components are repaired, serviced, or stored should be kept clean and free from moisture, metal chips, and other contaminants. Required period checks should be performed on equipment used to service hydraulic systems. Hydraulic fluid MIL-PRF-46170D should be used in stationary hydraulic test stands.

TYPES OF CONTAMINATION

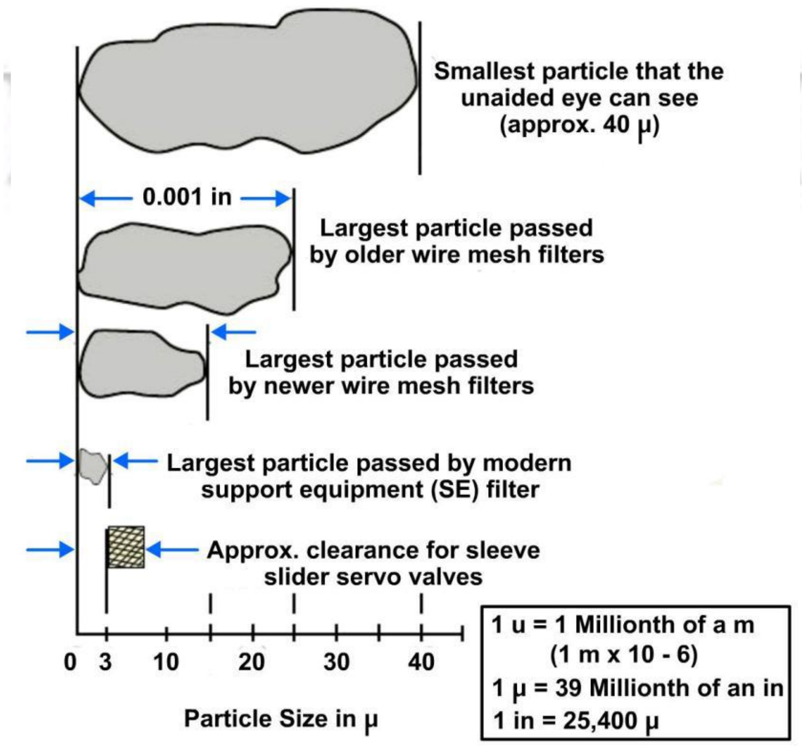
There are many different forms of contamination, including liquids, gases, and solid matter of various compositions, sizes, and shapes. Normally, contamination in an operating hydraulic system originates at several different sources. The rate of its introduction depends upon many factors directly related to wear and chemical reaction. Contamination removal can reverse this trend. Production of contaminants in the hydraulic system increases with the number of system components. The rate of contamination from external sources is not readily predictable. A hydraulic system can be seriously contaminated by poor maintenance practices that lead to introducing large amounts of external contaminants. Poorly maintained SE is another source of contamination.

Contaminants in hydraulic fluids are classified as particulate and fluid contamination. They may be further classified according to their type, such as organic, metallic solids, non-metallic solids, foreign fluids, air, and water.

PARTICULATE CONTAMINATION

The type of contamination most often found in aircraft hydraulic systems consists of solid matter. This type of contamination is known as "particulate contamination."

The size of particulate matter in hydraulic fluid is measured in microns (millionths of a meter). The largest dimensions of the particle (using points on the outside of the particle as reference) are measured when determining its size. The relative size of particles, measured in microns, is shown in *Figure below*. *Table below* shows the various classes of particulate contamination levels.



Graphic comparison of particle sizes

MICRON SIZE RANGE	PARTICLE CONTAMINATION LEVEL-BY CLASS						
	Acceptable						Unacceptable
	0	1	2	3	4	5	6
5-10	2,700	4,600	9,700	24,000	32,000	87,000	128,000
10-25	670	1,340	2,680	5,360	10,700	21,400	42,000
25-50	93	210	380	780	1,510	3,130	6,500
50-100	16	28	56	110	225	430	1,000
Over 100	1	3	5	11	21	41	92
Total	3,480	6,181	12,821	30,261	44,456	112,001	177,592

Notes: 1. The class of contamination is based upon the total number of particles in any size range per 100 ml of hydraulic fluid. Exceeding the allowable particle count in any one or more size range requires that the next higher class level be assigned.

2. Class 5 is the maximum acceptable contamination level for hydraulic systems in Naval aircraft. Fluid delivered by SE to equipment under test or being serviced must be Class 3, or cleaner.

3. The Class 5 level of acceptability shall be met at the inspection interval specified for the equipment under test.

Contamination of hydraulic fluid with particulate matter is a principal cause of wear in hydraulic pumps, actuators, valves, and servo valves. Spool-type electro-hydraulic valves have been used in particle contamination experiments. The valves are easy to control and respond rapidly to repositioning. In these experiments, the valves were operated with both ultra clean and contaminated hydraulic fluids. The experiments proved that wear is accelerated by even small amounts of contamination. Contamination increases the rate of erosion of the sharp spool edges and general deterioration of the spool surfaces. Because of the extremely close fit of spools in servo valve housings, the valves are particularly susceptible to damage or erratic operation when operated with contaminated hydraulic fluid.

Organic Contamination

Organic solids or semisolids are one of the particulate contaminants found in hydraulic systems. They are produced by wear, oxidation, or polymerization (a chemical reaction). Organic solid contaminants found in the systems include minute particles of O-rings, seals, gaskets, and hoses. These contaminants are produced by wear or chemical reaction.

Oxidation of hydraulic fluids increases with pressure and temperature. Antioxidants are blended into hydraulic fluids to minimize such oxidation. Oxidation products appear as organic acids, asphaltics, gums, and varnishes. These products combine with particles in the hydraulic fluid to form sludge. Some oxidation products are oil soluble and cause an increase in hydraulic fluid viscosity, while other oxidation products are not oil soluble and form sediment. Oil oxidation products are not abrasive. These products cause system degradation because the sludge or varnish-like materials collect at close-fitting, moving parts, such as the spool and sleeve on servo valves. Collection of oxidation products at these points causes sluggish valve response.

Metallic Solid Contamination

Metallic solid contaminants are usually found in hydraulic systems. The size of the contaminants will range from microscopic particles to those you can see with the naked eye. These particles are the result of the wearing and scoring of bare metal parts and plating materials, such as silver and chromium. Wear products and other foreign metal particles, such as steel, aluminum, and copper, act as metallic catalysts in the formation of oxidation products. Fine metallic particles enter hydraulic fluid from within the system. Although most of the metals used for parts fabrication and plating are found in hydraulic fluid, the major metallic materials found are ferrous, aluminum, and chromium particles.
Hydraulic pumps usually contribute the most contamination to the system because of their high-speed, internal movement. Other hydraulic systems produce hydraulic fluid contamination due to body wear and chipping.
Hydraulic actuators and valves are affected by contamination. Large metallic or hard nonmetallic particles collect at the seal areas. These particles may groove the inside wall of the actuator body due to a scraping action. Smaller particles act as abrasives between the seals and the actuator body, causing wear and scoring. Eventually, the fluid leaks and the seals fail because the seal extrudes into the enlarged gap between the piston head and the bore of the actuator body. Once wear begins, it increases at a faster rate because wear particles add to the abrasive material. In a similar manner, metallic or nonmetallic parts may lodge in the poppets and poppet-seat portions of valves and cause system malfunction by holding valves open.

Inorganic Solid Contamination

The inorganic solid contaminant group includes dust, paint particles, dirt, and silicates. These and other materials are often drawn into hydraulic systems from external sources. The wet piston shaft of a hydraulic actuator may draw some of these foreign materials into the cylinder past the wiper and dynamic seals. The contaminant materials are then dispersed in the hydraulic fluid. Also, contaminants may enter the hydraulic fluid during maintenance when tubing, hoses, fittings, and components are disconnected or replaced. To avoid these problems, all exposed fluid ports should be sealed with approved protective closures.
Glass particles from glass bead peening and blasting are another contaminant. Glass particles are particularly undesirable because glass abrades synthetic rubber seals and the very fine surfaces of critical moving parts.

FLUID CONTAMINATION

Hydraulic fluid can be contaminated by air, water, solvents, and foreign fluids. These contaminants and their effects are discussed in the following text.

Air Contamination

Hydraulic fluids are adversely affected by dissolved, entrained, or free air. Air may be introduced through improper maintenance or as a result of system design. Air is sometimes introduced when changing filters. This kind of contamination can be minimized by putting hydraulic fluid into the filter holder before reassembling the filter. By doing this, less air is introduced into the hydraulic system. The presence of air in a hydraulic system causes *spongy* response during system operation. Air causes cavitation and erodes hydraulic components. Air also contributes to the corrosion of hydraulic components.

Water Contamination

Water is a serious contaminant of hydraulic systems. Corrective maintenance actions must be taken to remove all free or emulsified water from hydraulic systems. Hydraulic fluids and hydraulic system components are adversely affected by dissolved, emulsified, or free water. Water may be induced through the failure of a component, seal, line, or fitting; poor or improper maintenance practices; and servicing. Water may also be condensed from air entering vented systems.

The presence of water in hydraulic systems can result in the formation of undesired oxidation products, and corrosion of metallic surfaces will occur. These oxidation products will also cause hydraulic seals to deteriorate and fail, resulting in leaks. If the water in the system results in the formation of ice, it will reduce fluid flow and impede the operation of valves, actuators, or other moving parts within the system. This is particularly true of water located in static circuits or system extremities and subject to high-altitude, low-temperature conditions. Microorganisms will grow and spread in hydraulic fluid contaminated with water. These microorganisms will clog filters and reduce system performance.

Solvent Contamination

Solvent contamination is a special form of foreign-fluid contamination. The original contaminating substance is a chlorinated solvent introduced by improper maintenance practices. It is extremely difficult to stop this kind of contamination once it occurs. This type of contamination can be prevented by using the right cleaning agents when performing hydraulic system maintenance.

Chlorinated solvents, when allowed to combine with minute amounts of water, hydrolyze to form hydrochloric acids. These acids attack internal metallic surfaces in the system, particularly those that are ferrous, and produce severe rust-like corrosion that is virtually impossible to arrest. Extensive component overhaul and system decontamination are generally required to restore the system to an operational status.

Foreign Fluids Contamination

Contamination of hydraulic fluid can occur when the wrong fluids get into the system, such as oil, engine fuel, or incorrect hydraulic fluids. For instance, hydraulic oil coolers, which are used in some aircraft, may leak and cause contamination of hydraulic fluids. If contamination has occurred, the system must be checked by chemically analyzing fluid samples. This analysis is conducted by the cognizant engineering activity, which verifies and identifies the contaminant and directs decontamination procedures.

The effects of foreign fluid contamination depend upon the nature of the contaminant. The compatibility of the construction materials and the system hydraulic fluid with the foreign fluid must be considered when dealing with contamination. Other effects of this type of contamination are hydraulic fluid reaction with water and changes in flammability and viscosity characteristics. The effects of contamination may be mild or severe, depending upon the contaminant, how much is in the system, and how long it has been there.

SAMPLING POINTS

A fluid sampling point is a physical point in a hydraulic system from which small amounts of hydraulic fluid are drawn to analyze it for contamination. Sampling points include air bleed valves, reservoir drain valves, quick-disconnect fittings, removable line connections, and special valves installed for this specific purpose.

Hydraulic fluid sampling points for most naval aircraft are designated in the applicable MIM. Two major factors determine if a sampling point is adequate—its mechanical feature and its location in the system. To determine the contamination level, a single fluid sample is required. This sample must be representative of the working fluid in the system, and it should be a "worst case" indication of the system particulate level. The worst case requirement is necessary because the particulate level in an operating system is not constant throughout the system. Instead, particulate levels differ because of the effects of components (such as filters) on circulating particulates.

The mechanical features of a prospective sampling point are evaluated on the basis of accessibility and ease of operation. The sampling point should not distort the particulate level of the sampled fluid either by acting as a filter or by introducing external or self-generated contaminants. The latter point is particularly critical. The introduction of external or self-generated contaminants can be minimized before collecting a sample by cleaning the external parts of the valve or fitting and by dumping a small amount of the initial fluid flow.

Consideration must also be given to removal of any static fluid normally entrapped between the actual sampling point and the main body of the fluid to be sampled. To remove this, an initial quantity of the sampled fluid should be dumped. Problems may be encountered where a long line is involved, as in certain reservoir drain lines. The fluid sample should be taken from a main system return line, pump suction line, or system reservoir. Also the sample should be taken upstream of any return or suction line filters that may be present. Reservoir samples should not be taken in a system that has a makeup reservoir, or if the reservoir is bypassed during SE-powered operation. A makeup reservoir is a configuration in which all of the system's return line fluid does not pass through the reservoir. Fluid exchange in the reservoir is limited, and results only from the changes in fluid volume that occurs elsewhere in the system.

The sampling point should be usable after an aircraft flight, without requiring the use of external SE. Taking a sample with the aircraft engines turning is satisfactory, provided no personnel hazards are involved. The sampling point should be usable when the system is being powered by external SE, or immediately after such an operation.

The sampling point should be next, or reasonably close, to the main body or stream of fluid being sampled. A minimum amount of static fluid is acceptable; however, it should be purged when the sample flow is started. The sample should not be taken from a point in an area of high sedimentation. If this cannot be avoided, care must be taken that sedimentation effects are minimized by discarding an initial quantity of the sample fluid drawn. Ideally, sample fluid should be obtained from turbulent high-flow areas.

When a sample is taken at the sampling point, significant external contaminants should not be introduced into the fluid collected. The background level attributable to the sample point itself should not exceed 10 percent of the normally observed particulate level if the external parts of the valve or fitting are pre-cleaned and the valve or fitting is self-flushed before the sample is taken. The internal porting of the sampling point should not impede the passage of hard particulate matter up to 500 microns in diameter. The sampling point should be accessible and convenient. There must be sufficient clearance beneath the valve or fitting to position the sample collection bottle. Under normal system operating pressure, the sample fluid flow rate should be between 100 and 1,000 milliliters per minute (approximately 3 to 30 fluid ounces). The flow rate should be manageable, and the time required to collect the required sample should not be excessive. The mechanical integrity of the sampling valve or fitting should not degrade because of repeated use. When not in use, it is mechanically secured in the closed position.

ANALYSIS METHODS

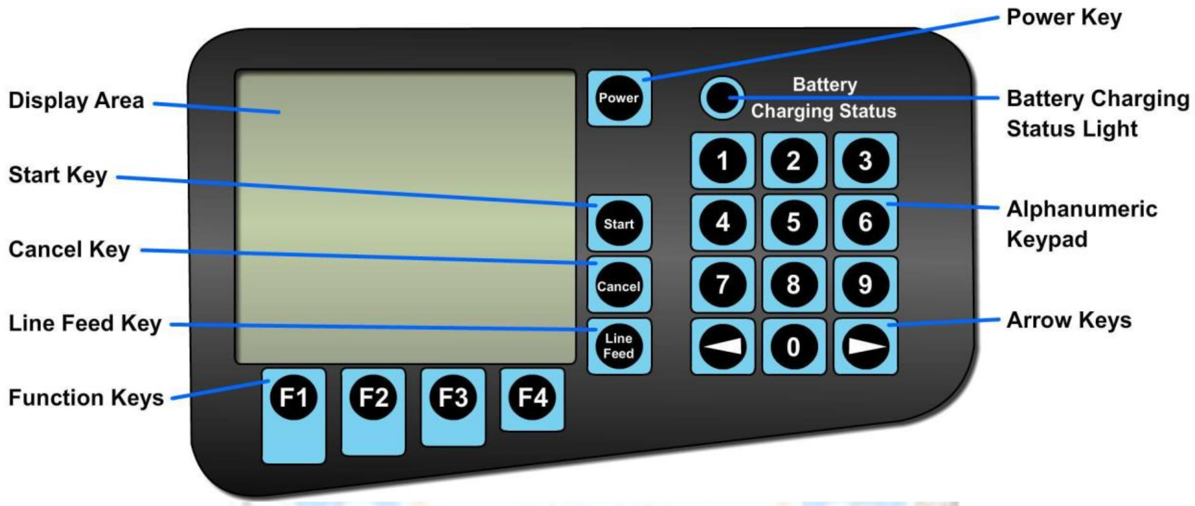
Contamination analysis is used to determine the particulate level of a hydraulic system and the presence of free water or other foreign substances. The methods used to identify and measure contamination is the HACH Ultra Analytics Portable Oil Diagnostic System (PODS) and the patch testing System. The Contamination Analysis Kit 57L414 shall be used for testing only if electronic particle count testing is not available either directly or via the appropriate supporting Intermediate Level (I-level) activity or Navy Oil Analysis Program (NOAP) laboratory.

HACH Ultra Analytics Portable Oil Diagnostic System (PODS)

The PODS is an intelligent, portable, and durable analysis instrument for measuring, storing, and reporting oil contamination levels important for maintaining reliable hydraulic systems operation, shown in *Figure below*.

Portable Oil Diagnostic System (PODS)

The PODS can analyze fluid either in the bottle sampling mode or the online sampling mode. There are currently two versions of the PODS: Type 1, MXU-973E and Type 2, MXU-976E. Type 1 can analyze MIL-PRF-83282C and MIL-PRF-5606H and is compatible with most petroleum-based fluids. Type 1 is not compatible with phosphate ester-based fluids (e.g. Skydrol). Type 2 is compatible with phosphate ester-based hydraulic fluids, synthetic and petroleum-based fluids. *Figure 5-32* shows the features included on the keypad. To prevent fluid cross contamination, the Type 2 PODS is used only for phosphate ester-based hydraulic fluids. The unit is capable of online sampling at pressures and temperatures up to 13.8 bar (200 psig) and 131EF (55 °C), respectively. In bottle sampling mode, the PODS require a clean, dry, steady, pressurized air source. The PODS accessory case contains both an electric-driven compressor and two refillable CO2 bottles. The CO2 bottles are quieter and take less space than the compressor. Electronic particle counters are used to determine counts of the number of particles in the various size ranges. The counts obtained are compared with the maximum allowable under Navy Standard Class 5. Counts that exceed the maximum allowable in any size range make the fluid unsuitable for use in Navy aircraft. The test results obtained by using automatic particle counters and the contamination analysis kit are not always precisely the same. Automatic particle counters optically sense particles contained in the fluid sample and electronically size and count them. Most fleet equipment is calibrated so that the smallest particle counted has an effective diameter of 5 microns. Particles smaller than 5 microns, although always present, do not affect the particle count. The contamination analysis kit uses a patch-test method in which the fluid is filtered through a test-filter membrane. The sample causes the membrane to discolor proportionally to the particulate level. The test filters used have a filtration rating of 5 microns (absolute). However, they also retain a large percentage of those particles less than 5 microns in size. The contamination standards provided with the contamination analysis kit are representative of test indications that result if the fluid sample has a particle size distribution (number of particles versus size) typical of that found in the average naval aircraft. Samples from aircraft systems having typical particle size distributions will, therefore, show good correlation if tested using both particle count and patch test methods.

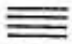
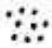


Portable Oil Diagnostic System (POD) keypad features.

Some operating hydraulic systems have peculiar design characteristics, so they produce a particle size distribution different from that found in typical naval aircraft. Fluid samples from these systems generally contain an abnormally large amount of silt-like particles smaller than 5 microns in size. Experience has shown that this condition results from inadequate system filtration or from using hydraulic components that have abnormally high wear rates. It is this type of fluid sample that could produce different results when tested, using both particle-counting and patch-test methods. The difference is caused by the particle counter not counting those particles smaller than 5 microns, while many of them are retained by the patch-test filter membrane, causing it to discolor proportionately. When test results conflict, the equipment tested is considered unacceptable if it fails either test method. The equipment should then be subjected to decontamination. It must be recognized that the differing test results may indicate system deficiencies and justify a request for an engineering investigation of the equipment. Poor correlation between particle counts and patch tests can result from improper sample-taking procedures, incorrect particle counter calibration, or faulty test procedures. These possibilities must be carefully investigated if a correlation problem is encountered.

COLOUR CODING IN AN AIRCRAFT

Table below shows some of the common piping symbols used in piping prints. When a print shows more than one piping system of the same kind, additional letters are added to the symbols to differentiate between the systems.MIL-STD-101C established the colour code used to identify piping carrying hazardous fluids. It applies to all piping installations in naval industrial plants and shore stations where colour is used. While all valve wheels on hazardous fluid piping must be colour coded, the piping itself is optional. The following colours are painted on valve wheels and pipe lines carrying hazardous fluids: Yellow — Flammable materials Brown— Toxic and poisonous materials Blue—Anesthetics and harmful materials Green—Oxidizing materials Gray—Physically dangerous materials Red—Fire protection materials Fluid lines in aircraft are marked according to MIL-STD-1247C, *Markings, Functions, and Designations of Hoses, Piping, and Tube Lines for Aircraft, Missiles, and Space Systems.* Figure below lists the types of aircraft fluid lines with the colour codeand symbol for each type. Aircraft fluid lines are also

FUNCTION	COLOR	SYMBOL
Fuel	Red	
Rocket Oxidizer	Green, Gray	
Rocket Fuel	Red, Gray	
Water Injection	Red, Gray, Red	
Lubrication	Yellow	
Hydraulic	Blue, Yellow	
Solvent	Blue, Brown	
Pneumatic	Orange, Blue	
Instrument air	Orange, Gray	
Coolant	Blue	
Breathing Oxygen	Green	
Air Conditioning	Brown, Gray	
Monopropellant	Yellow, Orange	
Fire Protection	Brown	
Deicing	Gray	
Rocket Catalyst	Yellow, Green	
Compressed gas	Orange	
Electrical Conduit	Brown, Orange	
Inerting	Orange, Green