AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 1

1. HYDRAULIC SYSTEMS

Hydraulic systems in aircraft provide a means for the operation of aircraft components like landing gear, flaps, flight control surfaces, and brakes.

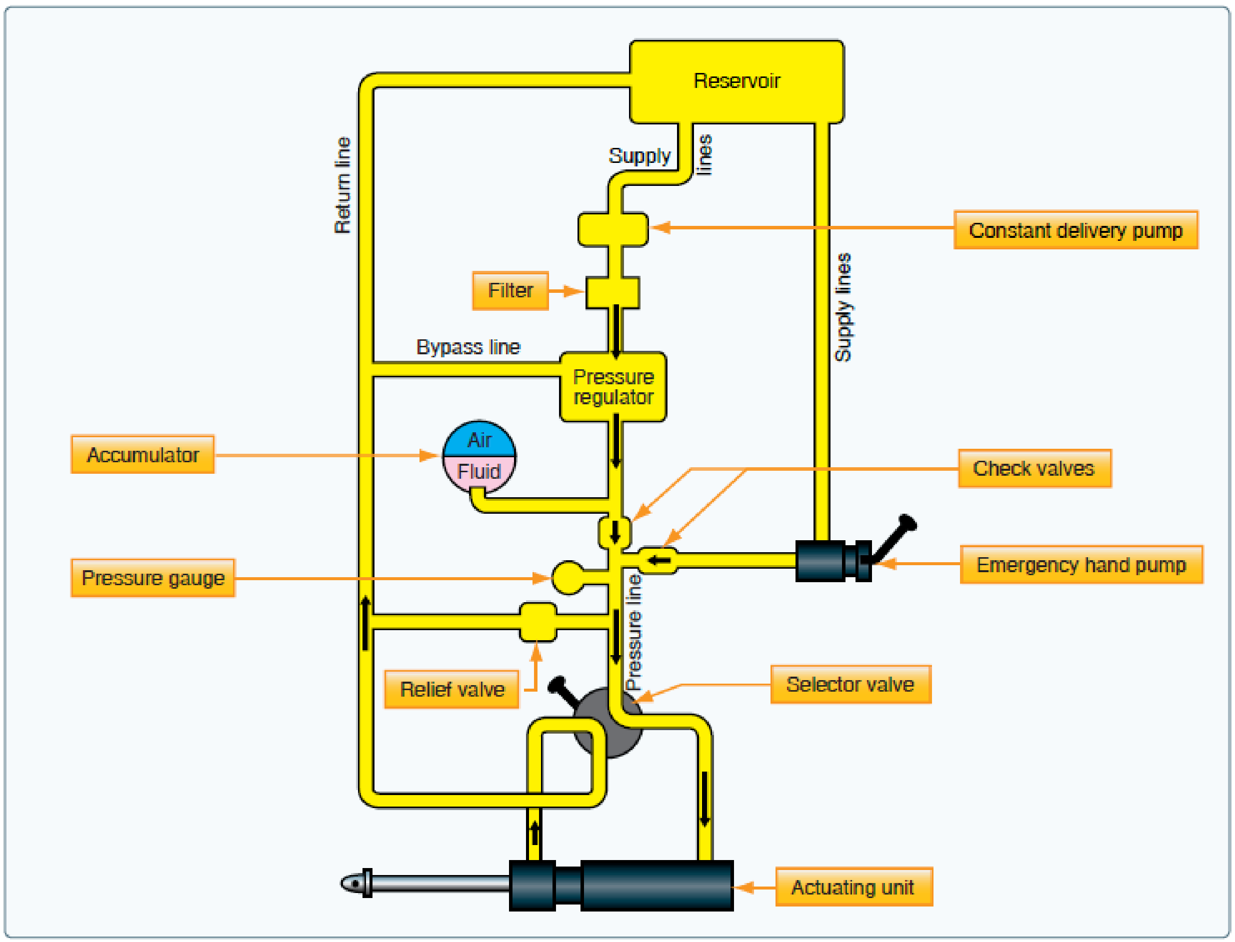


Fig: Typical Hydraulic System

- **Reservoir**: Stores the supply of hydraulic fluid for operation of the system. It replenishes the system fluid when needed and provides room for thermal expansion.
- **Pump** : It is necessary to create a flow of fluid.
- **Filter**: removes foreign particles from the hydraulic fluid, preventing dust, or other undesirable matter from entering the system.

- **Pressure Regulator**: Unloads or relieves the power-driven pump when the desired pressure in the system is reached. Thus, it is often referred to as an unloading valve.
- **Accumulator**: It serves a twofold purpose:
  - It acts as a shock absorber by maintaining an even pressure in the system.
  - It stores enough fluid under pressure to provide for emergency operation of certain actuating units.
- **Check valves:** Allow the flow of fluid in one direction only.
- **Pressure gage:** Indicates the amount of hydraulic pressure in the system.
- **Relief valve:** Safety valve installed in the system to bypass fluid through the valve back to the reservoir in case excessive pressure is built up in the system.
- **Selector valve**: Used to direct the flow of fluid. These valves are normally actuated by solenoids or manually operated, either directly or indirectly through use of mechanical linkage.
- **Actuating cylinder**: Converts fluid pressure into useful work by linear or reciprocating mechanical motion.

1.1 Advantages of Hydraulic system

- Large load capacity with almost high accuracy and precision.
- Smooth movement.
- Automatic lubricating provision to reduce wear.
- Division and distribution of hydraulic power is simpler.
- Limiting and balancing of hydraulic forces are easily performed.

1.2 Disadvantages of Hydraulic system

- Hydraulic elements need to be machined to a high degree of precision.
- Leakage of hydraulic oil poses problems to hydraulic operators.
- Special treatment is needed to protect them from rust, corrosion, dirt etc.
- Hydraulic oil may pose problems if it disintegrates due to aging and chemical deterioration.
- Hydraulic oils are messy and almost highly flammable.

1.3 Hydraulic System Controller Modes of Operation

The Hydraulic System Controller (HSC) has two modes, **auto or manual**. Only one mode is in control at any time. If an active HSC channel fails, control is automatically transferred to an alternate HSC channel. If the second HSC channel fail, the system automatically reverts to the manual mode, and the crew manually operates the hydraulic system for the remainder of the flight.

In the auto mode the HSC performs the following functions:

- Controls the hydraulic system components which supply and route hydraulic pressure.
- Monitors the phase of flight and configures components accordingly.
- Conducts a preflight pressure test of the auxiliary hydraulic pumps when initiated by the flight crew.
- Conducts a test of engine-driven hydraulic pumps after engine start.
- Reconfigures the hydraulic systems for various component, system, and aircraft failures.
- Monitors itself and hydraulic components for proper operation and reports faults to the Centralized Fault Display System (CFDS) and EIS.
- Reverts to manual mode if the auto mode is inoperative or if any combination of hydraulic system, and/or aircraft abnormal operation requires more than four engine-driven hydraulic pumps to be commanded off.

2. AIRCRAFT PNEUMATIC SYSTEM

Aircraft pneumatic systems are primarily used as emergency sources of pressure for hydraulically operated sub-systems.

Pneumatic systems are used for:

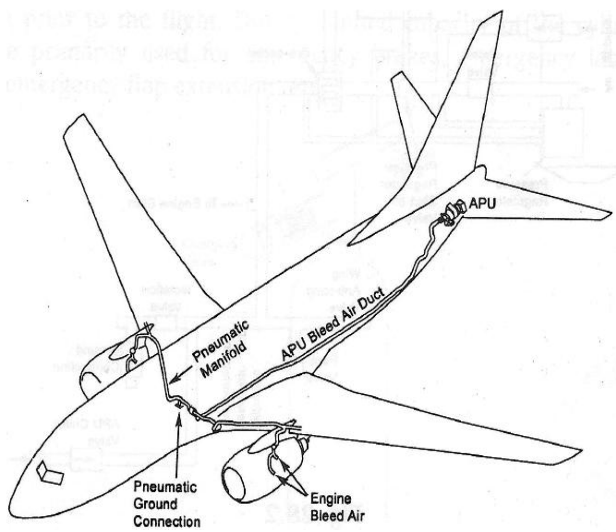
- Air conditioning and Pressurization
- Engine starting
- Anti-icing/de-icing
- Hydraulic reservoir pressurization
- Emergency lowering of landing gear and braking,
- Nose wheel steering,
- Passenger doors, etc.

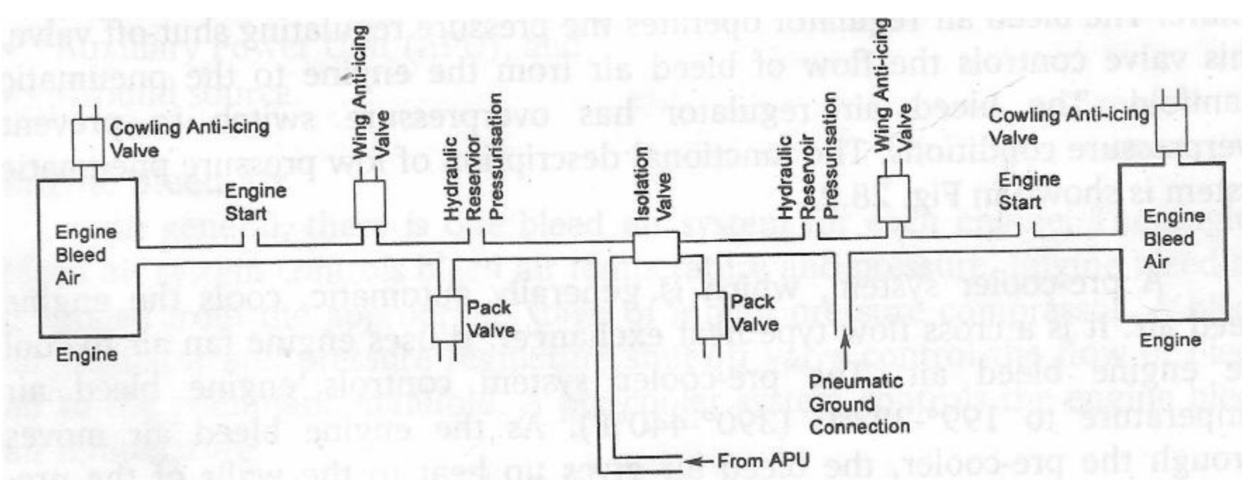
2.1 LOW PRESSURE SYSTEM

On large turbine engine aircraft, the pneumatic system is primarily used for engine starting, anti-icing/de-icing, air conditioning and pressurization. In this, the regulated pressure is of the order of 45 to 50 psi.

The sources of pneumatic power are:

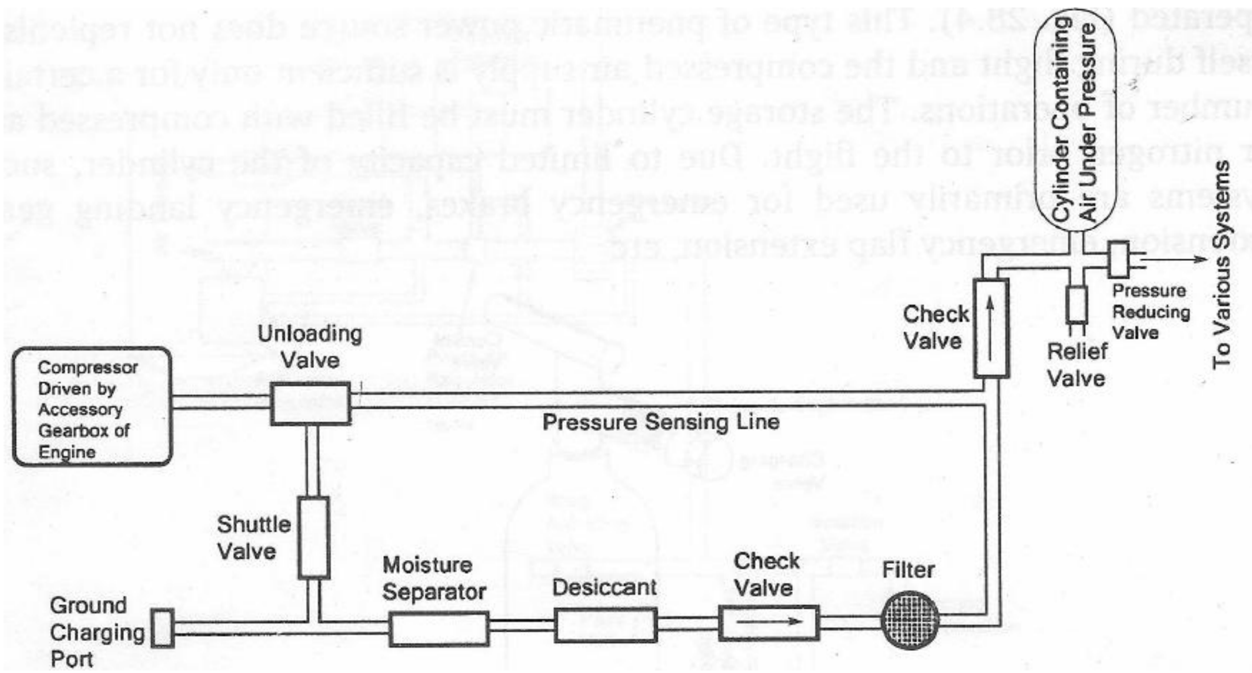
- Engine bleed air,
- Auxiliary Power Unit (APU)
- Ground source.





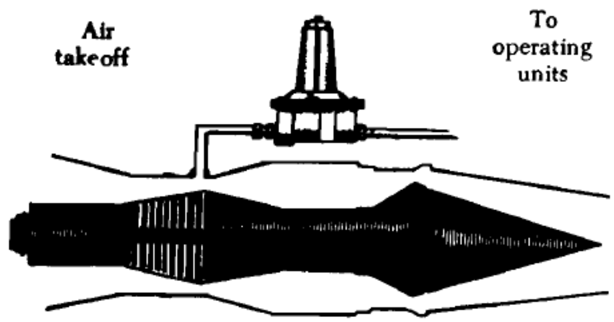
2.2 HIGH PRESSURE SYSTEM

The high pressure pneumatic system usually consists of one or more high pressure air cylinders, pressure gauges and pressure warning lights. Such a system is used for operation of landing gear, wheel brakes, flaps, doors, etc. In this the air is stored in metallic cylinders at pressure ranging from 1000 - 3000 psi.



2.3 MEDIUM PRESSURE SYSTEM

A medium-pressure pneumatic system (100-150psi.) usually does not include an air bottle. Instead, it generally draws air from a jet engine compressor section.



2.4 Advantages of Pneumatic System

- Low inertia effect of pneumatic components due to light density of air.
- System is light in weight.
- Comparatively easy operations of valves.
- Power losses and leakages are less in pneumatic systems.
- Low cost.

2.5 Disadvantages of Pneumatic System

- Suitable only for light loads or small loads.
- Availability of the assembly components is doubtful.

S. No.	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
2.	An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
3.	Generally designed as closed system	Usually designed as open system
4.	The system slows down when leakage occurs	Leakage does not affect the system much
5.	Valve operations are difficult	Valve operations are easy
6.	Heavier in weight	Lighter in weight
7.	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases
8.	The system is unsafe to fire hazards	The system is free from fire hazards
9.	Automatic lubrication is provided	Special arrangements for lubrication are needed

3 AIRCRAFT BRAKE SYSTEM

The brakes are used for slowing, stopping, holding, or steering the aircraft. Brakes are installed in each main landing wheel and they may be actuated independently of each other by applying toe pressure to the rudder pedals. Pushing on the top of the right rudder pedal activates the brake on the right main wheel(s) and pushing on the top of the left rudder pedal operates the brake on the left main wheel(s). The basic operation of brakes involves converting the kinetic energy of motion into heat energy through the creation of friction.

Brake Actuating Systems - Different means of delivering the required hydraulic fluid pressure to brake assemblies are:

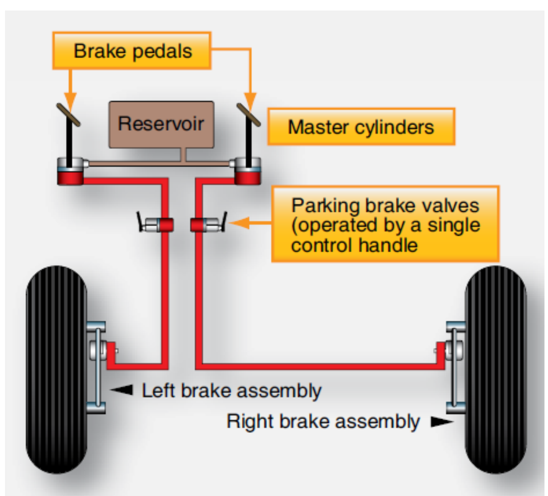
(1) **Independent systems-**not part of the aircraft main hydraulic system.

(2) **Power control systems-** only uses the aircraft main hydraulic system(s) as a source of pressure.

(3) **Power boost systems-** uses the aircraft hydraulic system intermittently when needed.

3.1 INDEPENDENT BRAKE SYSTEM

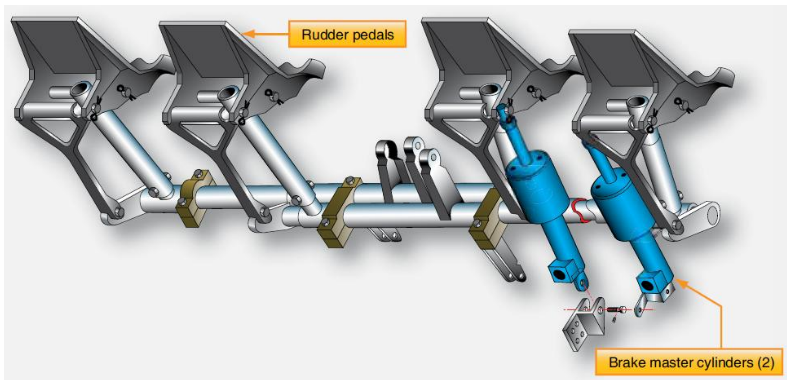
In general, the independent brake system used on small aircraft. This type of brake system has its own reservoir and is entirely independent of the aircraft's main hydraulic system.



The system is composed of a reservoir, one or two master cylinders, mechanical linkage which connects each master cylinder with its corresponding brake pedal, connecting fluid lines, and a brake assembly in each main landing gear wheel.

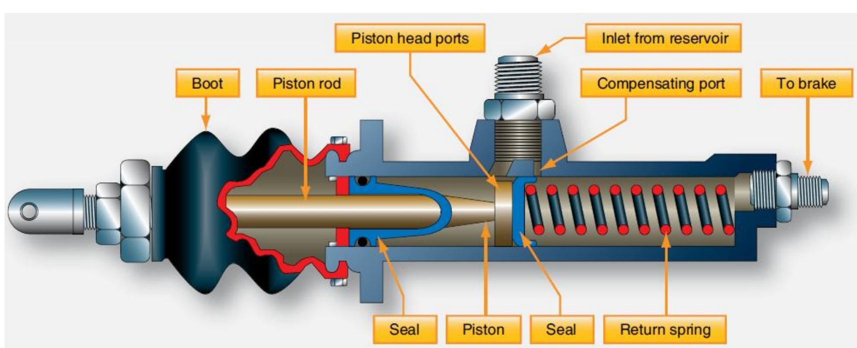
Each master cylinder is actuated by toe pressure on its related pedal. The master cylinder builds up pressure by the movement of a piston inside a sealed, fluid-filled cylinder. The resulting hydraulic pressure is transmitted to the fluid line connected to the brake assembly in the wheel. This results in the friction necessary to stop the wheel.

When the brake pedal is released, the master cylinder piston is returned to the "off position by a return spring. Fluid that was moved into the brake assembly is then pushed back to the master cylinder by a piston in the brake assembly. The brake assembly piston is returned to the "off position by a return spring in the brake.



The typical master cylinder has a compensating port or valve that permits fluid to flow from the brake chamber back to the reservoir when excessive pressure is developed in the brake line due to temperature changes. This ensures that the master cylinder won't lock or cause the brakes to drag. Two well-known master cylinders are the **Goodyear and the Warner.**

3.1.1 Goodyear Master Cylinder



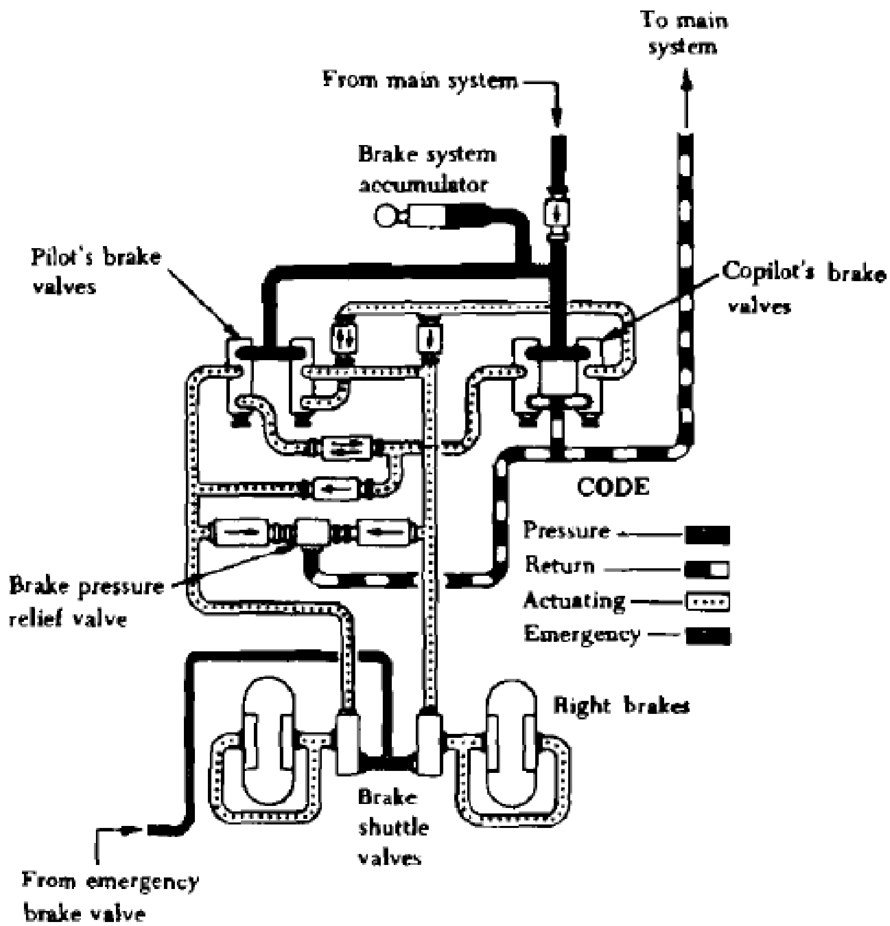
In the Goodyear master cylinder fluid is fed from an external reservoir by gravity to the master cylinder. The fluid enters through the cylinder inlet port and compensating port and fills the master cylinder casting ahead of the piston and the fluid line leading to the brake actuating cylinder. Application of the brake pedal, which is linked to the master cylinder piston rod, causes the piston rod to push the piston forward inside the master cylinder casting. A slight forward movement blocks the compensating port, and the buildup of pressure begins. This pressure is transmitted to the brake assembly.

When the brake pedal is released and returns to the "off position, the piston return spring pushes the front piston seal and the piston back to full "off' position against the piston return stop.This again clears the compensating port. Fluid that was moved into the brake assembly and brake connecting line is then pushed back to the master cylinder by the brake piston which is returned to the "off position by the pressure of the brake piston return springs. Any pressure or excess volume of fluid is relieved through the compensating port and passes back to the fluid reservoir. This prevents the master cylinder from locking or causing the brakes to drag.

3.2 POWER BRAKE CONTROL SYSTEM

Power brake control valve systems are used on aircraft requiring a large volume of fluid to operate the brakes. Because of their weight and size, large wheels and brakes are required. In this system a line is tapped off from the main hydraulic system pressure line. The first unit in this line is a check valve which prevents loss of brake system pressure in case of main system failure.The next unit is the accumulator which stores a reserve supply of fluid under pressure.

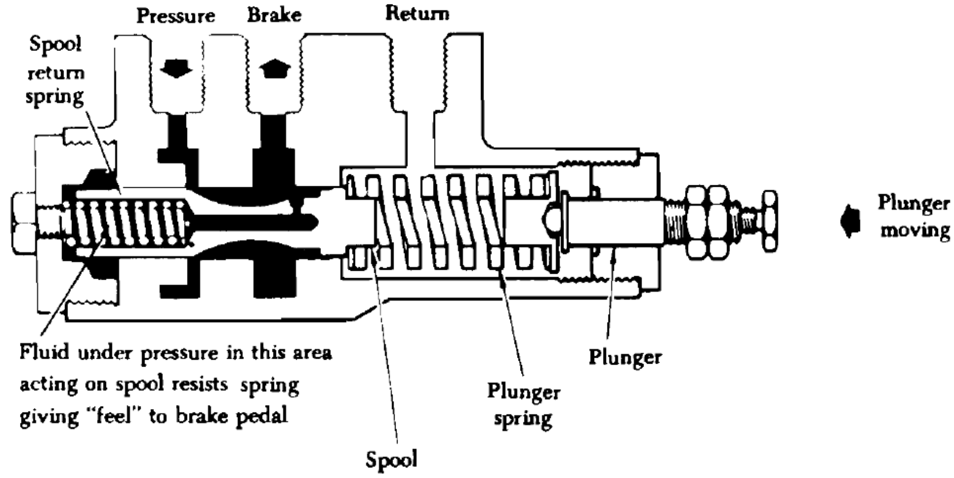
When the brakes are applied and pressure drops in the accumulator, more fluid enters from the main system and is trapped by the check valve. Following the accumulator are the pilot's and copilot's control valves. The control valves regulate and control the volume and pressure of the fluid which actuates the brakes. The next unit in the brake actuating lines is the pressure relief valve. In this particular system, the pressure relief valve is preset to open at 825 p.s.i. to discharge fluid into the return line, and closes at 760 p.s.i. minimum. Each brake actuating line incorporates a shuttle valve for the purpose of isolating the emergency brake system from the normal brake system.

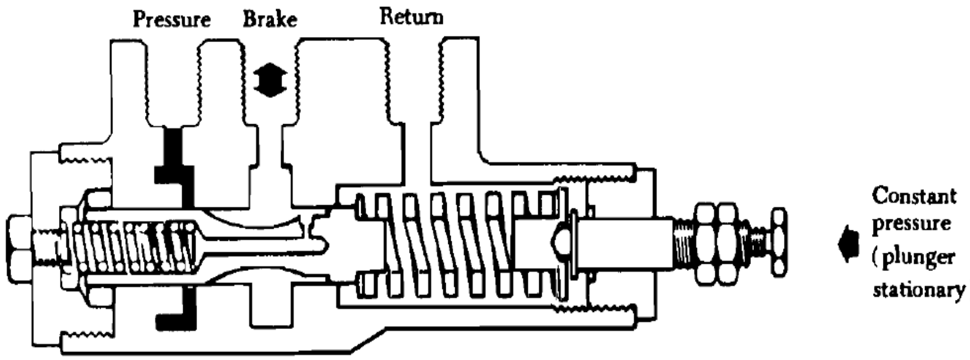


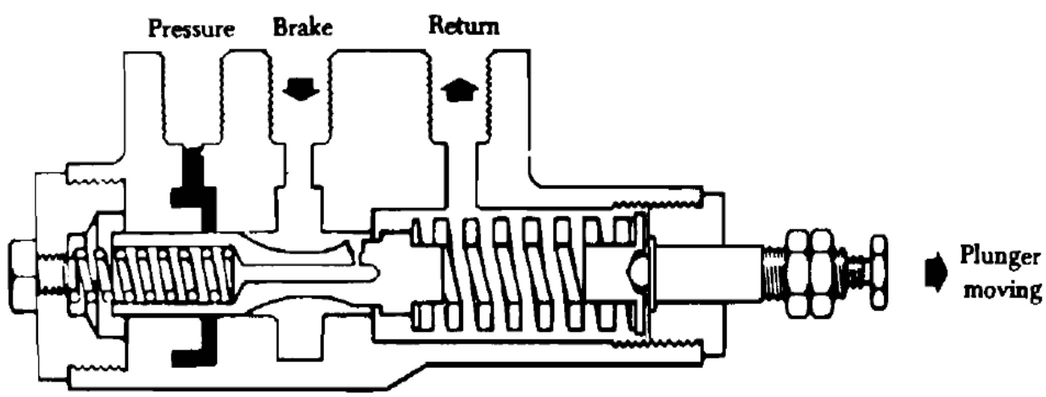
The key element in a power brake system is the brake control valve, sometimes called a brake metering valve. It responds to brake pedal input by directing aircraft system hydraulic fluid to the brakes. As pressure is increased on the brake pedal, more fluid is directed to the brake causing a higher pressure and greater braking action.

3.2.1 Sliding Spool Type Brake control valve

A sliding spool power brake control valve basically consists of a sleeve and spool installed in a housing. The spool moves inside the sleeve, opening or closing either the pressure or return port of the brake line.Two springs are provided. The large spring, referred to as the plunger spring, provides "feel" to the brake pedal. The small spring returns the spool to the "off" position.

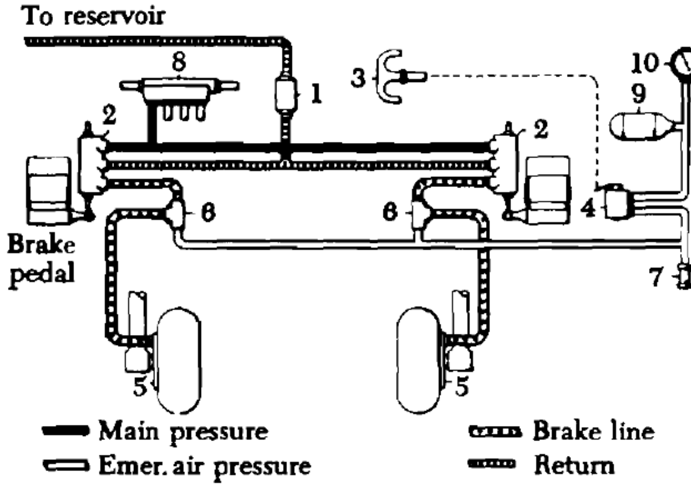






3.3 POWER BOOST BRAKE SYSTEM

Power boost brake systems are normally used on aircraft that land too fast to employ the independent brake system, but are too light in weight to require power brake control valves. A typical power boost brake system consists of a reservoir, two power boost master cylinders, two shuttle valves, and the brake assembly in each main landing wheel. A compressed air bottle with a gage and release valve is installed for emergency operation of the brakes.



1. Brake reservoir
2. Power boost master cylinder
3. Emergency brake control
4. Air release valve
5. Wheel brake
6. Shuttle valve
7. Air vent
8. Main system pressure manifold
9. Emergency air bottle
10. Emergency air gage

In this type of system, a line is tapped off the main hydraulic system pressure line, but main hydraulic system pressure does not enter the brakes. Main hydraulic system pressure is routed from the pressure manifold to the power master cylinders. When the brake pedals are depressed, fluid for actuating the brakes is routed from the power boost master cylinders through the shuttle valves to the brakes.

When the brake pedals are released, the main system pressure port in the master cylinder is closed. Fluid that was moved into the brake assembly is forced out the return port by a piston in the brake assembly, through the return line to the brake reservoir which is connected to the main hydraulic system reservoir to assure an adequate supply of fluid to operate the brakes.

3.4 BRAKE ASSEMBLIES

Modern aircraft typically use disc brakes. The disc rotates with the turning wheel assembly while a stationary caliper resists the rotation by causing friction against the disc when the brakes are applied.

Brake assemblies commonly used on aircraft are the

- Single-disc
- Dual-disc
- Multiple-disc
- Segmented Rotor
- Expander Tube

The single- and dual-disk types are more commonly used on small aircraft; the multiple-disk type is normally used on medium-sized aircraft; and the segmented rotor and expander tube types are commonly found on heavier aircraft. Braking is accomplished by applying friction to both sides of the disc from a non-rotating caliper bolted to the landing gear axle flange.

This brake assembly has a three-cylinder, one-piece hawing. Each cylinder in the housing contains a piston, a return spring and an automatic adjusting pin. Each brake assembly has six brake linings or pucks three on the inboard side of the rotating disc and three on the outboard side of the rotating disc. The outboard lining pucks are attached to the three pistons and move in and out of the three cylinders when the brakes are operated. The inboard lining pucks are stationary. The brake disc is keyed to the wheel. It is free to move laterally in the key slots.

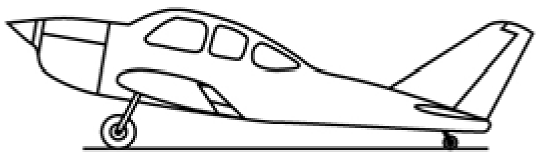
When the brakes are applied, the pistons move out from the outboard cylinders and their pucks contact the disc. The disc slides slightly in the key slots until the inboard stationary pucks also contact the disc. The result is a fairly even amount of friction applied to each side of the disc and thus, the rotating motion is slowed. When brake pressure is released, the return spring in each piston assembly forces the piston back away from the disc. The spring provides a preset clearance between each puck and the disc.

4 LANDING GEAR SYSTEMS

4.1 LANDING GEAR CONFIGURATIONS

4.1.1 Conventional Landing Gear

This type of airplane landing gear uses the main wheels ahead of the center of gravity and a small wheel supporting the tail when the airplane is on the ground.



It has the advantage of reduced drag in the air and reduced landing-gear weight. There is some loss of forward visibility for the pilot when maneuvering on the ground due to the aircraft nose-high attitude. This configuration is less stable on the ground and requires more skill when taxiing and during takeoff and landing.

4.1.2 Tricycle Landing Gear

It uses two main wheels located behind the center of gravity and a nose wheel well ahead of the center of gravity. The ease of ground handling of aircraft with tricycle landing gear has made this the most widely used landing gear configuration.

It allows more forceful application of the brakes without nosing over when braking, which enables higher landing speeds. Provides better visibility from the flight deck, especially during landing and ground maneuvering. Since the aircraft center of gravity is forward of the main gear, forces acting on the center of gravity tend to keep the aircraft moving forward rather than looping, such as with a tail wheel-type landing gear.

4.1.3 Tandem Landing Gear

This type of landing gear has the main gear and tail gear aligned on the longitudinal axis of the aircraft. Some aircraft uses small outrigger gear under the wings for support.


4.2 LANDING GEAR TYPES

4.2.1 Fixed Landing Gear

Non-retractable (fixed) landing gear is generally attached to structural members of the airplane with bolts, but it is not actually "fixed," because it must absorb stresses; therefore, the wheels must move up and down while landing or taxiing in order to absorb shocks. Fixed landing gear is usually found on small aircraft and aircraft where aerodynamic cleanliness for an efficient cruise configuration is not a major factor.

4.2.2 Retractable Landing Gear

Retractable landing gear was developed to eliminate, as much as possible, the drag caused by the exposure of the landing gear to airflow during flight.bUsually the landing gear is completely retractable (that is, it can be drawn entirely into the wing or fuselage). The retraction is normally accomplished with hydraulic or electric power. Emergency systems are usually provided to ensure that the landing gear can be lowered in case of main system failure

4.2.3 Non-Shock Absorbing Landing Gear

These type of landing gears do not dissipate the energy of the aircraft contacting the ground during landing. They only temporarily store the energy and return it to the aircraft

a) **Rigid landing gear**

b) **Shock cord landing gear**

c) **Leaf type spring landing gear**

a) Rigid landing gear

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.

b) Shock cord (Bungee Cord) landing gear

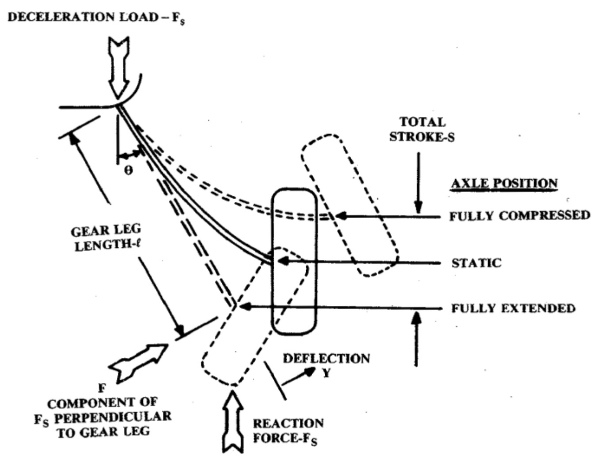
Bungee cords are positioned between the rigid airframe structure and the flexing gear assembly to take up the loads and return them to the airframe at a non-damaging rate. The bungees are made of many individual small strands of elastic rubber.

c) Leaf type spring landing 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. Landing gear struts of this type made from composite materials are lighter in weight with greater flexibility and do not corrode.

As the flexible struts are deflected, the wheel undergoes an angle of travel, as the wheel stroke is non-vertical, this motion causes excess wear on the sides of the tires, and is known as 'scrubbing'. Another difficulty with this shock absorber arrangement is that there is no damping of the shock-induced vibration. The strut reverberates up and down causing the aircraft to 'bounce' during landing.



4.2.4 Shock Absorbing Landing Gears

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:

- The shock energy is altered and transferred throughout the airframe at a different rate and time than the single strong pulse of impact,
- The shock is absorbed by converting the energy into heat energy.

Most of these types of landing gear do this by forcing a fluid through a restriction. The movement of this fluid generates heat, and the heat is radiated into the surrounding atmosphere thus dissipating the landing energy.

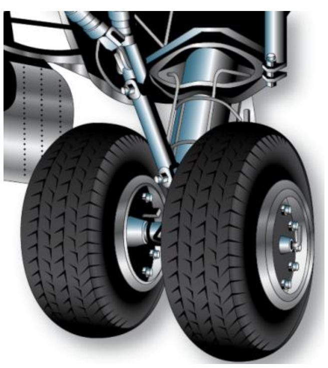
Two types:

- Spring-oleo struts
- Air-oleo struts

Spring-oleo struts:

It consists of a piston-type structure and a heavy coiled spring. The piston-and-cylinder arrangement provides an oil chamber and an orifice through which oil is forced during landing. When the airplane is airborne, the strut is extended and the oil flows by gravity to the lower chamber. When the plane lands, the piston with the orifice is forced downward into the cylinder and the oil is forced through the orifice into the upper chamber. This action provides a cushioning effect to absorb the primary shock of landing.

The number and location of wheels on the main gear vary. Some main gears have two wheels as shown.

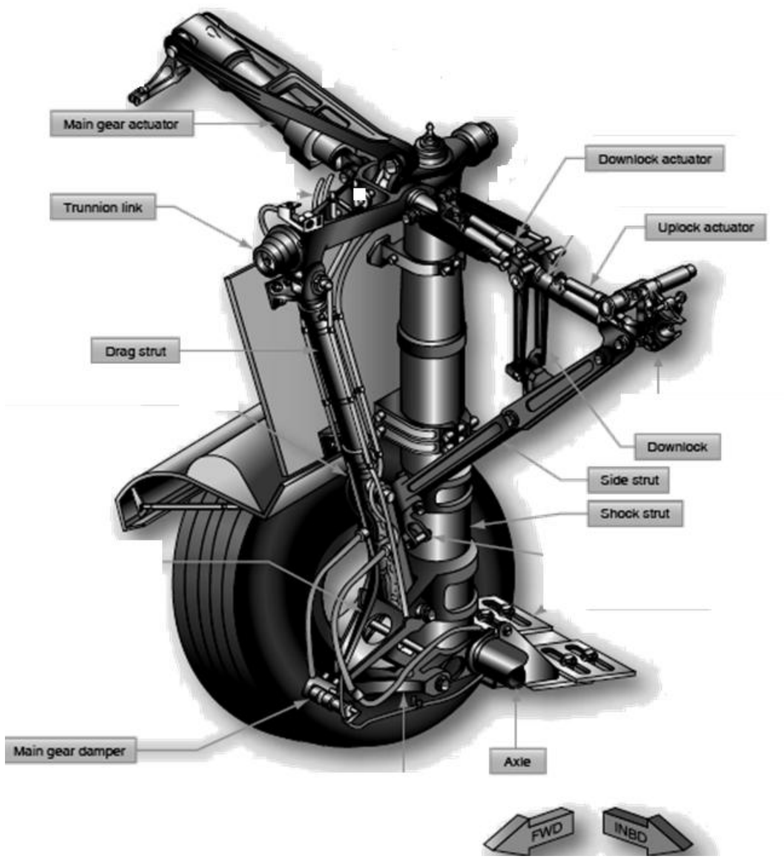


When more than two wheels are attached to a landing gear strut, the attaching mechanism is known as a **bogie**. The number of wheels included in the bogie is a function of the gross design weight of the aircraft and the surface type on which the loaded aircraft is required to land.

4.3 LANDING GEAR COMPONENTS

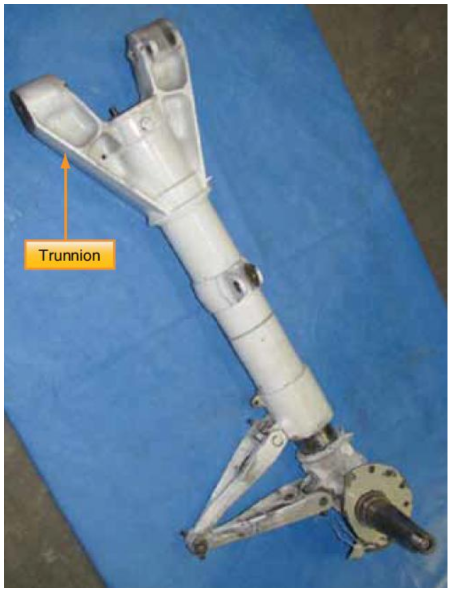
The tricycle arrangement of the landing gear is made up of many assemblies and parts.

- Air/oil shock struts
- Main gear alignment units
- Support units
- Retraction and safety devices
- Auxiliary gear protective devices
- Nose wheel steering system
- Aircraft wheels, tires, tubes
- Aircraft brake systems.



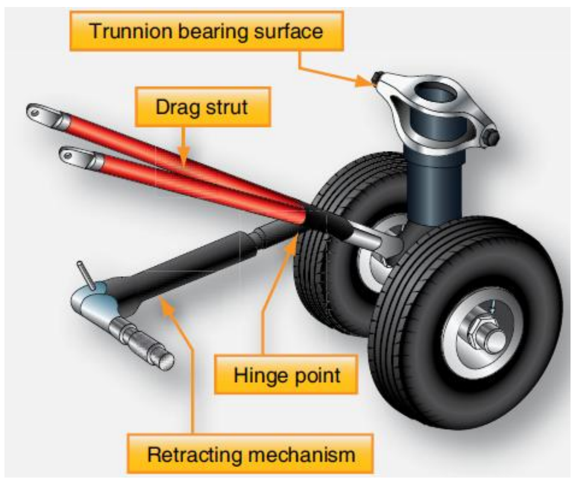
4.3.1 Trunnion

It is the portion of the landing gear assembly attached to the airframe. The trunnion is supported at its ends by bearing assemblies which allow the gear to pivot during retraction and extension.



4.3.2 Drag Strut

A drag strut is designed to stabilize the landing-gear assembly longitudinally. If the gear retracts forward or aft, the drag strut will be hinged in the middle to allow the gear to retract.



4.3.3 Truck

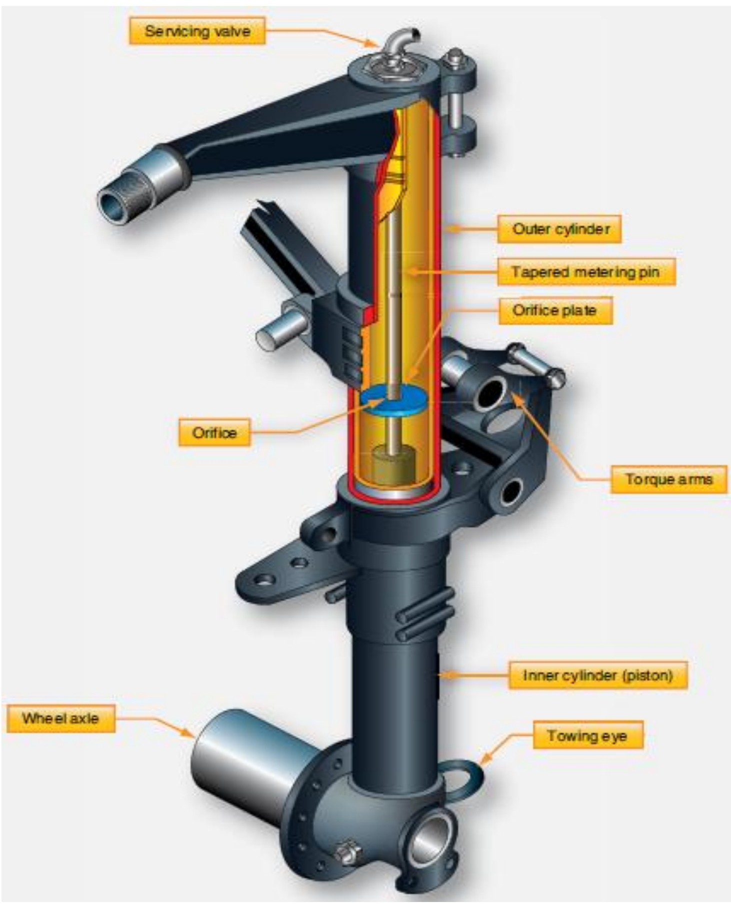
The truck is located on the bottom of the strut piston and has the axles attached to it. A truck is used when wheels are to be placed in tandem arrangement.

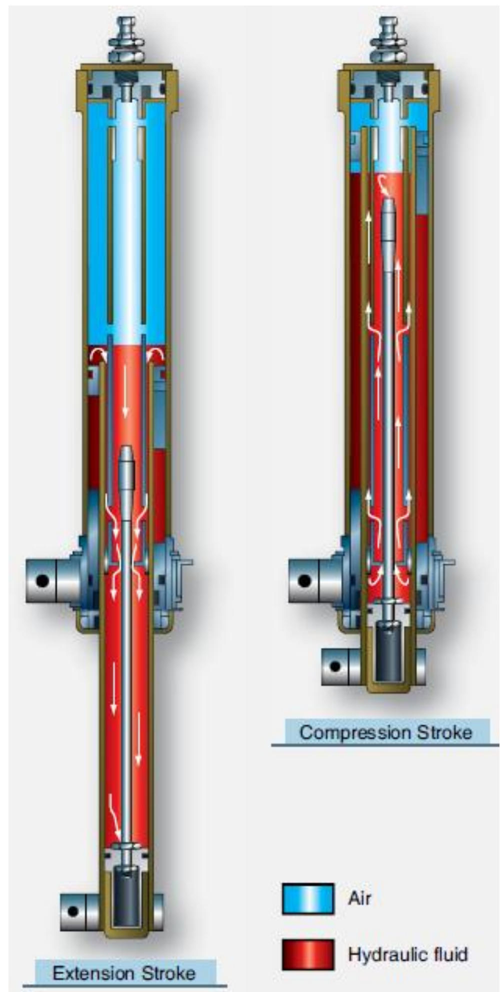
4.3.4 Shock Struts

Shock struts are self-contained hydraulic units that support an aircraft while on the ground and protect the structure during landing. A typical pneumatic/hydraulic shock strut uses compressed air or nitrogen combined with hydraulic fluid to absorb and dissipate shock loads and is often referred to as an **air/oil** or **oleo strut.**

a) Shock Strut (Metering pin type)

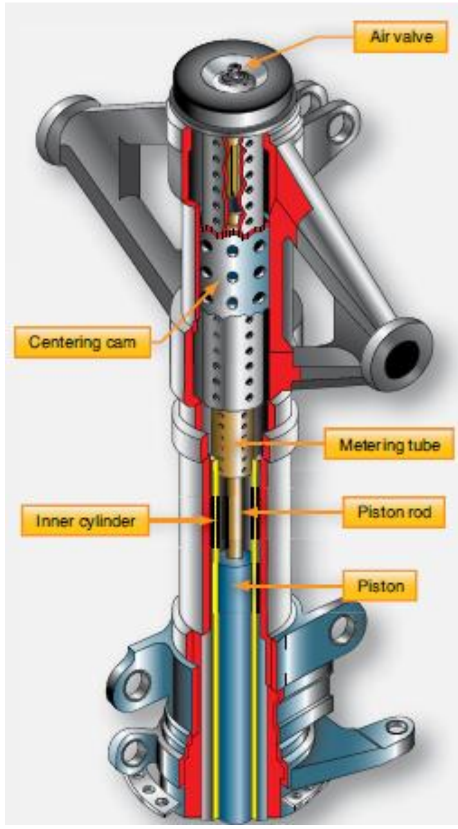
The compression stroke of the shock strut begins as the aircraft wheels touch the ground. As the center of mass of the aircraft moves downward, the strut compresses, and the lower cylinder or piston is forced upward into the upper cylinder. The metering pin is therefore moved up through the orifice. The taper of the pin controls the rate of fluid flow from the bottom cylinder to the top cylinder at all points during the compression stroke. In this manner, the greatest amount of heat is dissipated through the walls of the strut.





Energy stored in the compressed air in the upper cylinder causes the aircraft to start moving upward in relation to the Ground. At this instant, the compressed air acts as a spring to return the strut to normal.

b) Shock Strut (Metering tube type)



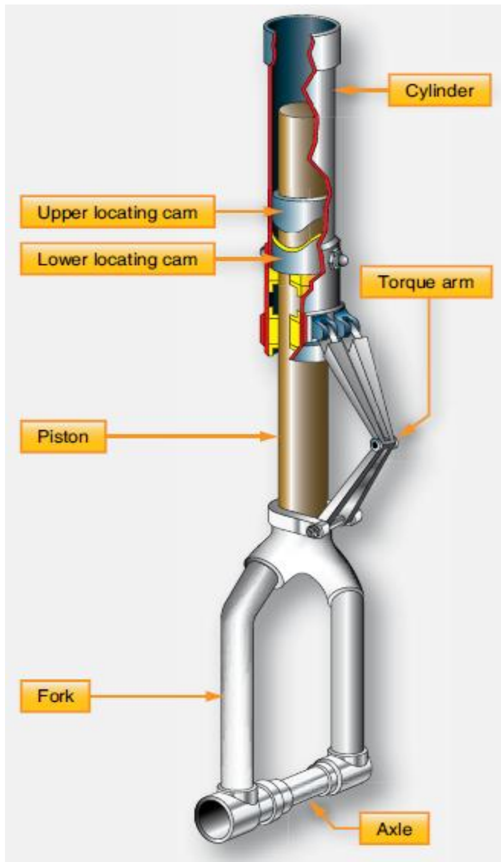
A fitting consisting of a fluid filler inlet and air valve is located near the upper *end of* each shock strut to provide a means of filling the strut with hydraulic fluid and inflating it with air or nitrogen.

4.3.5 Torque Links

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.

4.3.6 Nose Gear Shock Strut

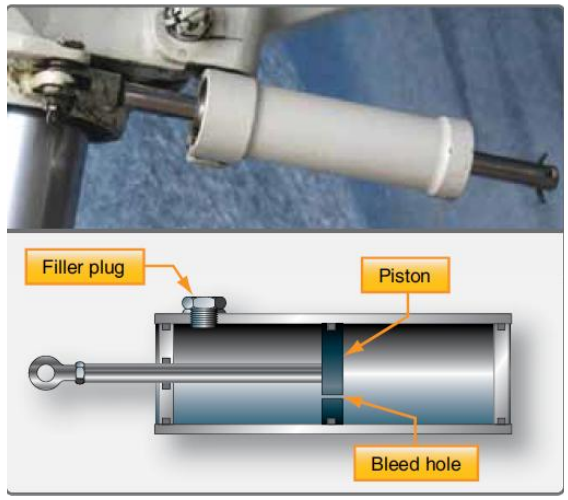
Nose gear shock struts are provided with an upper locating cam attached to the upper cylinder and a mating lower locating cam attached to the lower cylinder. These cams line up the wheel and axle assembly in the straight-ahead position when the shock strut is fully extended. This also prevents the nose wheel from being cocked to one side when the nose gear is retracted, thus preventing possible structural damage to the aircraft.



4.3.7 Shimmy Damper

Many nose gear shock struts also have attachments for the installation of an external shimmy damper. Torque links 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. It is active during all phases of ground operation while permitting the nose gear steering system to function normally. 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.



4.4 LANDING GEAR RETRACTION

The purpose of retractable landing gear is to reduce the drag of the aircraft or to adapt the aircraft for landing on different surfaces.

4.4.1 Mechanical System

Some older aircraft use a mechanical retractable landing gear system. A mechanical system is powered by the pilot moving a lever or operating a crank mechanism. A lever arrangement is found on many older aircraft and involves the use of a lever which moves through an arc of 90 degree to retract or extend the gear. When the lever is moved from the vertical to the horizontal position, the lever unlocks the gear, and, through the use of over center springs, torque tubes, and bell cranks, retracts the gear.

4.4.2 Electrical System

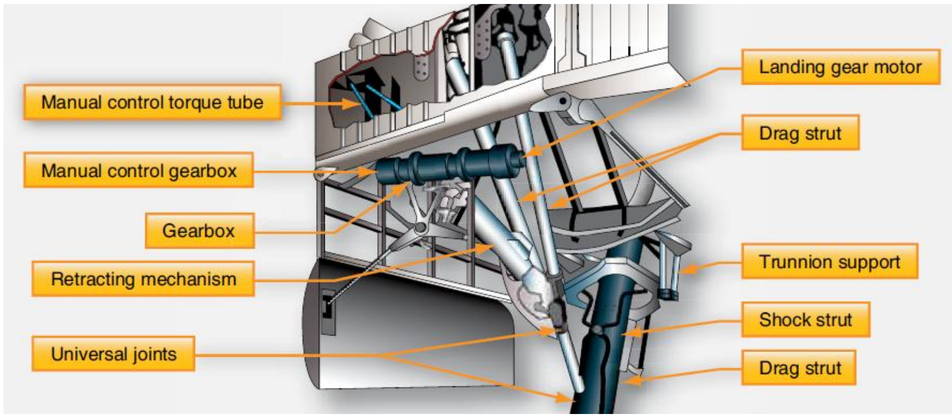
It includes:

(1) A motor for converting electrical energy into rotary motion.

(2) A gear reduction system for decreasing the speed and increasing the force of rotation.

(3) Other gears for changing rotary motion (at a reduced speed) into push-pull movement.

(4) Linkage for connecting the push-pull movement to the landing gear shock struts.



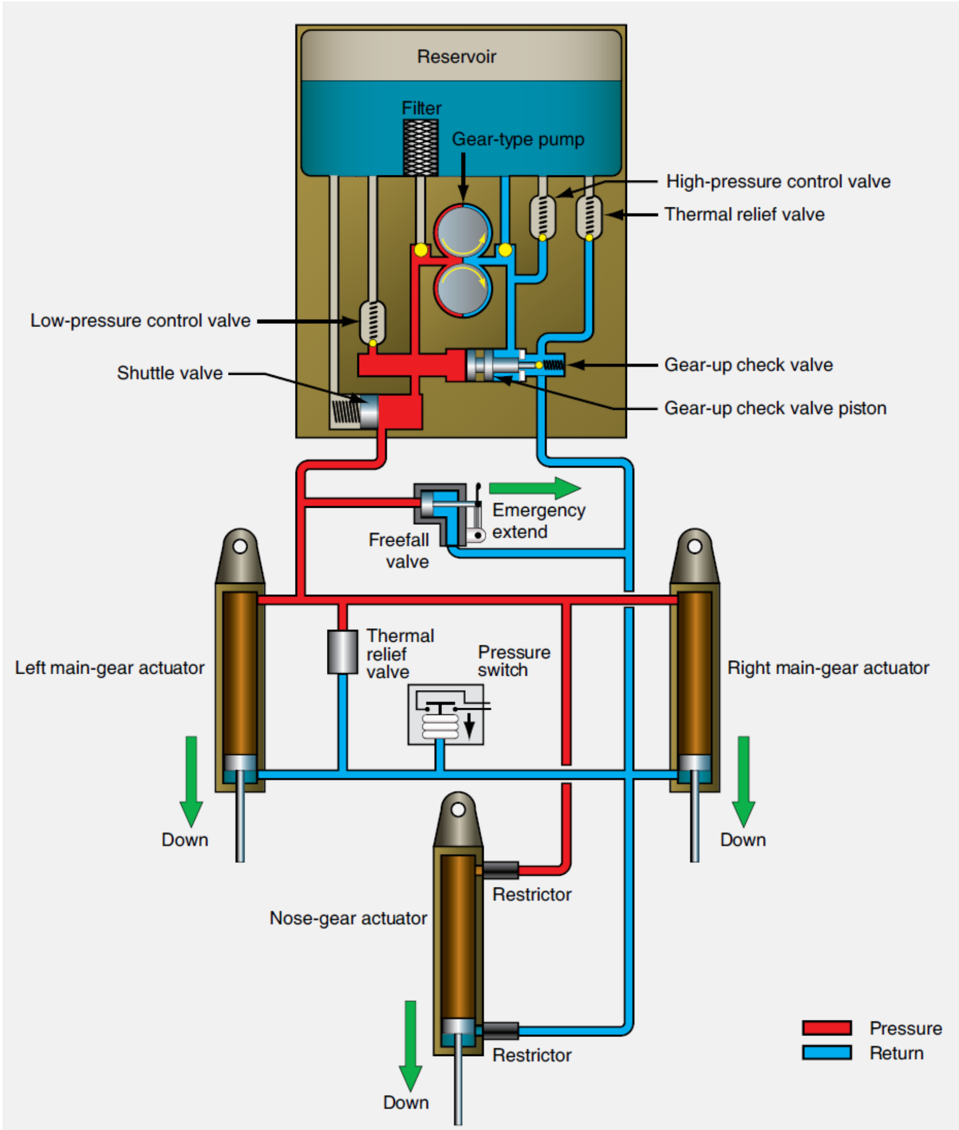
When a switch in the cockpit is moved to the "up" position, the electric motor operates. Through a system of shafts, gears, adapters, an actuator screw, and a torque tube, a force is transmitted to the drag strut linkages. Thus, the gear retracts and locks. If the switch is moved to the "down" position, the motor reverses and the gear moves down and locks.

4.4.3 Electric/Hydraulic System

A more common use of electricity in gear retraction systems is that of an electric/hydraulic system, also known as a **power pack 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.

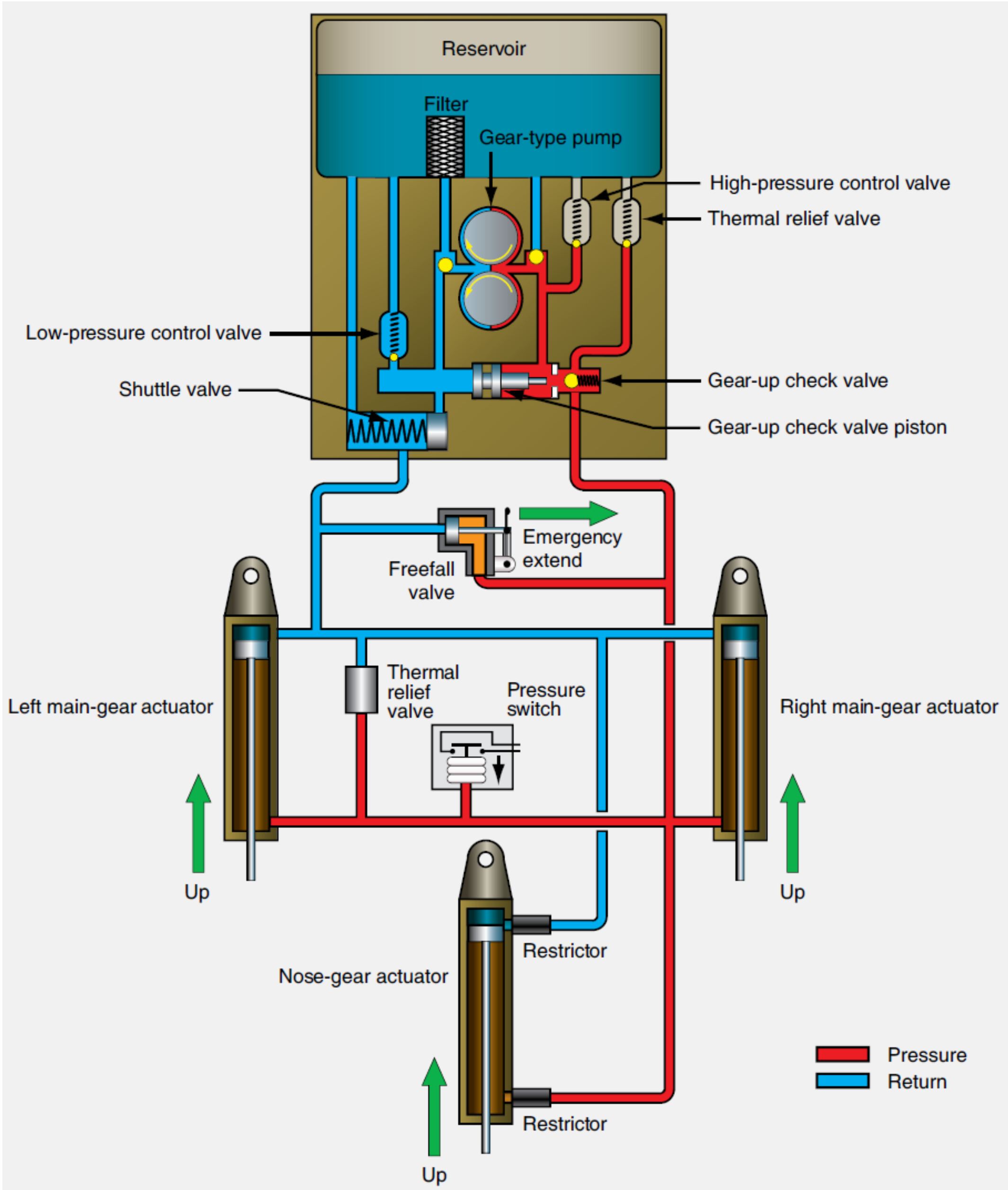
When the flight deck gear selection handle is put in the gear down position, a switch is made that turns on the electric motor in the power pack. The motor turns in the direction to rotate the hydraulic gear pump so that it pumps fluid to the gear-down side of the actuating cylinders. Pump pressure moves 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 gear are down and locked.



A hydraulic power pack in the gear down condition.

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 in the gear up condition.

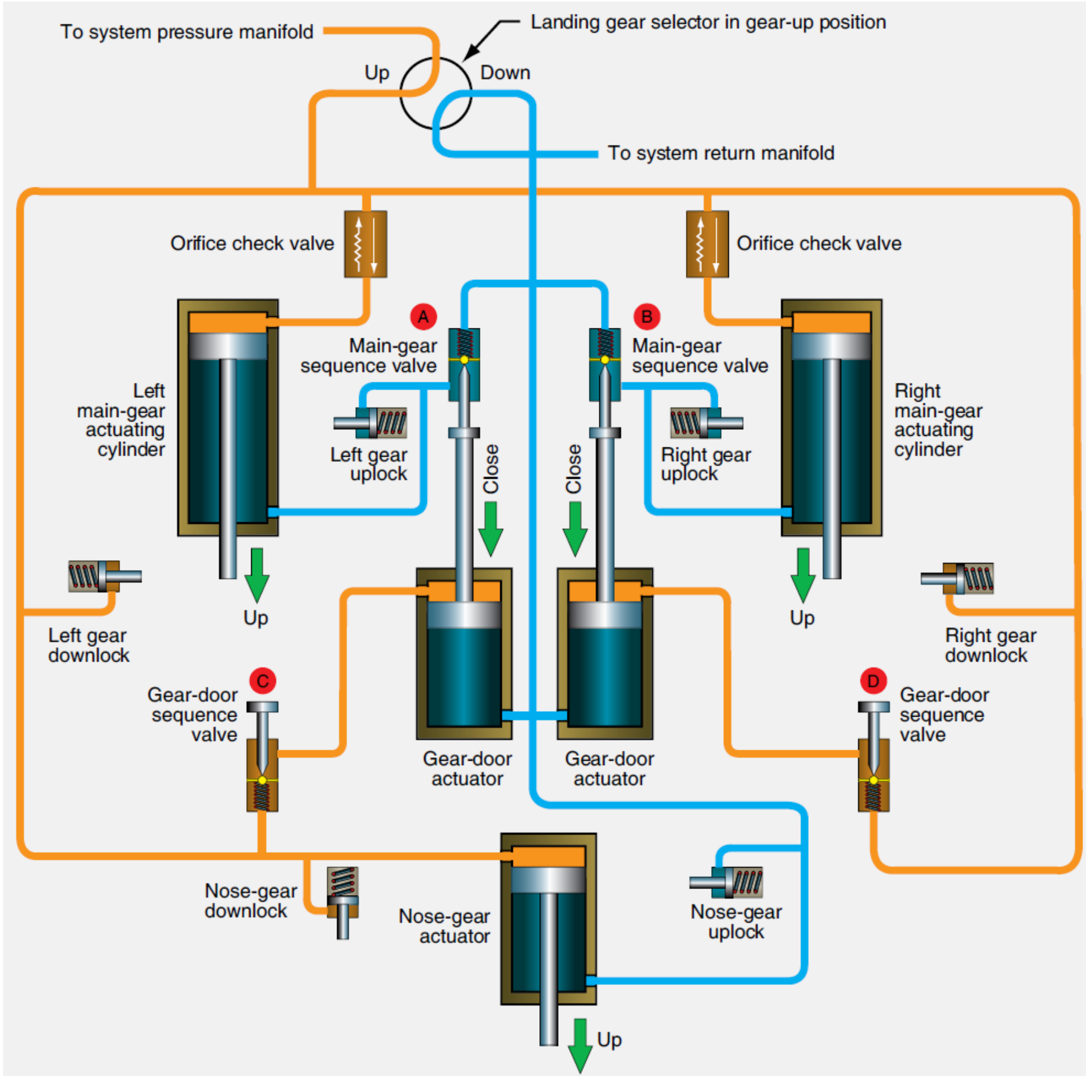
4.4.4 Hydraulic System

Large aircraft retraction systems are nearly always powered by hydraulics. Components used in a hydraulically-operated retraction system include actuating cylinders, selector valves, uplocks, downlocks, 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. *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.

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 downlocks 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 open the 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.

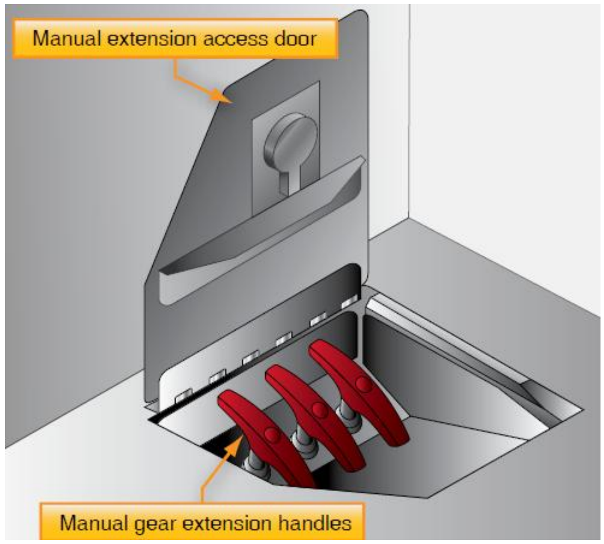
To lower the gear, the selector is put in the gear-down position. Pressurized hydraulic fluid flows from the hydraulic manifold to the nose gear uplock, which unlocks the nose gear. Fluid flows to the gear-down side of the nose gear actuator and extends it. Fluid also flows to the open side of the main gear door actuators. As the doors open, sequence valves A and B block fluid from unlocking the main gear uplocks 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 uplocks, 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.



A large aircraft hydraulic gear retraction system

4.5 Emergency Extension Systems

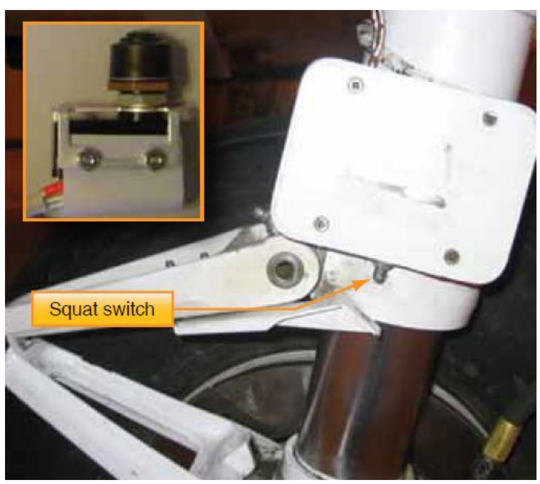
The emergency extension system lowers the landing gear if the main power system fails. Some aircraft have an emergency release handle in the flight deck that is connected through a mechanical linkage to the gear uplocks. When the handle is operated, it releases the uplocks and allows the gear to free-fall to the extended position under the force created by gravity acting upon the gear. Other aircraft use a non-mechanical back-up, such as pneumatic power, to unlatch the gear.



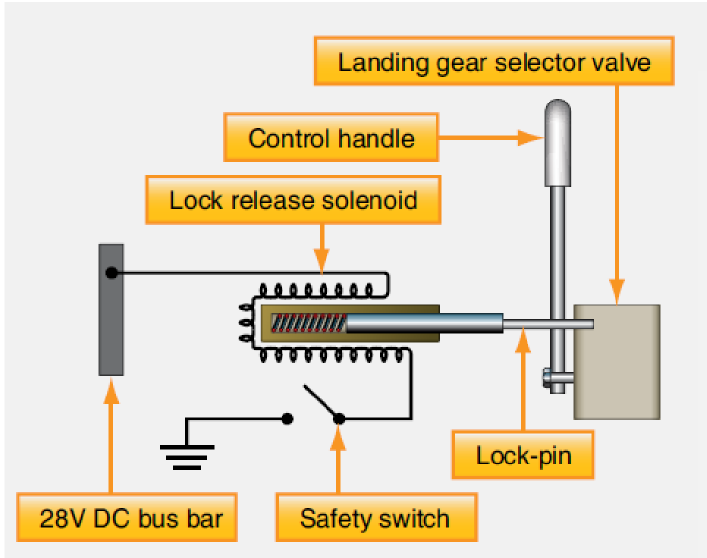
Large and high performance aircraft are equipped with redundant hydraulic systems. This makes emergency extension less common since a different source of hydraulic power can be selected if the gear does not function normally.

4.6 Safety Switches

The most safety switches are those that prevent the gear from retracting or collapsing while on the ground. Gear indicators are another safety device. They are used to communicate to the pilot the position status of each individual landing gear at any time.



A landing gear squat switch, or safety switch, is found on most aircraft. This is a switch positioned to open and close depending on the extension or compression of the main landing gear strut. The squat switch is wired into any number of system operating circuits. One circuit prevents the gear from being retracted while the aircraft is on the ground. There are different ways to achieve this lockout. A solenoid that extends a shaft to physically disable the gear position selector is one such method found on many aircraft.



When the landing gear is compressed, the squat safety switch is open, and the center shaft of the solenoid protrudes a hardened lock-pin through the landing gear control handle so that it cannot be moved to the up position.

At takeoff, the landing gear strut extends. The safety switch closes and allows current to flow in the safety circuit. The solenoid energizes and retracts the lock-pin from the selector handle. This permits the gear to be raised.

4.7 Ground Locks

Ground locks are commonly used on aircraft landing gear as extra insurance that the landing gear will remain down and locked while the aircraft is on the ground. They are external devices that are placed in the retraction mechanism to prevent its movement. A ground lock can be as simple as a pin placed into the pre-drilled holes of gear components that keep the gear from collapsing. Another commonly used ground lock clamps onto the exposed piston of the gear retraction cylinder that prevents it from retracting. All ground locks should have a red streamers attached to them so they are visible and removed before flight. Ground locks are typically carried in the aircraft and put into place by the flight crew during the post landing walk-around.

4.8 Position Indicators

Landing gear position indicators are located on the instrument panel adjacent to the gear selector handle. They are used to inform the pilot of gear position status. There are many arrangements for gear indication. Usually, there is a dedicated light for each gear. The most common display for the landing gear being down and locked is an illuminated green light. Three green lights means it is safe to land.

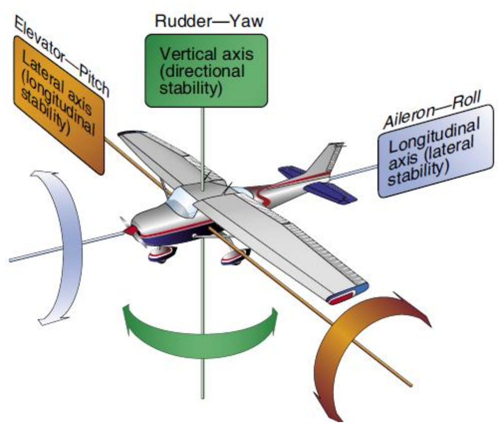
AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 2

1. FLIGHT CONTROL SYSTEMS

Flight control system is a collection of mechanical and electronic equipment that allows an aircraft to be flown with exceptional precision and reliability. A control system consists of cockpit controls, sensors, actuators (hydraulic, mechanical or electrical) and computers. The flight controls keep the aircraft at a required attitude during flight. Movable control surfaces are installed on the wings and the empennage of the aircraft.

Aircraft flight control systems consist of **primary and secondary** systems. The ailerons, elevator and rudder constitute the primary control system and are required to control an aircraft safely during flight. Wing flaps, leading edge devices, spoilers, and trim systems constitute the secondary control system and improve the performance characteristics of the airplane or relieve the pilot of excessive control forces.



Aircraft Principal Axes

1.1 Primary Flight Controls

Control yoke (control column), governs the aircraft's roll and pitch. Pitch control is provided by fore and aft movement of the control column to move the elevators. Roll control is provided by turning or deflecting the control column left and right to move ailerons.

Rudder pedals to control yaw, which move the rudder; left foot forward will move the rudder left for instance.

Throttle controls to control engine speed or thrust.

1.2 FLIGHT CONTROL SYSTEM TYPES

a) Direct Mechanical Flight Control System

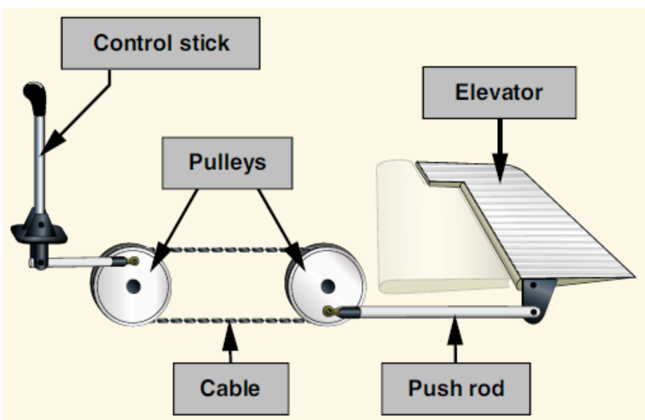
- Push-pull rods
- Cable-pulley

b) Powered Flight Control System

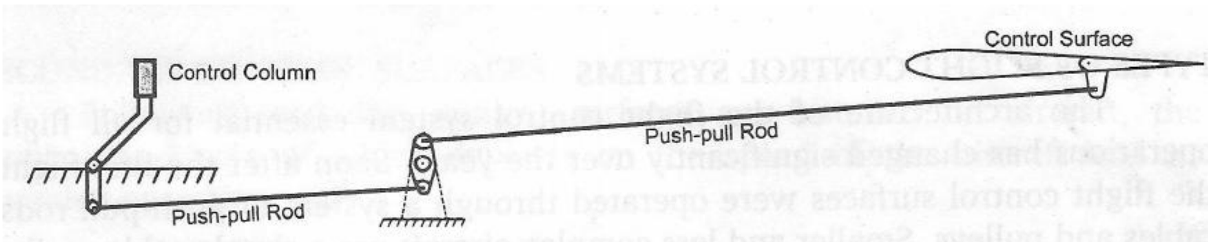
- Power Assisted
- Power Actuated
- Fully Powered
    - Fly-By-Wire
    - Fly-By-Light
    - Autopilot

1.2.1 Direct Mechanical Flight Control

It is the basic method of controlling an aircraft used in early aircraft and currently in small aircraft where the aerodynamic forces are not excessive. It uses a collection of mechanical parts such as rods, tension cables, pulleys, counterweights, and sometimes chains to transmit the forces applied from the cockpit controls directly to the control surfaces.



1.2.1.1 Push-Pull Rod System



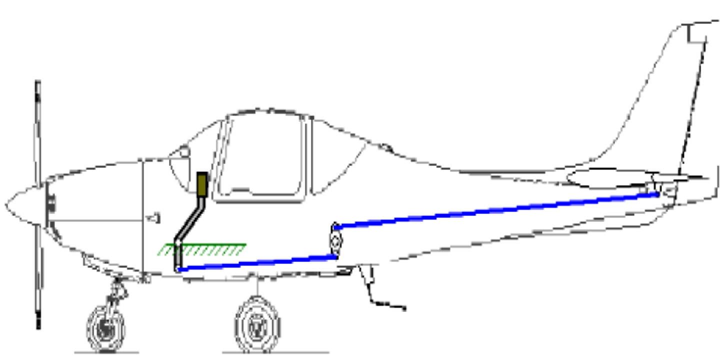
Here a sequence of rods link the control surface to the cabin input.

Bell Crank

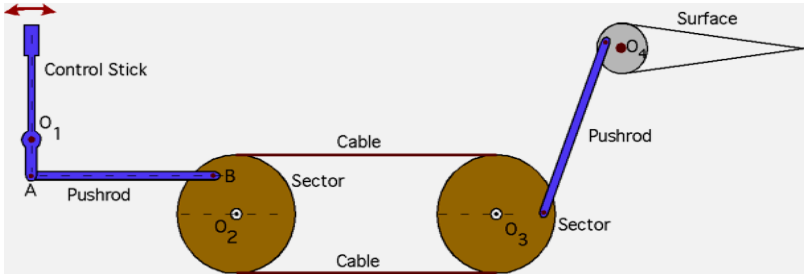
It is a double lever in an aircraft control system used to change the direction of motion. Bell cranks are normally used in aileron controls and in the steering system of nose wheels.

Figure given below shows Push-pull control rod system between the elevator and the cabin control column; the bell-crank lever is necessary to alter the direction of the transmission and to obtain the conventional coupling between stick movement and elevator deflection.

Push Pull Rod System for Elevator Control



1.2.1.2 Cable-Pulley System



Here couples of cables are used in place of the rods. In this case, pulleys are used to alter the direction of the lines, equipped with **idlers** to reduce any slack due to structure elasticity, cable strands relaxation or thermal expansion. A **torque tube** is attached to the control surface, which changes linear motion of the cable into rotary motion to deflect the control surface. In case of large aircraft, often the cable-pulley solution is preferred, because is more flexible and allows reaching more remote areas of the airplane.

Turnbuckle

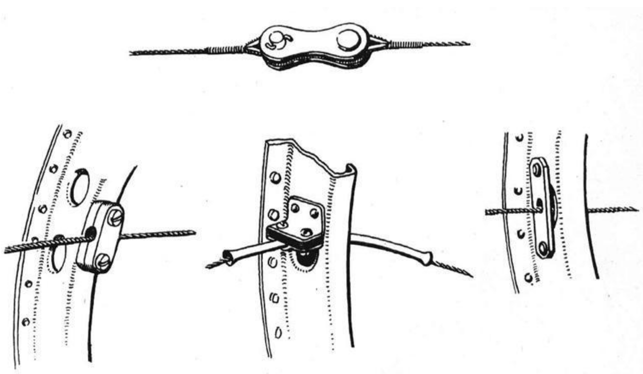
A **turnbuckle**, **stretching screw** or **bottlescrew** is a device for adjusting the tension or length of ropes, cables, tie rods and other tensioning systems.

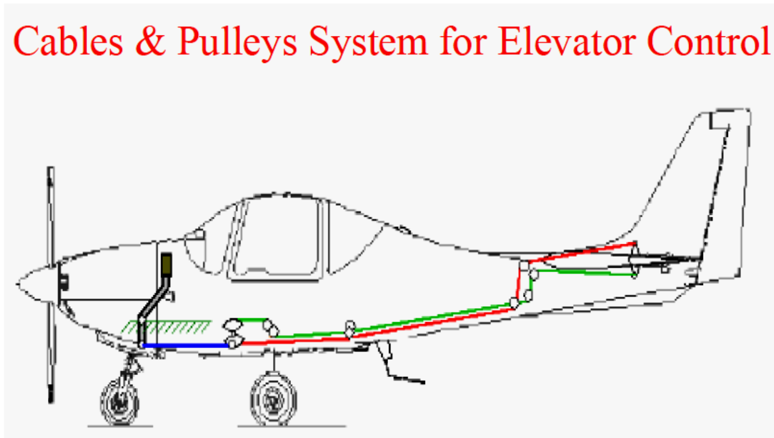
Torque Tube

A tube in an aircraft control system that transmits a torsional force from the operating control to the control surface. Torque tubes are often used to actuate ailerons and flaps.

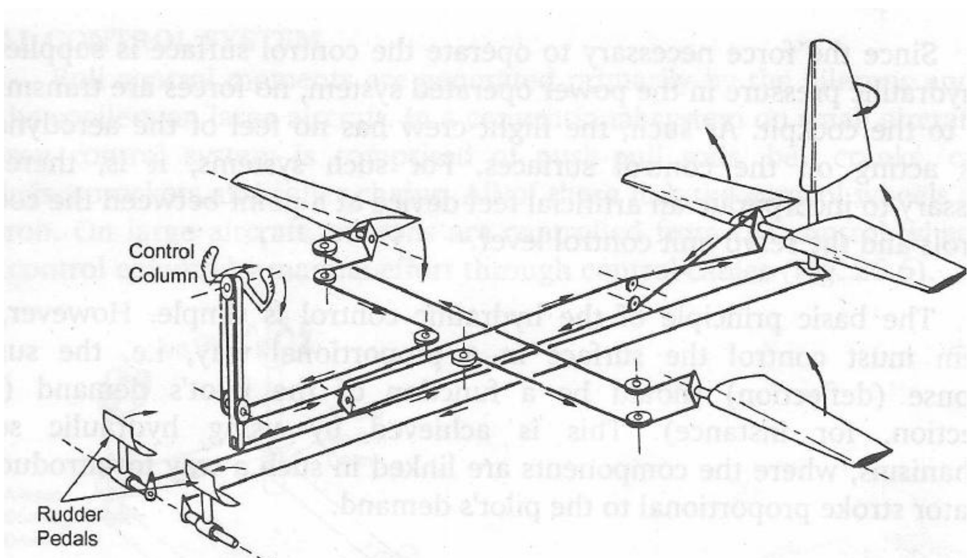
Fairleads

A fairlead is a device to guide a line, rope or cable around an object, out of the way or to stop it from moving laterally. Typically a fairlead will be a ring or hook. The fairlead may be a separate piece of hardware, or it could be a hole in the structure.





Here the control column is linked via a rod to a quadrant, which the cables are connected to the elevator



Pitch control moments on the aircraft are generated by the elevators and its associated tabs.

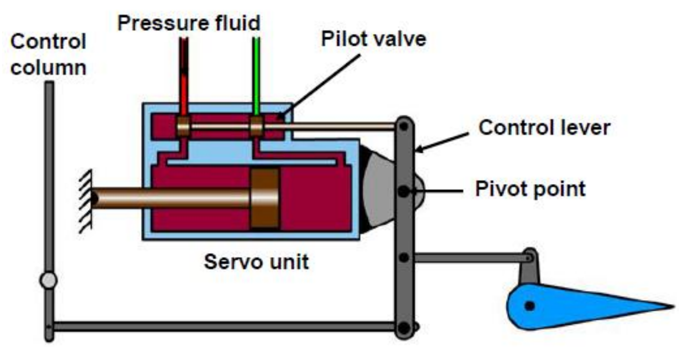
Direct Mechanical Flight Control Increases in the control surface area required by large aircraft or higher loads caused by high airspeeds in small aircraft lead to a large increase in the forces needed to move them. Consequently complicated mechanical gearing arrangements were developed to extract maximum mechanical advantage in order to reduce the forces required from the pilots.

1.2.2 Powered Flight Control System

The Complexity and Weight of the mechanical system increased with Size and Performance of the aircraft. When the pilot's action is not directly sufficient for the control, the main option is a powered system that assists the pilot. The hydraulic system has demonstrated to be a more suitable solution for actuation in terms of reliability, safety, weight per unit power and flexibility.

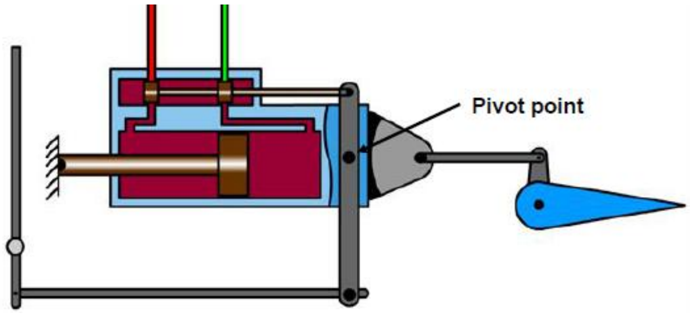
1.2.2.1 Power Assisted Flight Control System

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 signaling is obtained by push-pull rods, or more commonly by cables and pulleys. Electrical signaling is a solution of more modern and sophisticated vehicles



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 and then obtaining a deflection that is proportional to the demand. It is a reversible control.

1.2.2.2 Power Actuated Flight Control System



Here the movement of control column only moves the pilot valve (Irreversible controls)

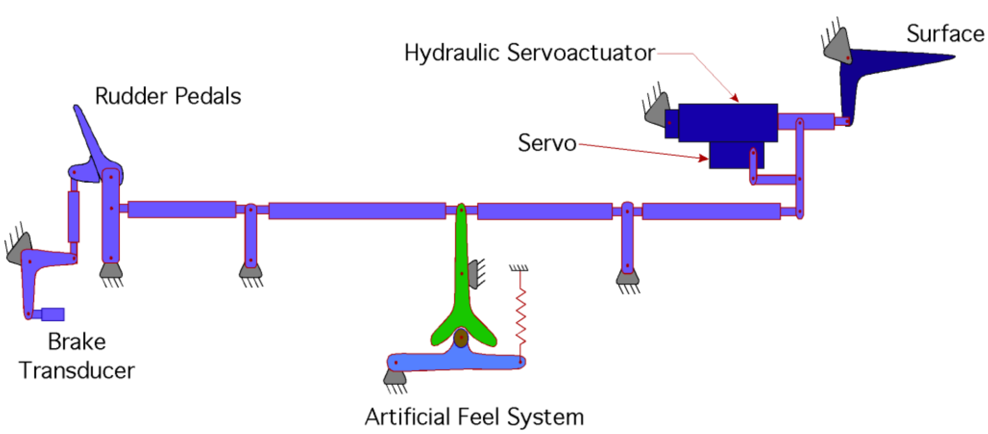
Two aspects must be noticed when a powered control is introduced:

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

ii) 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. 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. For this reason an artificial feel is introduced in powered systems, acting directly on the cabin control stick or pedals.

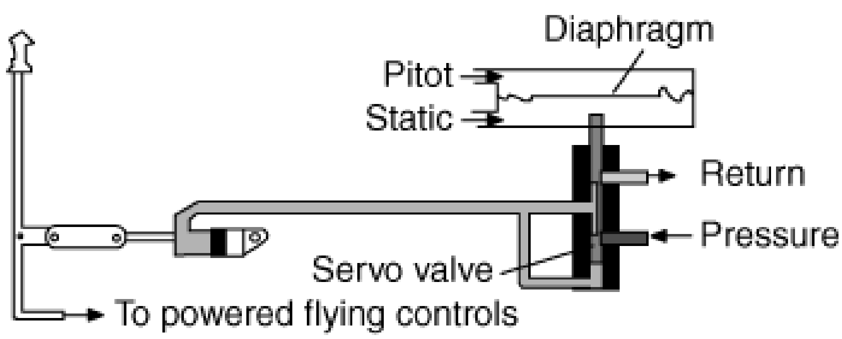
The simplest solution is a spring system, which responding to the pilot's demand with a force proportional to the stick deflection. This solution has the limit to be not sensitive to the actual flight conditions.



A more sophisticated artificial feel is the **Q feel**. This system receives data from the pitot-static probes, reading the dynamic 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.



1.3 Disadvantages Hydro-Mechanical Systems

- Heavy and require careful routing of flight control cables through the aircraft using pulleys, cranks, tension cables and hydraulic pipes.
- They require redundant backup to deal with failures, which again increases weight.
- Limited ability to compensate for changing aerodynamic conditions.
- Dangerous characteristics such as stalling, spinning and pilot-induced oscillation (PIO), which depend mainly on the stability and structure of the aircraft concerned rather than the control system itself, can still occur with these systems.

2. AIRCRAFT ENGINE CONTROLS AND INDICATORS

Aircraft engine controls provide a means for the pilot to control and monitor the operation of the aircraft‘s power plant.

2.1 Basic Controls and Indicators

- **Master Switch**- Most often actually two separate switches, the Battery Master and the Alternator Master.
- The Battery Master activates a relay (sometimes called the battery contactor) which connects the battery to the aircraft's main electrical bus. The alternator master activates the alternator by applying power to the alternator field circuit. These two switches provide electrical power to all the systems in the aircraft.

- **Throttle** - Sets the desired power level. The throttle controls the mass flow-rate of air (in fuel-injected engines) or air/fuel mixture (in carbureted engines) delivered to the cylinders.

- **Propeller Control** - Adjusts the Constant Speed Unit, which in turn adjusts the propeller pitch and regulates the engine load as necessary to maintain the set R.P.M.

- **Mixture Control** - Sets the amount of fuel added to the intake airflow. At higher altitudes the air pressure (and therefore the oxygen level) declines so the fuel volume must also be reduced to give the correct air/fuel mixture. This process is known as "leaning".

- **Ignition Switch** - Activates the magnetos by opening the grounding or 'p-lead' circuit; with the p-lead ungrounded the magneto is free to send its high-voltage output to the spark plugs. In most aircrafts, the ignition switch also applies power to the starter motor during engine start.

- **Tachometer** - A gauge to indicate engine speed in revolutions per minute (RPM) or percentage of maximum.

- **Manifold Pressure (MP) Gauge** - Indicates the absolute pressure in the intake manifold.

- **Oil Temperature Gauge** - Indicates the engine oil temperature.

- **Oil Pressure Gauge** - Indicates the supply pressure of the engine lubricant.

- **Exhaust Gas Temperature (EGT) Gauge** - Indicates the temperature of the exhaust gas just after combustion. Used to set the fuel/air mixture (leaning) correctly.

- **Cylinder Head Temperature (CHT) Gauge** - Indicates the temperature of at least one of the cylinder heads. Used to set the fuel/air mixture.

- **Carburetor Heat Control** - Controls the application of heat to the carburetor venturi area to remove or prevent the formation of ice in the throat of the carburetor as well as bypassing the air filter in case of impact icing.

- **Alternate Air** - Bypasses the air filter on a fuel-injected engine.

2.2 Fuel Controls and Indicators

- **Fuel Primer Pump** - A manual pump to add a small amount of fuel at the cylinder intakes to assist in starting a cold engine. Fuel injected engines do not have this control. For fuel injected engines, a fuel boost pump is used to prime the engine prior to start.

- **Fuel Quantity Gauge** - Indicates the amount of fuel remaining in the identified tank (One per fuel tank).

- **Fuel Select Valve** - Connects the fuel flow from the selected tank to the engine.

If the aircraft is equipped with a fuel pump:

- **Fuel Pressure Gauge** - Indicates the supply pressure of fuel to the carburetor (or in the case of a fuel injected engine, to the fuel controller).

- **Fuel Boost Pump Switch** - Controls the operation of the auxiliary electric fuel pump to provide fuel to the engine before it starts or in case of failure of the engine powered fuel pump.

2.3 Propeller Controls and Indicators

If the aircraft is equipped with adjustable-pitch or constant-speed propeller(s):

- **Propeller Control** - Used to set the desired propeller speed. Once the pilot has set the desired propeller speed, the propeller governor maintains that propeller speed by adjusting the pitch of the propeller blades, using the engine's oil pressure to move a hydraulic piston in the propeller hub.

- **Manifold Pressure Gauge** - Indicates the (absolute) pressure in the engine's intake manifold.

2.4 Cowl Controls and Indicators

If the aircraft is equipped with adjustable Cowl Flaps:

- **Cowl Flap Position Control** - Cowl Flaps are opened during high power/low airspeed operations like takeoff to maximize the volume of cooling airflow over the engine's cooling fins.
- **Cylinder Head Temperature Gauge** - Indicates the temperature of all cylinder heads or on a single CHT system, the hottest head.

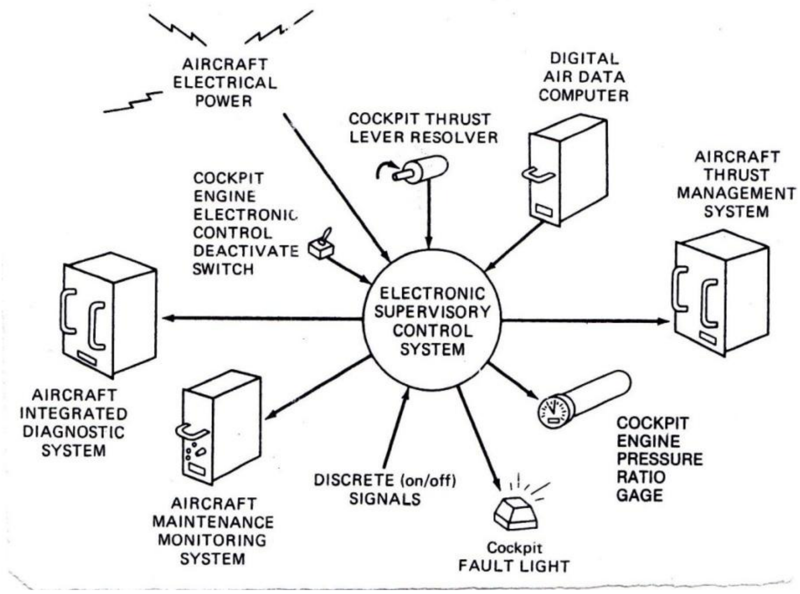
3. AIRCRAFT ENGINE CONTROL SYSTEMS

Advances in gas turbine technology have demanded more precise control of engine parameters that can be provided by hydromechanical fuel controls alone. These demands are met by electronic engine control, or EEC of which there are of two types:

- Supervisory Electronic Engine Control
- Full Authority Digital Engine Control (FADEC)

3.1 Supervisory Electronic Engine Control

The supervisory EEC includes a computer that receives the information regarding various engine operating parameters and adjusts a standard hydromechanical FCU to obtain most effective engine operation. The hydromechanical unit responds to EEC commands and actually performs the function necessary for engine operation and protection. Supervisory EEC includes the bleed air and stator vane control also. The hydromechanical element controls the basic operation of the engine including starting, acceleration, deceleration, and shut down. High pressure rotor speed, compressor stator vane angles, engine bleed system is also controlled hydromechanically.



The EEC acting in a supervisory capacity modulates the engine fuel flow to maintain the designated thrust. The pilot simply moves the throttle lever to a desired thrust setting position, such as full take off thrust, or maximum climb. The control adjusts engine pressure ratio (EPR) as required to maintain the thrust rating, compensating for changes in flight and environmental conditions.

If a problem develops, controls automatically revert to the hydromechanical system with no discontinuity in thrust. A warning signal is displayed in the cockpit, but no immediate action is required by the Pilot. The Pilot can also revert to the hydromechanical control at any time. Although the EEC uses aircraft electrical power for some of its functions, electric power for the basic operation of EEC is supplied by separate engine driven permanent – magnet alternator.

3.2 Full Authority Digital Engine Control (FADEC)

FADEC is an engine control and monitoring system. EEC is the brain of FADEC that computes and commands the control functions. It contains one or more microprocessors and read data from sensors, control actuators, valves and other aircraft systems. Using these readings together with the pilot's input EEC computes the position of actuators. EEC operates in a closed loop system. EEC also gathers and transmit information about engine condition data and faults to the cockpit. A serial data bus is used to exchange information between FADEC and aircraft systems, such as FMS and ADS.

3.2.1 Function of FADEC

As the aircraft take-off and climb to higher altitude, the surrounding environmental conditions: temperature, pressure and, density changes. Since gas turbine engine operate by accelerating mass of air, as these factors change, the thrust produced by the engine also change. Pilots' main job is to fly the aircraft safely. To allow this FADEC take over the engine monitoring and control based on pilots' or FMS inputs. Controlling is mainly achieved by varying fuel flow and other parameters. Monitoring function of FADEC diagnoses engine systems and alert the pilot, ensuring that engine operates within the set limits. FADEC monitor and/or control the following typical functions:

- EGT
- Fuel flow to the fuel injectors
- N1 and N2 speed
- Variable stator vane scheduling
- Bleed valve operation
- Turbine blade and vane cooling
- Turbine case cooling
- Oil temperature
- Fuel temperature
- Valves, Solenoids and actuators
- Starting and restarting
- Thrust reverser

FADEC also provide the engine parameters, status messages and fault messages to aircraft systems to display in the flight deck. In Boeing this information is displayed in EICAS (Engine indication crew alerting system) displays and in Airbus it is displayed in ECAM (Electronic centralised aircraft monitor) displays. Some FADEC systems may integrate an Engine Health Monitoring (EMH) system, to provide data about engines' health to support maintenance scheduling Thus it can help an airline to reduce cost associated with scheduled and unscheduled maintenance.

3.2.2 Operation

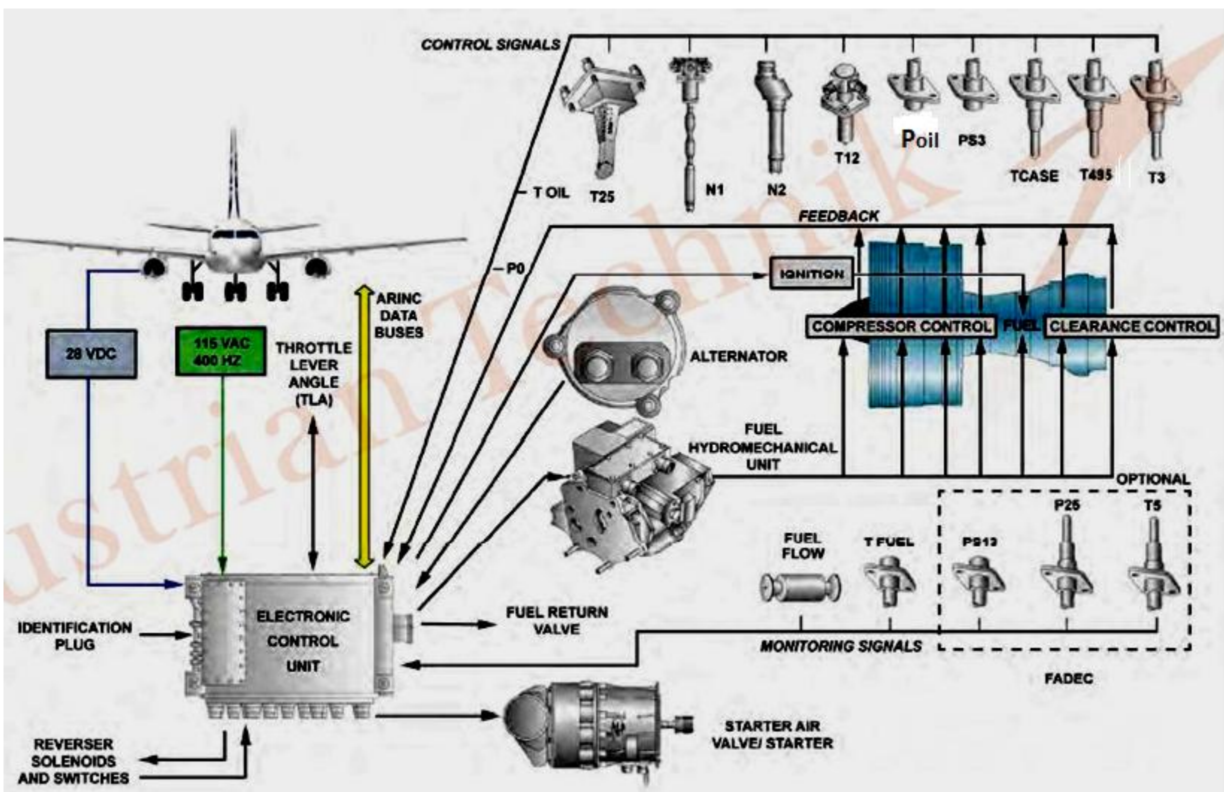
The following components are considered as the basic components of FADEC:

- Electronic controller (EEC or ECU)
- Engine driven generator

- Sensors and transducers
- Data bus

In order for EEC to function, it requires lot of input signals. These are provided by aircraft systems or from sensors directly connected to EEC. Sensors provide information about engine condition, pilot demand and feedback from actuators. Engine parameters monitored and/or controlled include:

- Engine temperatures (EGT, etc)
- Engine pressures (P1, P2 etc)
- Engine RPM (N1 and N2)
- Fuel flow
- Variable stator vane position
- Airplane bleed status
- Vibration



FADEC

Symbol	Function
T_3	Total temperature compressor discharge
T_{495}	Total temperature LPT inlet
T_{case}	Case temperature
P_{s3}	Static pressure compressor discharge
T_{oil}	Engine oil temperature
P_{oil}	Engine oil pressure
T_{25}	Total temperature HPC inlet
T_{12}	Total temperature fan inlet
P_o	Ambient total pressure
N_1	LP spool speed
N_2	HP spool speed
T5	Total temperature turbine discharge
P25	Total pressure HPC inlet
Ps13	Static pressure fan discharge
Tfuel	Engine fuel temperature

Additional sensors may be used to monitor aircrafts' immediate environmental conditions: such as temperature, pressure and air density. Alternatively, this information may be obtained from ADC or FMC. A RVDT, LVDT or another form of transducer is used to determine the throttle lever position. Sensors and actuators are described in details in another section.

Two channels of EEC are always operating, but there is only one channel in command called the active channel. If the active channel fails, EEC automatically switches to alternative channel. In other words, EEC always select most healthy channel. If both channels are unable to control an engine function, it is set to a predetermined failsafe position, which protects the engine. In some cases this may result in total shutdown of the engine. Each channel receives two signals of the same parameter. One signal is received from the hardwired sensors, and the other signal over the cross link. A validation test is carried out to assess the validity of the signals before they are processed. Input parameters are used to calculate the command functions for servos which control actuators.

There are two EEC control modes: EPR mode and N1 mode. EPR mode is the normal mode, in which the EEC maintains a commanded EPR by altering the fuel flow. N1 mode is automatically selected upon failure of EPR mode. In this mode fuel flow is controlled as a function of N1. Selection of N1 mode will trigger an advisory message in the flight deck display.

3.2.3 Design

EEC is enclosed in an aluminium chassis and mounted on the fan case with shock absorbers to provide protection against shock and vibration. The housing protects EEC from the hostile environment, where it is subjected to high temperature and Electromagnetic Induction (EMI) from airport radar and lightning. Similarly the wiring harnesses that connect EEC to other components (such as: sensors, actuators, etc) have metal braiding to shield from EMI. These wiring harnesses are usually designed for easy replacement, i.e. they are line replaceable. To prevent overheating of the EEC, ambient air from air scoop is used for cooling.

Unlike supervisory EEC, FADEC has the full authority over engine control, which means there is no manual override. Failure of FADEC results in engine failure. Therefore, many safety features are built into the system to prevent total system failure. FADEC has two independent EEC channels. Two channels are identical and each has its own processor, power supply, memory, sensors, wiring harnesses, and electrical parts of transducers. A cross link allow data to be transferred between channels without allowing fault to propagate from one channel to the other.

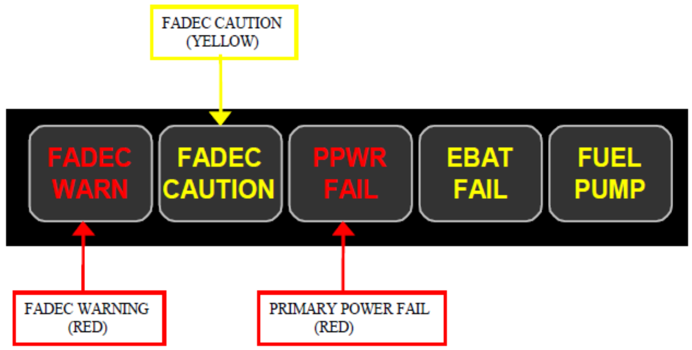
To ensure uninterrupted power supply, two channels of EEC are powered by multiple independent sources. Aircraft normal bus, emergency bus and engine driven generator (alternator) provides AC power to EEC. In the EEC, the current is rectified and the voltage is regulated. Aircraft power supply is used to power the EEC for engine starting. However, upon N1 reaching certain speed, power supply is switched to alternator, which is the primary source of electrical power. There are two windings within the same alternator to provide independent power supply to two channels of EEC. In the event of failure of primary power supply, EEC automatically switches to an alternative power supply.

3.2.4 Power Supplies

- Primary Power Source (PPS): 14v 60Amp alternator and 12v 25Ah lead acid battery.
- Secondary Power Source (SPS): 12v 7Ah lead acid battery.

A data bus is employed at the FADEC-Aircraft interface to exchange information. EEC sends engine parameter data and associated messages to other aircraft systems via this data bus. Most aircraft use unidirectional ARINC 429 data bus.

3.2.5 Health Status Annunciator Panel



FADEC WARN: Engine failure is about to occur, more than (1) cylinder is affected. Land ASAP.

FADEC CAUTION: 99.99% of installed components are working. For example bad EGT sensor.

PPWR FAIL:Primary battery is not being charged.

EBAT FAIL :Backup battery is not being charged.

FUEL PUMP:Fuel pressure is out of 20-40 psi range.

3.2.6 Advantages of FADEC

- 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
- 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".
- Saves weight.

3.2.7 Disadvantages of FADEC

- 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.
- High system complexity compared to hydro mechanical, analogue or manual control systems.
- High system development and validation effort due to the complexity.

AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 3

1. MODERN CONTROL SYSTEMS

1.1 FLY-BY-WIRE (FBW) FCS

- A fly-by-wire flight control system is that where control inputs from the pilot are transmitted to the control surfaces by electronic signals rather than mechanical means.
- The control columns have electronic transducers that sense the position of the control column and send that information to independent computers, which use this information to position the control surfaces.
- The control signals interpreted by the computers are transmitted by wires are converted into a hydraulic signal to operate the hydraulically powered flight control unit to move the control surface.
- Engine control is also mediated by the FCS computers
- The current tendency in flight control system is to install hydraulic actuators and electro-hydraulic servo valves to operate the actuators, which converts small electrical voltages to hydraulic power.
- The actuator position is measured by the position transducers i.e. Linear Variable Differential Transformers (LVDTs) to translate linear motion into electrical signal and Rotary Variable Differential Transformers (RVDTs) to translate angular displacement into electrical signal.
- The pilot's demand is compared with the LVDT/RVDT feedback. When the feedback signal is equal to the command signal from the cockpit, a null condition is reached and the control surface movement stops.
- The flight control computers determine how to move the actuators at each control surface to provide the ordered response.
- The fly-by-wire system also allows automatic signals sent by the aircraft's computers to perform functions without the pilot's input, as in systems that automatically help stabilize the aircraft, or prevent unsafe operation of the aircraft outside of its performance envelope.

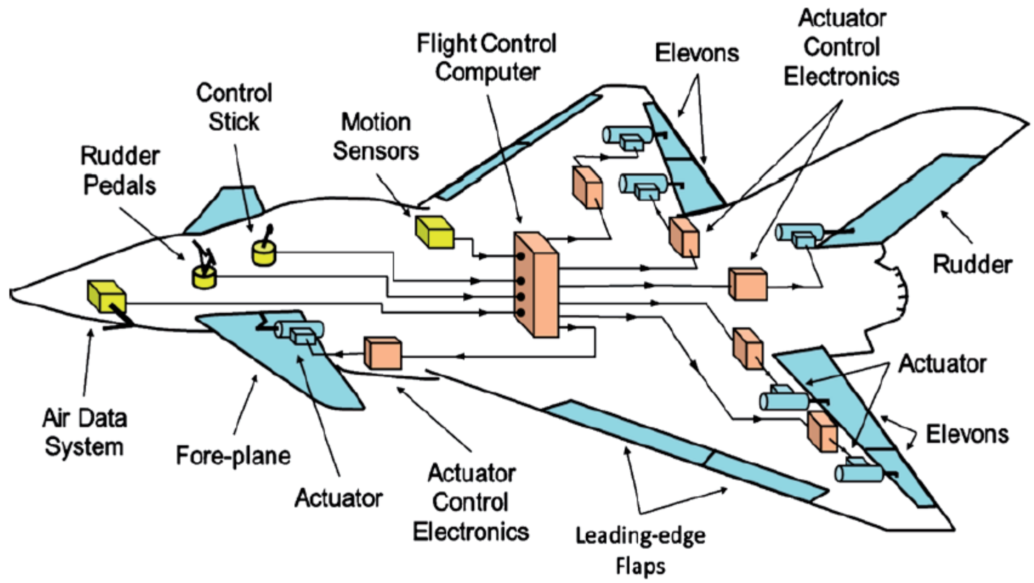
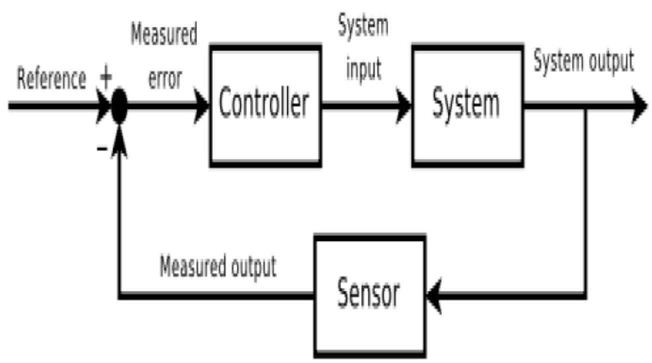
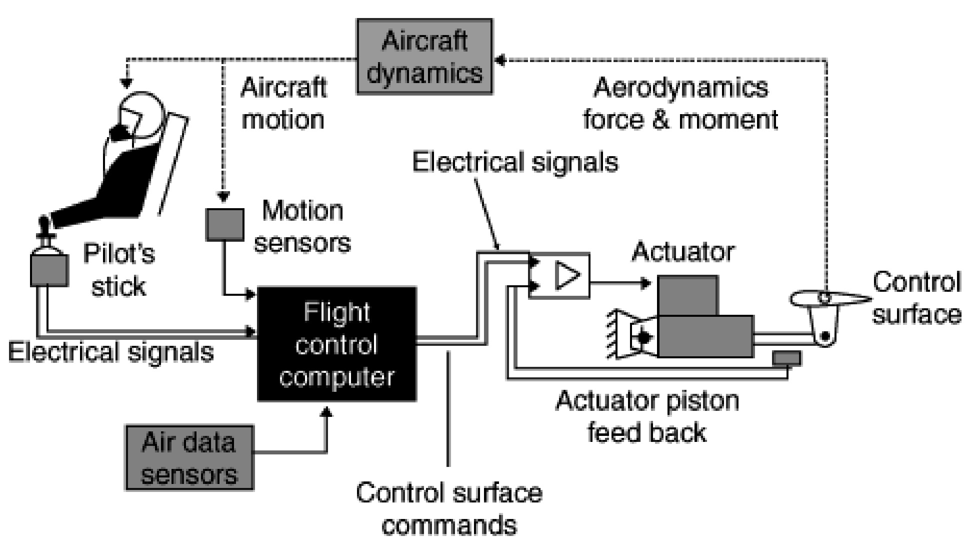


Fig: Basic Elements of FBW





Aircraft's Motion Sensors

- Rate gyroscopes : Rate of rotation about roll, pitch and yaw axes.
- Linear accelerometers: Normal and Lateral acceleration.
- Air data sensors : Height and Airspeed.
- Airstream sensors : Incidence angles in longitudinal and lateral planes.

The FBW control system can be designed so that the pilot is able to exercise a closed loop maneuver command control of the aircraft. This is achieved by pilot controlling the aircraft through the FBW computers with feedback of the aircraft motion from the appropriate sensors.

Essential Features of FBW

- Electrical Signal Transmission
  - Pilot's stick sensor signals, aircraft motion sensor signals, control surface actuator position signals and commanded control surface angles are transmitted electrically.
  - The total elimination of all the complex mechanical control runs and linkages.
- The interposition of a computer between the pilot's commands and the control surface actuators.
- The aircraft motion sensors which feed back the components of the aircraft's angular and linear motion to the computer.
- The air data sensors which supply height and airspeed information to the computer.
- The redundancy to enable failures in the system to be absorbed.

1.2 DIGITAL FLY BY WIRE (DFBW) FCS

- A digital fly-by-wire flight control system is similar to analog system. However, the signal processing is done by digital computers .
- Increases in flexibility of the flight control system, since the digital computers can receive input from any aircraft sensor (such as the altimeters and the pitot tubes).

- Increase in electronic stability - system is less dependent on the values of critical electrical components in an analog controller .
- The computers "read" position and force inputs from the pilot's controls and aircraft sensors.
- They solve differential equations to determine the appropriate command signals that move the flight controls in order to carry out the intentions of the pilot .
- The programming of the digital computers enable flight envelope protection.
- Flight-control computers continuously "fly" the aircraft, pilot's workloads can be reduced .
- In military and naval applications, it is now possible to fly military aircraft that have relaxed stability.
- Better maneuverability during combat and training flights and " carefree handling" because stalling, spinning. and other undesirable performances are prevented automatically by the computers .

Advantages of FBW FCS

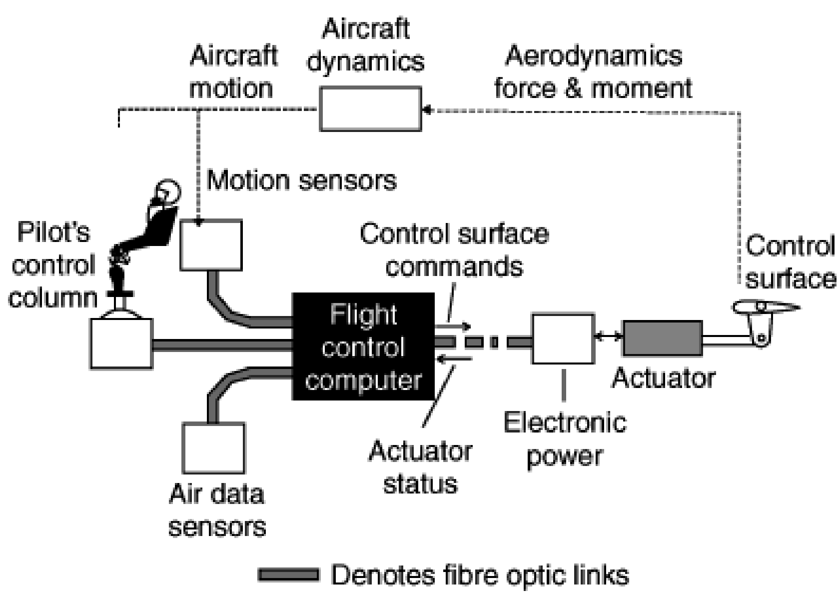
- Increased Performance
- Reduced Weight
- Enables a small, compact pilot’s control stick to be used allowing more flexibility in the cockpit layout.
- Good consistent handling and Pilot workload reduction
- Airframe safety
- Automatic Stabilization
- Ease of autopilot integration
- Maintenance reduction

1.3 FLY-BY-LIGHT (FBL) FCS

- It is a flight control system where all the command and control signals are transmitted through fibre-optic cables.

Need for FBL

- The aircraft systems operate in extremely high electromagnetic environments, especially near airfields and aircraft carrier flight decks. Hence, protection against Electromagnetic Interference(EMI) is a major concern.
- Currently, airframe and control system designers compensate for EMI by implementing safeguards such as shielding.
- By the optical data transmission in the fly by light control system the data are transmitted as a modulated light intensity signal along a fibre-optic cable which overcomes problems like EMI.
- Current avionics data bus systems using fibre optic data transmission operate in 20Mbits/sec to 100Mbits/sec.
- Fly By Light flight control technology not only improves the EMI tolerance of aircraft electronics, it also reduces system weight, volume and cost.



FBW	FBL
Affected by Electromagnetic radiation	Unaffected by Electromagnetic radiation
Bulky Cables weigh the aircraft down	Small & light optical Fibres
FBW aircraft is slower than FBL aircraft , to respond, taking more seconds	The digital signals of the fibre can be sent usually at a minimum of around 64,000 signals a second
Cheaper than Fly By Light, thus a good solution for light weight Aircraft.	Expensive components like high grade fibres are required.

1.4 AUTOPILOT

- The basic function of the autopilot is to control the flight of the aircraft and maintain it on a pre-determined path in space without any action being required by the pilot. (Once the pilot has selected the appropriate control mode(s) of the autopilot)
- The autopilot can thus relieve the pilot from the fatigue and tedium of having to maintain continuous control of the aircraft's flight path on a long duration flight so the pilot can concentrate on other tasks and the management of the mission.
- A well designed autopilot system which is properly integrated with the aircraft flight control system can achieve a faster response and maintain a more precise flight path than the pilot.
- Even more important, the autopilot response is always consistent whereas a pilot's response can be affected by fatigue and work load and stress.
- The autopilot is thus able to provide a very precise control of the aircraft's flight path for such applications as fully automatic landing in very poor, or even zero visibility conditions.
- In the case of a military strike aircraft, the autopilot can provide an all weather automatic terrain following capability.
- This enables the aircraft to fly at high speed (around 600 knots) at very low altitude (200 ft or less) automatically following the terrain profile to stay below the radar horizon of enemy radars.

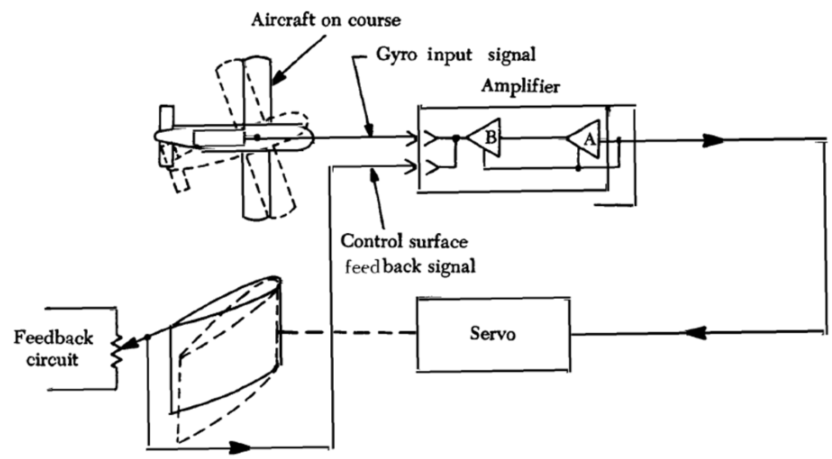


Fig: Basic Autopilot System

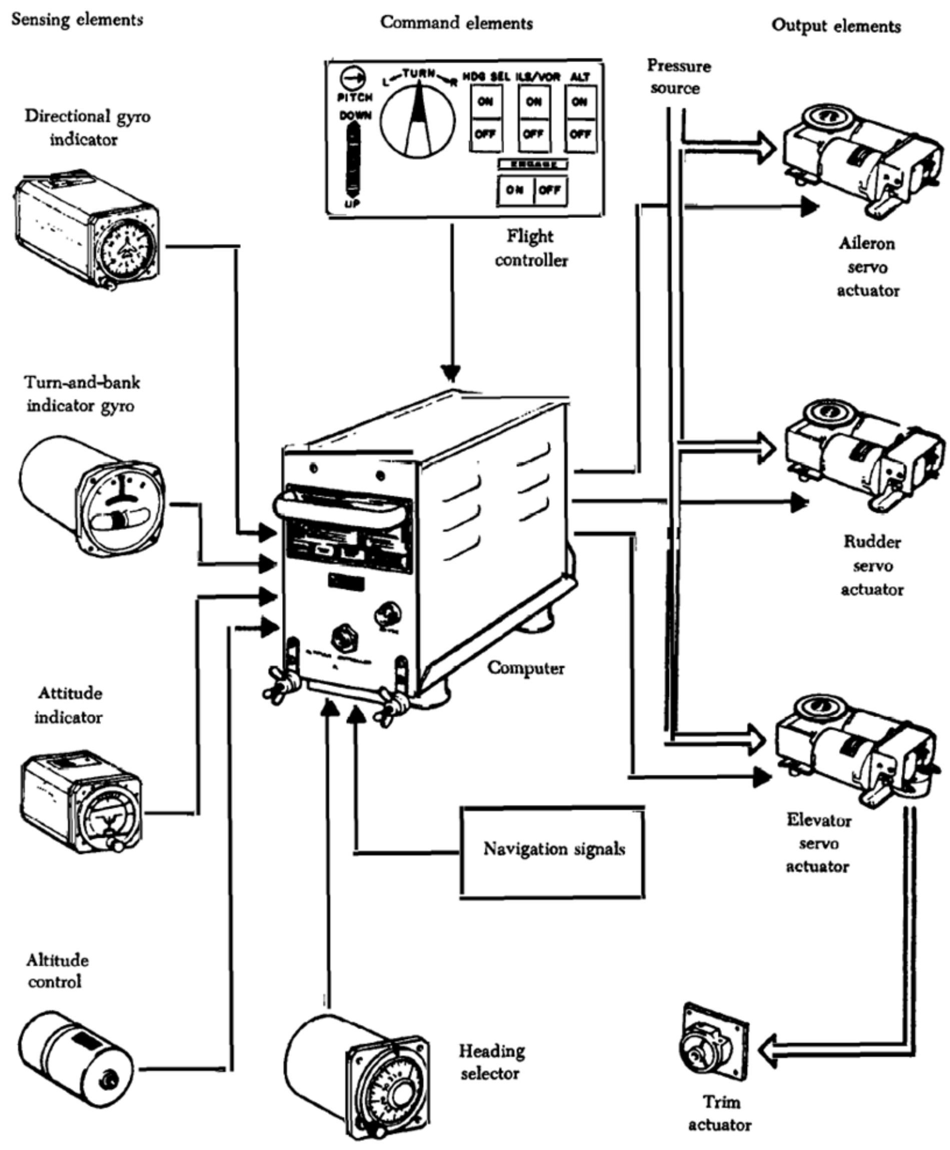


Fig: Components of Autopilot System

All auto-pilots contain the following basic components:

- Gyros to sense the aircraft movement.
- Servos to move the control surfaces.
- Amplifier to increase the gyro signal to operate the servos.
- Controller to engage the auto-pilot and also to allow small movements or corrections to be given to the flight control surfaces.
- The simplest systems use gyroscopic attitude indicators and magnetic compasses to control servos connected to the flight control system.
- The number and location of these servos depends on the complexity of the system. For example, a single-axis autopilot controls the aircraft about the longitudinal axis and a servo actuates the ailerons.
- A three-axis autopilot controls the aircraft about the longitudinal, lateral, and vertical axes.
- Three different servos actuate ailerons, elevator, and rudder. More advanced systems often include a vertical speed and/or indicated airspeed hold mode.

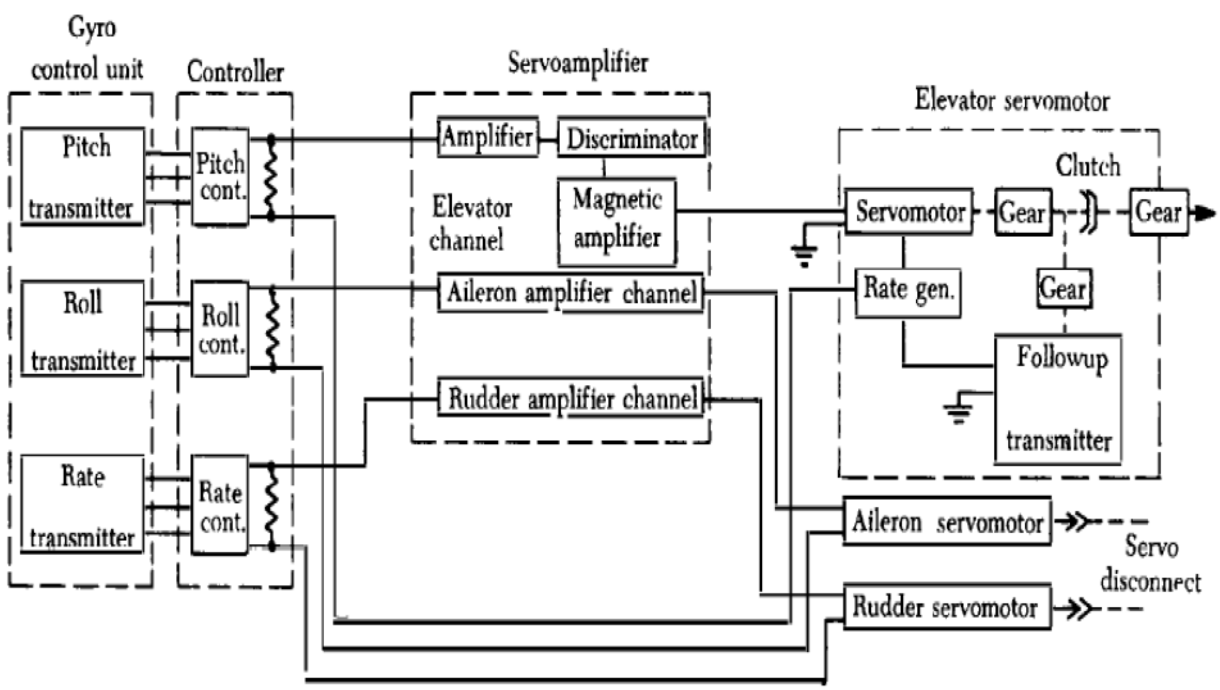


Fig: Autopilot Block Diagram

Most systems consist of four basic types of units, plus various switches and auxiliary units.

1) The sensing elements
2) Command elements
3) Output elements
4) Computing element

Sensing Elements

- The directional gyro, turn-and-bank gyro, attitude gyro, and altitude control are the sensing elements.
- These units sense the movements of the aircraft, and automatically generate signals to keep these movements under control.

The command unit (flight controller)

It is manually operated to generate signals which cause the aircraft to climb, dive, or perform coordinated turns.

- Additional command signals can be sent to the autopilot system by the aircraft's navigational equipment.
- The automatic pilot is engaged or disengaged electrically or mechanically, depending on system design.

Output Elements

- The output elements of an autopilot system are the servos which actuate the control surfaces. The majority of the servos in use today are either electric motors or electro/pneumatic servos.
- An aircraft may have from one to three servos to operate the primary flight controls.
- One servo operates the aileron, a second operates the rudder, and a third operates the elevators. Each servo drives its associated control surface to follow the directions of the particular automatic pilot channel to which the servo is connected.

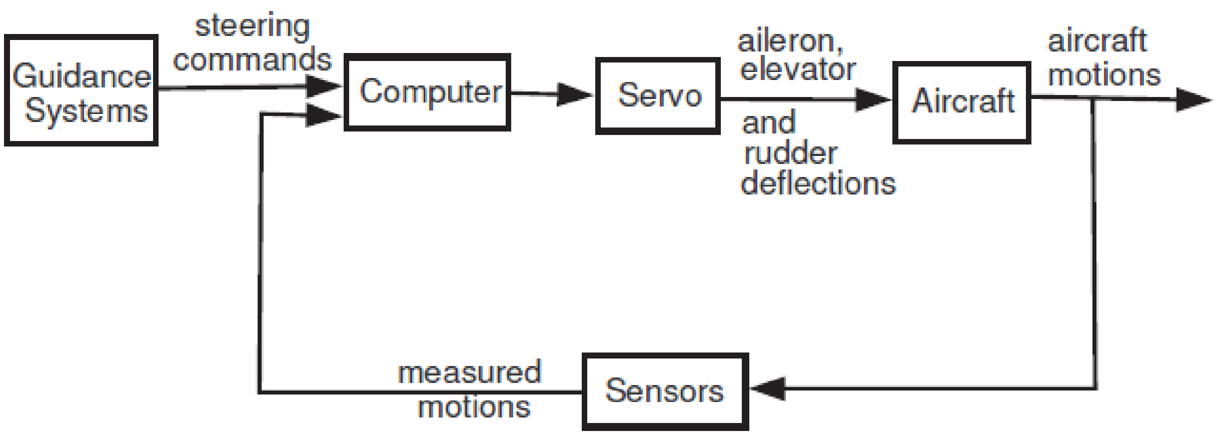
Computer or Amplifier

- The computing element consists of an amplifier or computer.

- The amplifier receives signals, determines what action the signals are calling for, and amplifies the signals received from the sensing elements.
- It passes these signals to the rudder, aileron, or elevator servos to drive the control surfaces to the position called for.

Autopilot loop

The basic loop through which the autopilot controls the aircraft's flight path is shown.



- The autopilot exercises a guidance function in the outer loop and generates commands to the inner flight control loop.
- These commands are generally attitude commands which operate the aircraft's control surfaces through a closed-loop control system so that the aircraft rotates about the pitch and roll axes until the measured pitch and bank angles are equal to the commanded angles.
- The changes in the aircraft's pitch and bank angles then cause the aircraft flight path to change through the flight path kinematics.
- For example, to correct a vertical deviation from the desired flight path, the aircraft's pitch attitude is controlled to increase or decrease the angular inclination of the flight path vector to the horizontal.
- The resulting vertical velocity component thus causes the aircraft to climb or dive so as to correct the vertical displacement from the desired flight path.
- To correct a lateral displacement from the desired flight path requires the aircraft to bank in order to turn and produce a controlled change in the heading so as to correct the error.

LATERAL AND LONGITUDINAL AUTOPILOTS

Longitudinal autopilot

- Displacement auto-pilot
- Pitch speed control system
- Acceleration control system
- Vertical speed control
- Mach control
- Altitude control

Lateral autopilot

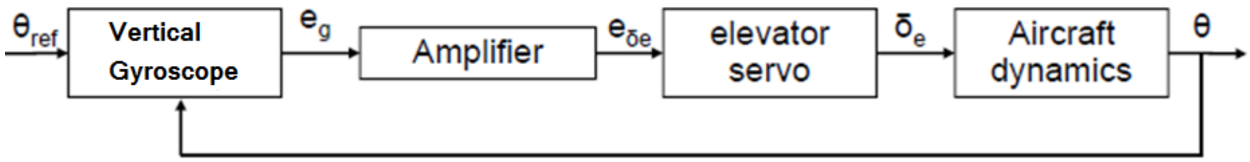
- Roll attitude AP
- Heading AP
- VOR Mode
- Navigation mode

LONGITUDINAL AUTOPILOT

Displacement Autopilot

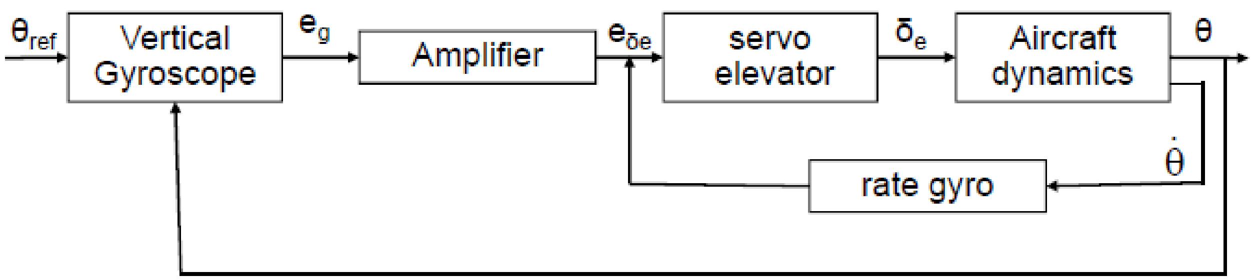
- A displacement type autopilot is used to control the angular orientation of the airplane.
- In pitch attitude displacement autopilot, the pitch angle is sensed by a vertical gyro and compared with the desired pitch angle to create an error angle. This is used to produce proportional displacements of the elevator so that the error signal is reduced.

Pitch Displacement Autopilot



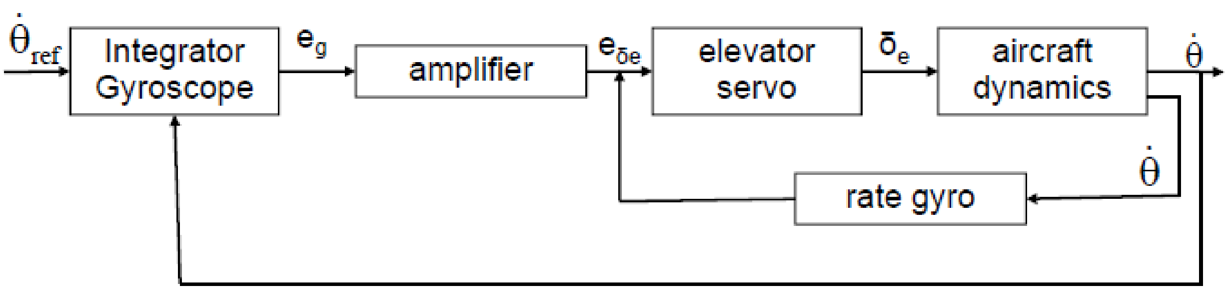
If pitch angle varies, voltage e_g is generated, it is amplified and given to elevator servo. It positions the elevator.

Pitch Rate Feedback



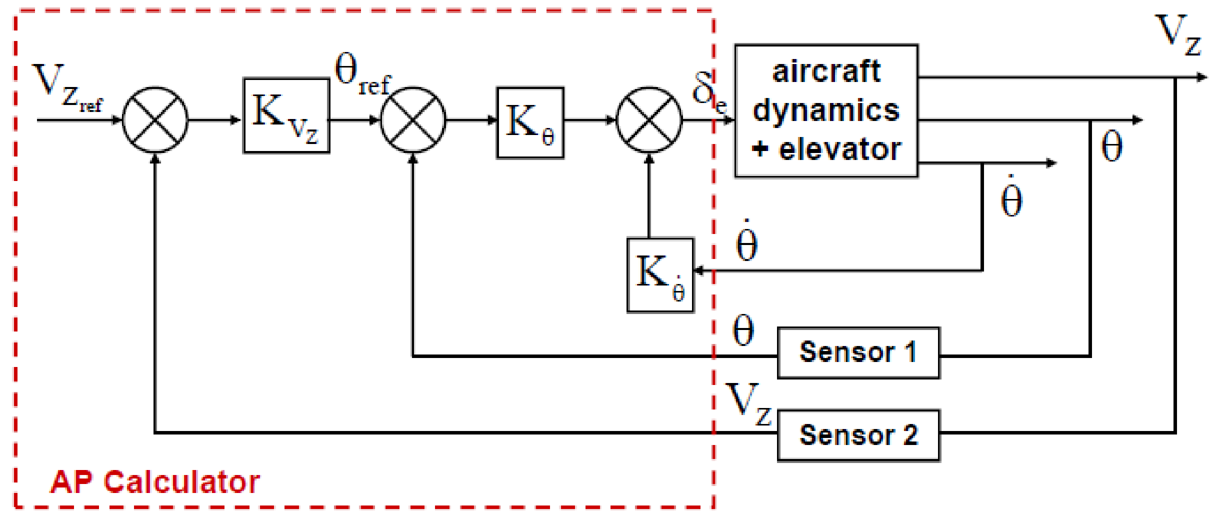
- Need to increase damping of the short oscillation mode by adding an inner feedback loop.

Pitch Speed Autopilot



- Used in aircraft with bad longitudinal stability. If pitch up occurs, which causes stall for great angles of attack.
- Automatic control system is used, which would allow the aircraft to fly with angles of attack higher than the critical one.

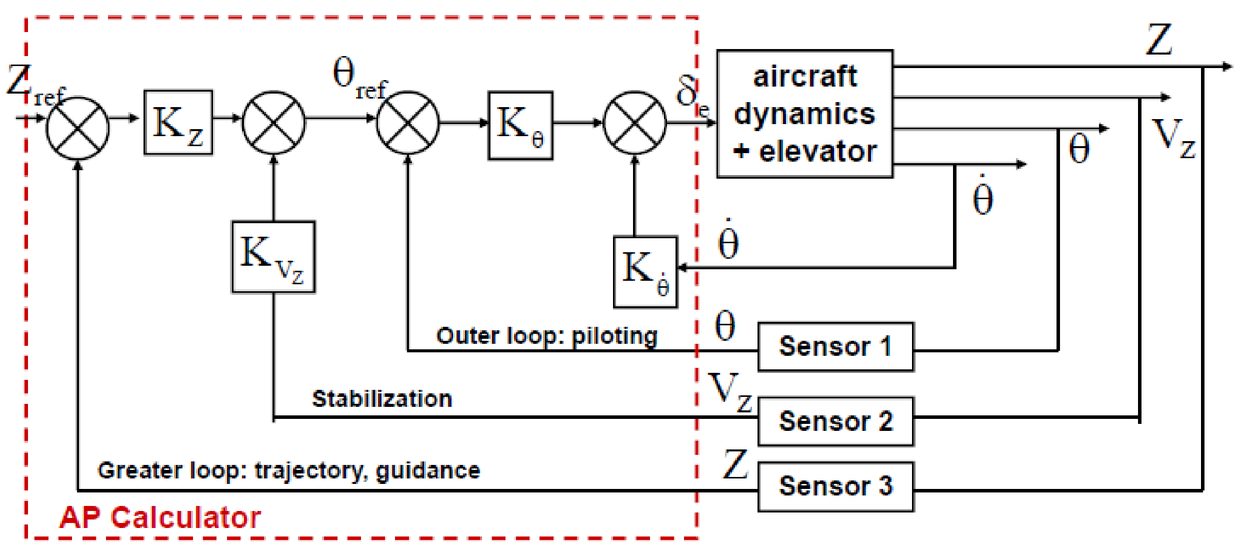
Vertical Speed Autopilot



sensor 1: Vertical gyro sensor 2: Variometer

Altitude Control

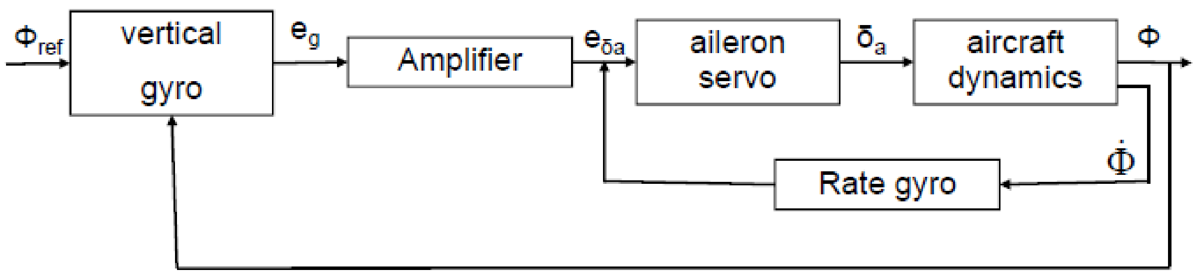
- Altitude is controlled by altering the pitch attitude of the aircraft.
- The pitch rate command inner loop provided by the pitch rate gyro feedback enables a fast and well damped response to be achieved by the pitch attitude command autopilot loop.



sensor 1: Vertical gyro sensor 2: Variometer sensor 3: Altimeter

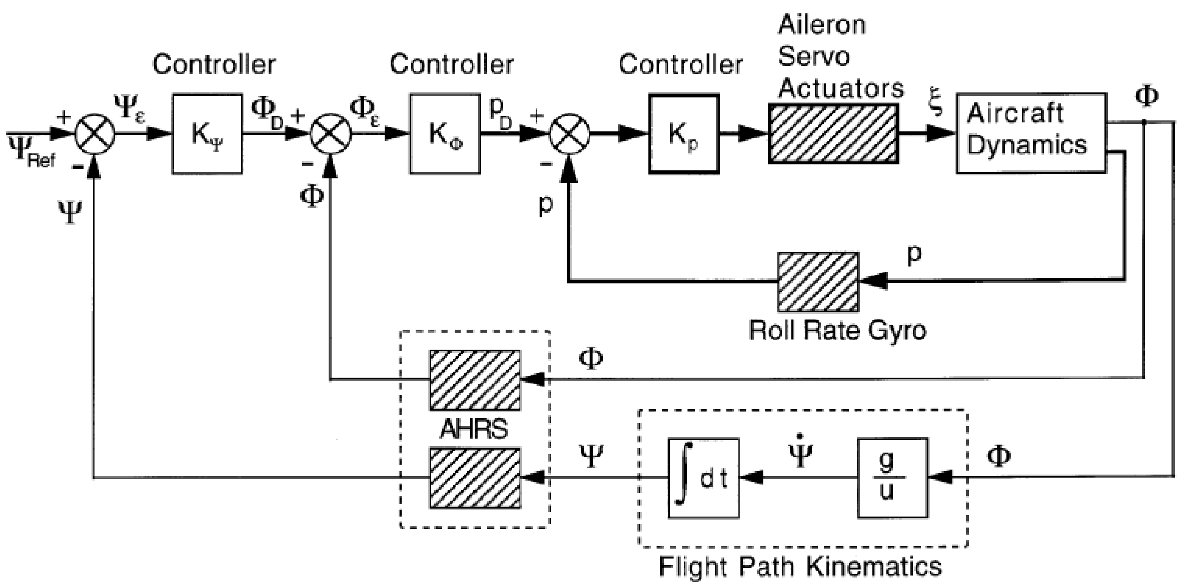
LATERAL AUTOPILOT

Roll Autopilot



Heading Control Autopilot

- The function of the heading control mode of the autopilot is to automatically steer the aircraft along a particular set direction.

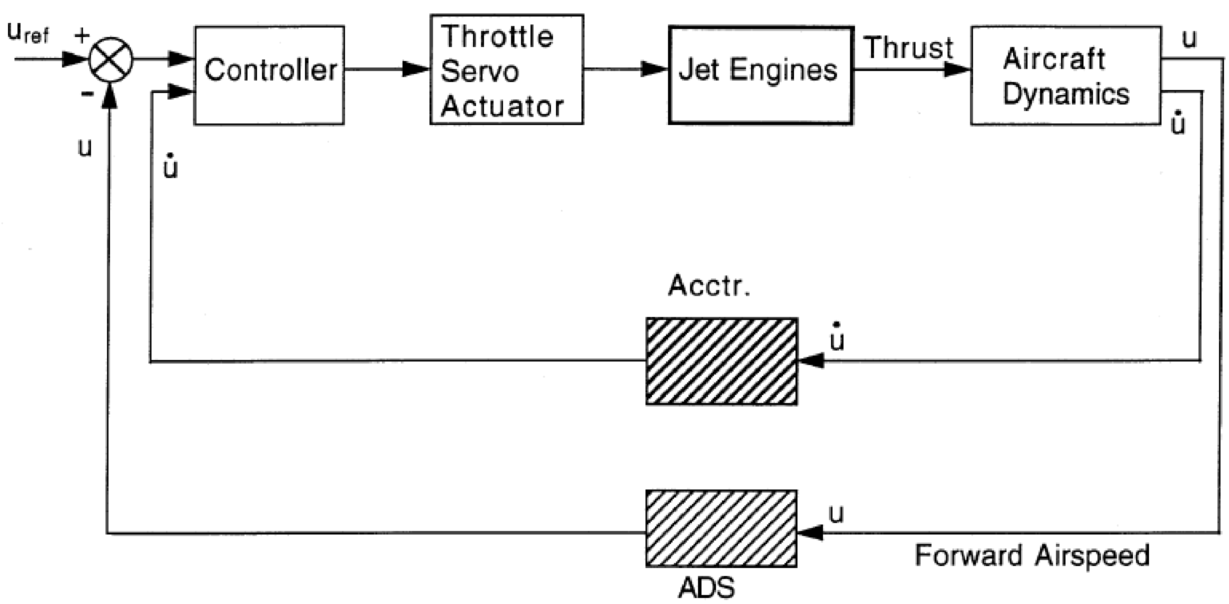


- U is the aircrafts forward velocity
- Ψ is the yaw angle
- Φ is the bank angle
- is the rate of change of heading
- Φ_D demanded bank angle
- Ψ_E heading error

- K is the gain
- p roll rate
- ξ aileron angle

Speed Control and Auto-Throttle Systems

- The aircraft speed is controlled by changing the engine thrust by altering the quantity of fuel flowing to the engines by operating the engine throttles.
- Automatic control of the aircraft's airspeed can be achieved by a closed-loop control system whereby the measured airspeed error is used to control throttle servo actuators which operate the engine throttles.
- The engine thrust is thus automatically increased or decreased to bring the airspeed error to near zero and minimize the error excursions resulting from disturbances.



2. ACTIVE CONTROL TECHNOLOGY

- Active control of aircraft can be defined as the use of active control systems, rather than passive aerodynamic design features, to drive a number of specific control surfaces of an aircraft.
- Active Control Technology is used in military fighters to maximize the aircraft's maneuverability.
- Civil transports also use ACT to reduce trim drag, reduce the pilot's workload and improve ride quality.
- Aircraft with Active Control systems use feedback control to compensate for changes in aerodynamics.
- This occurs without any input from the pilot, to make the aircraft stable and controllable with enhanced flight performance characteristics.

Components of Active Control

Active Control systems use sensors, a controller, and actuators.

- Sensors are used to measure such flight parameters as pitch angle, airspeed or altitude etc.
- Controller has a control law, which is a type of algorithm that is used to determine the required gains by which the error signal must be multiplied in order to achieve the desired output.
- An actuator is a device that causes the system response to be carried out, as determined by the controller.

Applications of Active Control

1. Active Lift Distribution Control (ALDC)

- ALDC involves redistribution of the wing spanwise lift through during in flight manoeuvres.
- ALDC is achieved by the deflection of control surfaces mounted at the trailing edge of the wing that effectively alters the aerodynamic characteristics of the aircraft wing.
- By this the centre of lift of the wing can be shifted and hence the lift can be redistributed along the wing surface, causing incremental wing stresses to be reduced in weak areas of the wing.
- The deflection of the control surfaces is regulated by feedback control loops that utilize data gathered from sensors along specific sections of the wing.

2. Ride Control (RC) System

- Ride Control systems are used to improve the smoothness of flight by actively cancelling vibrations caused by the aircraft.
- RC systems are used in cargo aircraft to reduce vibration in parts of the aircraft where vibration sensitive cargo is being transported, and in passenger aircraft to reduce vibration along the entire length of the passenger cabin.
- For fighters, RC must be used to control vibrations of weapons and weapon control systems to ensure that the pilot can successfully track targets.

3. Gust Load Alleviation

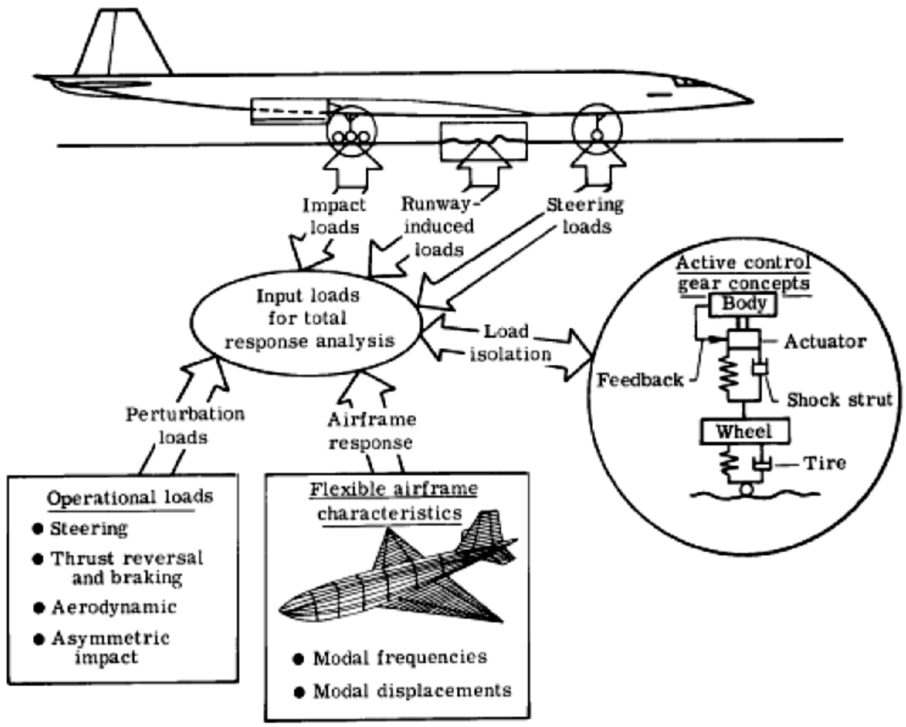
- A gust load is created by fluctuations in aerodynamic forces and moments generated by the aircraft as it travels through a constantly fluctuating atmosphere.
- These fluctuations cause the aircraft to pitch, roll and yaw in an undesired fashion and hence cause accelerations known as gust loads.
- Gust Load Alleviation involves the use of sensors on specific areas of the aircraft which deliver data to feedback controllers.
- These feedback controllers then cause deflections of control surfaces that generate aerodynamic forces which cancel the accelerations caused by these gust loads.

4. Flutter Mode Control (FMC)

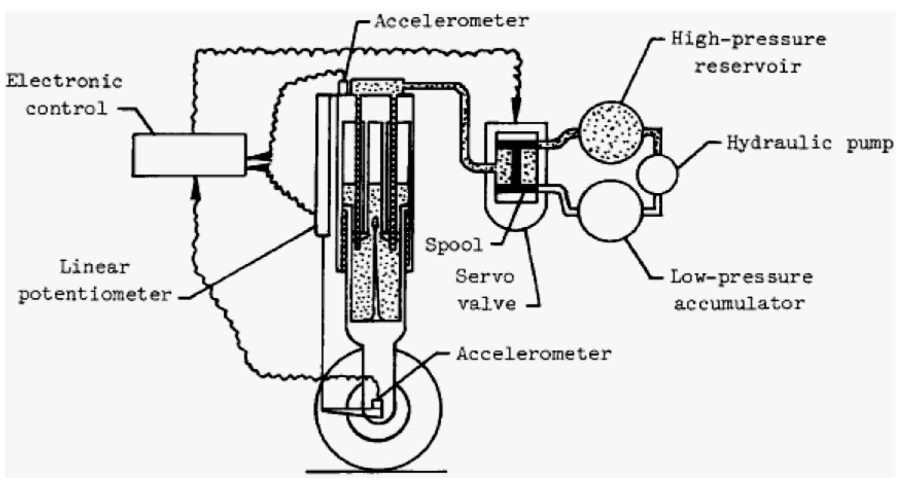
- Flutter Mode Control (FMC) is used almost exclusively in fighter aircraft, with the aim being to reduce the flutter (vibrational) mode of wings of the aircraft.
- FMC operates by the controlled deflection of auxiliary control surfaces to dampen the vibrational modes of the wings of the aircraft.

5. Aircraft Landing Gear Damping

- Landing impact and runway surface abnormalities can cause fatigue damage of the aircraft frame and passenger discomfort during aircraft landing and taxiing.
- Active Control technology can be used to significantly reduce the loads applied to aircraft frames during these situations.



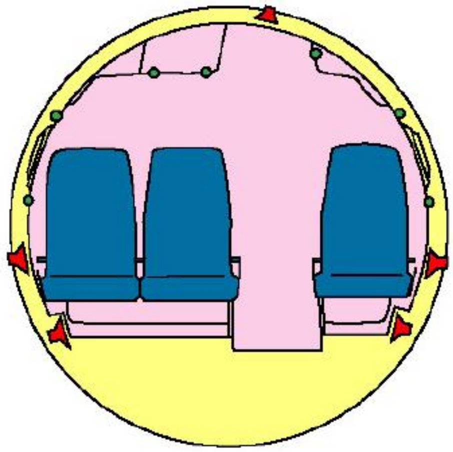
- The most common form of landing gear Active Control includes the use of series hydraulic control, where a hydraulically controlled actuator is placed in series with passive elements of the landing gear strut.



6. Active Noise Control

- Active Noise Control involves using sound pressure waves to cancel out sound created by the aircraft.
- Rather than eliminating the source of the aircraft noise, which in many cases is impractical, Active Noise Control reduces cabin noise in an aircraft through the use of microphones to measure the

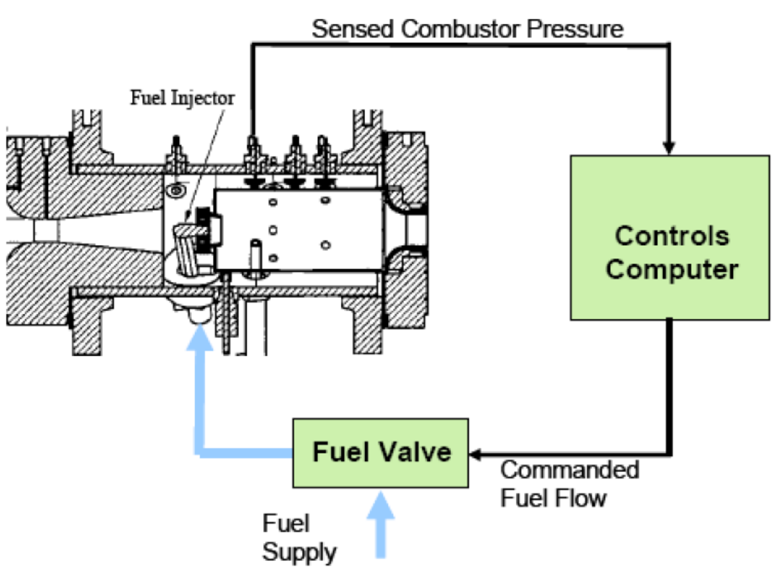
ambient sound and speakers to produce sound that is out of phase with the ambient sound in order to cancel it out.



- Another form of Active Noise Control in aircraft is to cancel out the unwanted noise at the source of the noise. An example of this type of Active Control is Aircraft Engine Inlet Noise Control.
- In this type of control system, the frequency and phase of sound produced by the engine fans is measured using sensors on the engine fan blades, while compact sound sources are planted inside the engine casing to produce a sound of a frequency that is perfectly out of phase of the vibrational frequency of the engine fans.

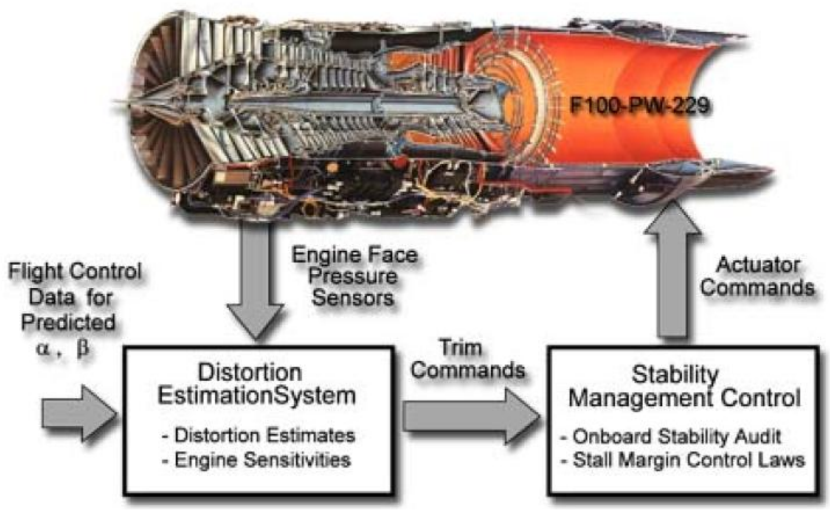
7. Active Combustion Control

- It involves the use of feedback based control of fuel injection into engine combustion chambers, thereby allowing active control of fuel air mixing and hence optimizing combustion efficiency and reducing combustion emissions.



8. High Stability Engine Control

- It involves a Distortion Estimation System with a small number of high response pressure sensors at the engine face to calculate the extent of distortion in real time.
- The Stability Management Control, through direct control of the fan and compressor pressure ratio, accommodates the distortion by transiently increasing the amount of stall margin available based on information from the Distortion Estimation System.



9. Autopilot System

- Active Control is perhaps most extensively and commonly used in autopilot systems.
- Autopilot systems operate by taking data inputs from the aircraft control systems and using them to actively control the aircraft characteristics.
- Many aircraft flight parameters can be controlled via auto pilot, such as pitch, roll, yaw, altitude and position.
- Autopilot systems can also control thrust of the aircraft and control the aircraft centre of mass by moving fuel around to different tanks in the aircraft.

Advantages of Active Control

- Improved Stability
- Improved Handling
- Improved Performance

- Improved Safety
- Allows Non-Conventional Aircraft Configurations

Disadvantages of Active Control

Sensor Limitations

Each automatic control system relies on the feedback of certain sensor signals. Limitations arise in sensors as they can not perfectly monitor flight parameters and the external environment.

Controller Instability

Abrupt changes, as well as frequent changes, can lead to an unstable controller being introduce.

Actuators

- In flight control systems, the control laws are designed with an assumed gain and phase characteristic for the actuators
- This means that any significant deviation from these ideal characteristics can lead to a reduction of aircraft gain and phase stability margins.

Aircraft Strength

- There are limitations imposed on all aircraft to ensure that their structural integrity is maintained. These are taken into account in maintaining stability of the Active Control system.

Crew Capabilities

- The main limitation imposed on the Active Control system by the pilot and crew is their physical capabilities.
- This can be extremely difficult to incorporate in control systems as human capabilities can be affected by many factors such as age, circadian rhythms, state of mind, physical health, attitude, emotions etc.

AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 4

1. FUEL SYSTEMS

The aircraft fuel system is used to deliver fuel to the engines safely under a wide range of operational conditions. The system must have a means of safely holding the fuel, allow filling and draining of the tanks, prevent unwanted pressure buildups in the system, protect the system from contamination, and assure a steady supply of fuel to the engine. The system must also provide a means of monitoring the quantity of fuel on the aircraft during flight and, in some aircraft, a means of checking fuel pressures, temperatures, and flow rates.

Aviation Fuel

Reciprocating Engine Fuel

- Reciprocating engines burn gasoline, also known as AVGAS (AVGAS 82UL, AVGAS 100, AVGAS 100 LL)
- It is primarily a hydrocarbon compound refined from crude oil by fractional distillation.
- It is very volatile and extremely flammable, with a low flash point.

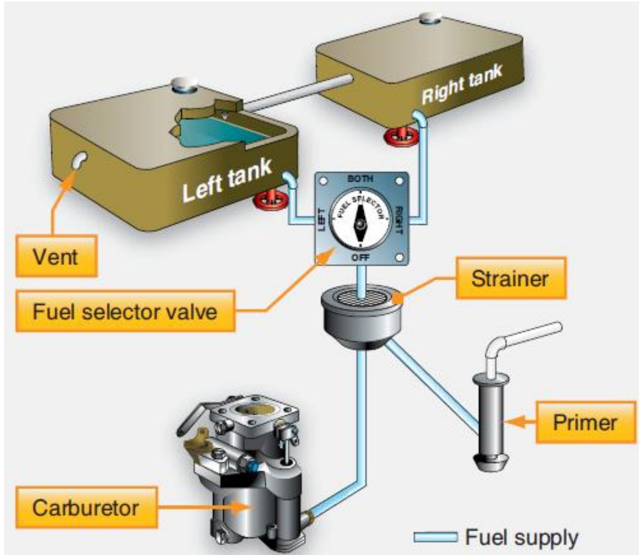
Turbine Engine Fuels

- Commonly known as jet fuel.(JET A, JET A1, JET B)
- Turbine fuel is a kerosene-type fuel with a much higher flash point so it is less flammable.

Types of Fuel Systems

1. Gravity Feed Fuel Systems

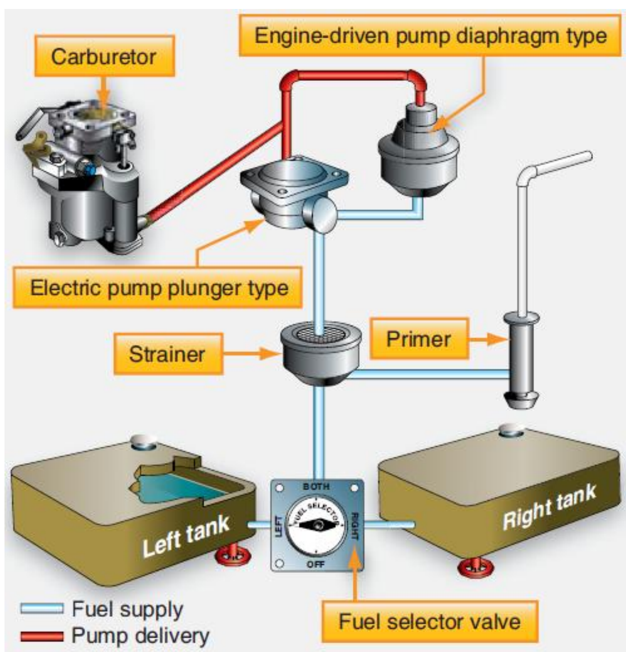
- It uses the force of gravity to cause fuel to flow to the engine fuel-control mechanism. For this to occur, the bottom of the fuel tank must be high enough to assure a proper fuel-pressure head at the inlet to the fuel-control component on the engine.
- In high-wing aircraft this is accomplished by placing the fuel tanks in the wing.



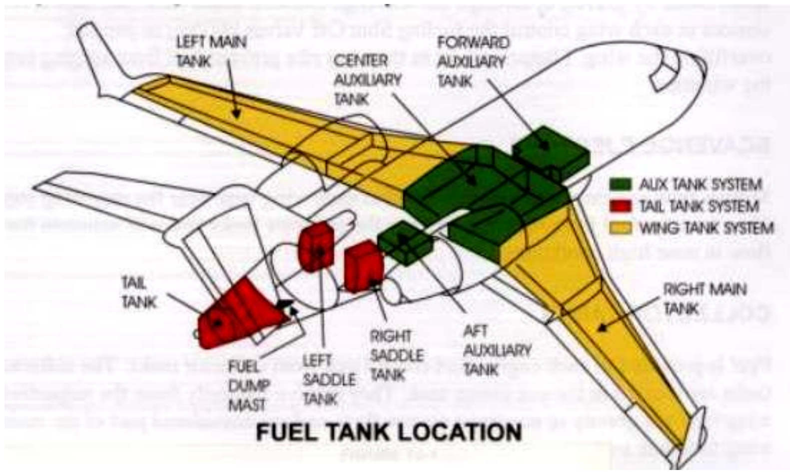
Gravity Feed Fuel System

2. Pressure Feed Fuel Systems

- It uses a pump to move fuel from the fuel tank to the engine fuel-control component.
- This arrangement is required because the fuel tanks are located too low for sufficient head pressure to be generated are used to move the fuel from the tanks to the engine.



Pressure Feed Fuel Systems



FUEL SYSTEM COMPONENTS

Fuel Tanks

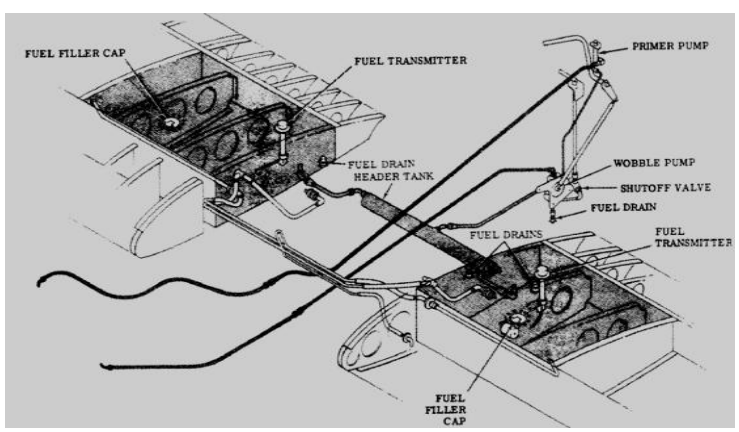
- Fuel tanks for aircraft may be constructed of aluminum alloy, fuel-resistant synthetic rubber, composite materials, or stainless steel.

Types

- **Integral Fuel Tanks**
- **Rigid Removable Tanks**
- **Bladder Fuel Tank**

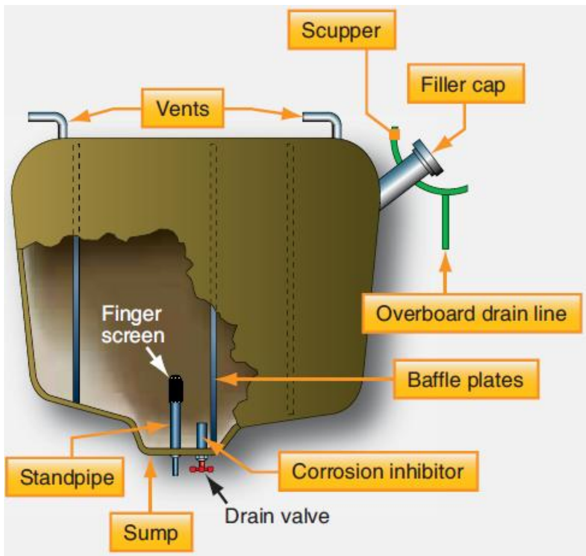
Integral Fuel Tanks

- An integral fuel tank is a tank that is part of the basic structure of the aircraft. Integral fuel tanks have commonly been located in the wing or fuselage, but may be located in other locations such as the horizontal stabilizer.



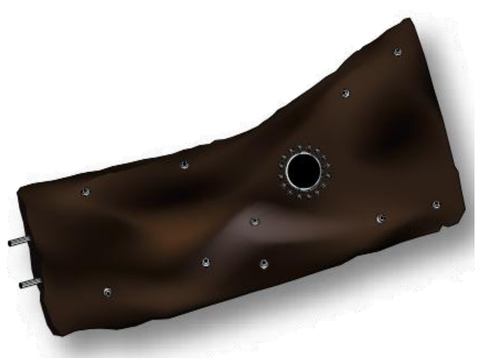
Rigid Removable Tanks

- A rigid removable fuel tank is one that is installed in a compartment designed to hold the tank. The tank must be fuel-tight, but the compartment in which it fits is not fuel-tight. The tank is commonly made of aluminum components welded together.
- Aircraft fuel tanks have a low area called a sump that is designed as a place for contaminants and water to settle. The sump is equipped with a drain valve used to remove the impurities during preflight inspection.



Bladder Fuel Tanks

- A bladder fuel tank, is essentially a reinforced rubberized bag placed in a non-fuel-tight compartment designed to structurally carry the weight of the fuel.
- The bladder incorporates all the components required for removable rigid fuel tanks, such as a vent, drain, quantity indicator, etc.



Surge Fuel Tanks

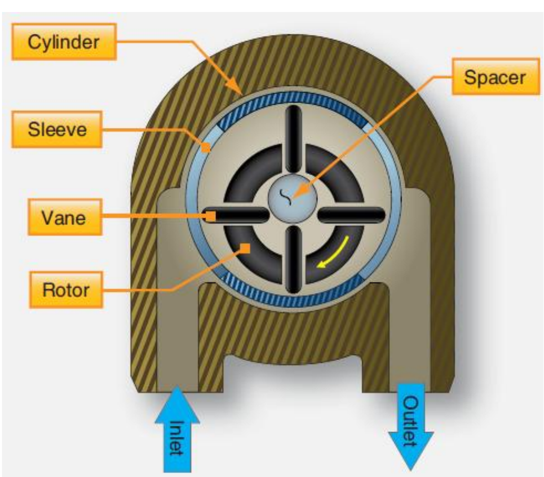
- Surge fuel tanks are normally located on transport-category aircraft and are constructed the same as integral fuel tanks.
- Surge tanks, which are normally empty, are designed to contain fuel overflow and prevent fuel spillage, particularly when fueling the aircraft.

Fuel Pumps

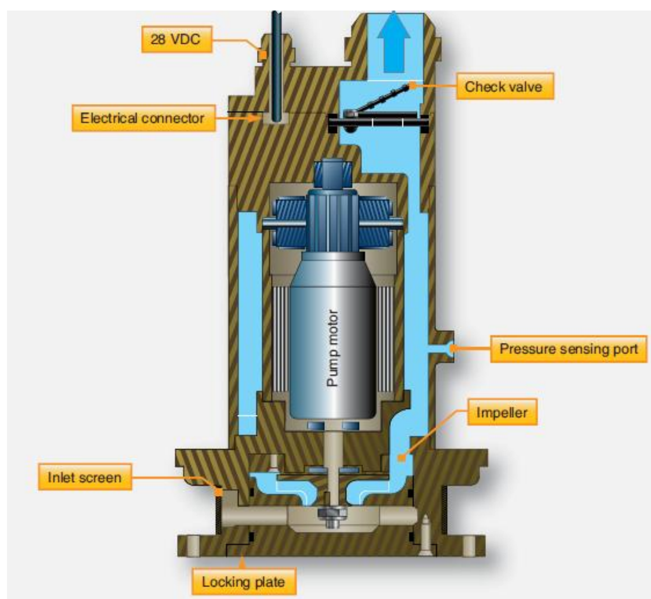
- Fuel pumps are used to move fuel through the fuel system when gravity flow is insufficient. These pumps are used to move fuel from the tanks to the engines, from tanks to other tanks, and from the engine back to the tanks.

➢ Vane Pump
➢ Centrifugal Pump
➢ Ejector Pump

Vane Fuel Pumps

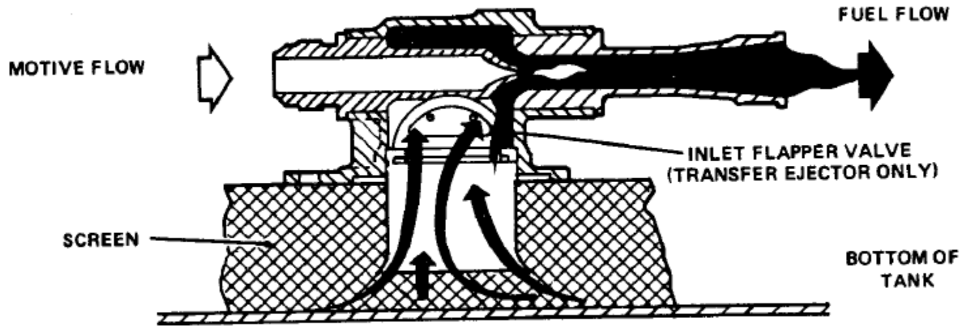


Centrifugal Fuel Pumps



Ejector Fuel Pumps

- This type of pump has no moving parts but relies on the flow of returned fuel from the engine-driven pump to pump fuel.

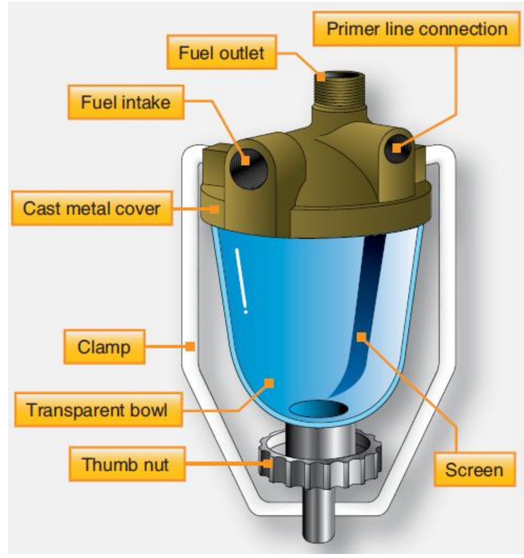


- The ejector pump works on the venturi principle.
- Engine-driven fuel pumps supply the engine fuel-control unit with more volume than is necessary for operation.
- Excess fuel from this pump is routed back to the motive flow inlet of the ejector pump. This returned fuel is at a high pressure but at a low volume.
- As the motive flow fuel exits the ejector nozzle in the venturi area, a pressure drop is created and fuel from the inlet screen is drawn into the low-pressure area.
- The motive flow continues on through the venturi and draws the fuel from the tank with it.

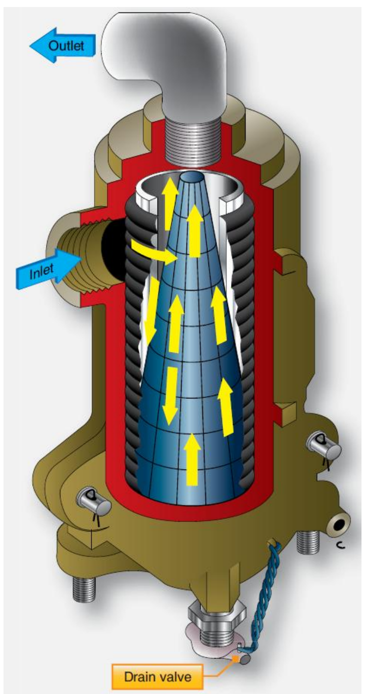
Fuel Strainers and Filters

- All aircraft fuel systems have filters and strainers to ensure that the fuel delivered to the engine is free from contaminants.
- Some type of screen is used to trap contaminants attempting to flow out of the tank into the fuel system. Finger screens are common on light aircraft.

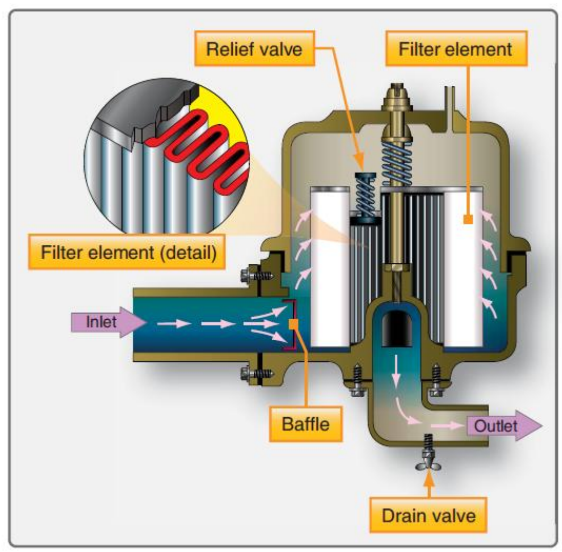
Fuel tank outlet finger strainers



Main fuel screen for a light aircraft



A large-area double-screen filter



Micronic fuel filter with changeable cellulose filter element

Drains

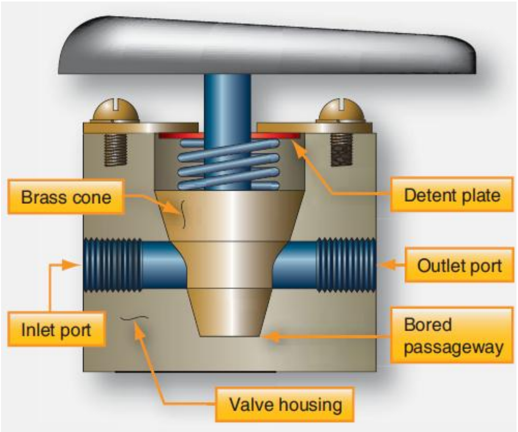
- Aircraft fuel systems must be provided with drains such that the entire system can be drained with the airplane in its normal ground attitude.
- Drains are available at fuel strainers, and at sumps as well as at other locations.

Fuel Valves

- Fuel valves provide a means of shutting off the fuel flow, selecting the tank from which to draw fuel in a multiple-tank installation, transferring fuel from one tank to another, and directing the fuel to one or more engines in a multi-engined airplane.
- Fuel valves include shutoff valve, transfer valve, crossfeed valve. These can be manually operated, solenoid operated, or operated by electric motor.
- The cone-type valve and the poppet type valve are commonly used in light general aviation aircraft as fuel selector valves.
- Gate valves are used on transport category aircraft as shutoff valves. While many are motor operated, there are several applications in which gate valves are hand operated.

Cone Type Valve

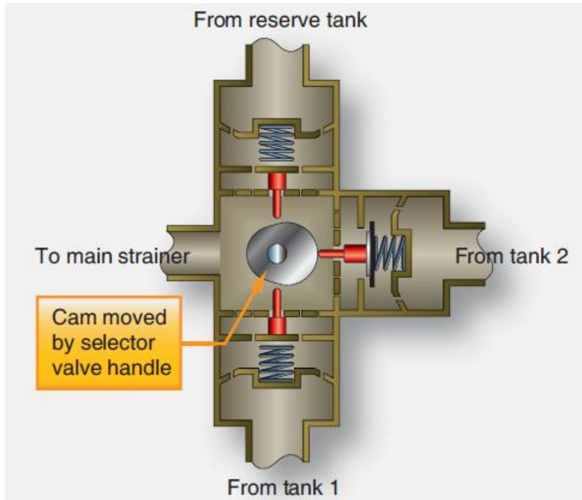
- A cone valve is open when the bored cone aligns the inlet and the outlet ports. It shuts off the flow when the un-bored portion of the cone is aligned with the inlet port.



- A cone valve, also called a plug valve, consists of a machined valve housing into which a rotatable brass or nylon cone is set.
- The cone is manually rotated by the pilot with an attached handle. Passageways are machined through the cone so that, as it is rotated, fuel can flow from the selected source to the engine.
- This occurs when the passageway aligns with the desired fuel input port machined into the housing.

Poppet Type Valve

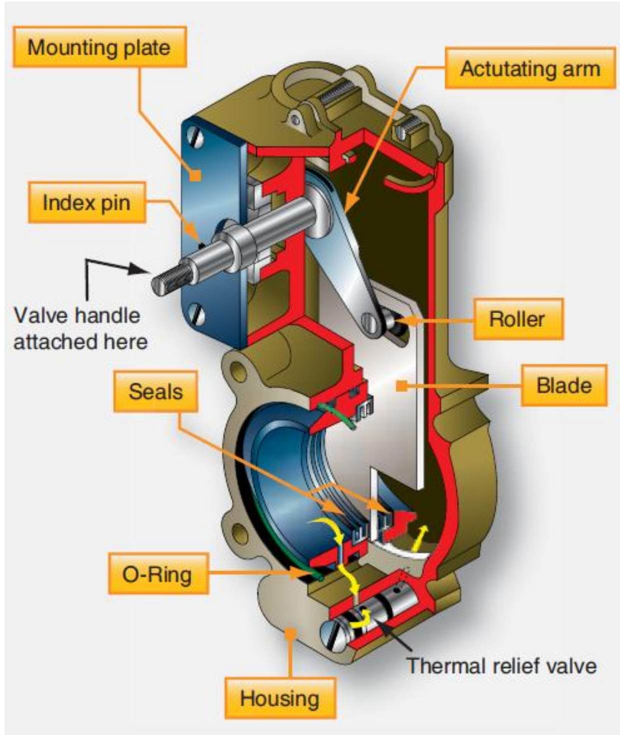
- Selector valves are also commonly the poppet type. As the handle is rotated in this valve, a cam on the attached shaft lifts the poppet off the seat of the desired port being selected.



Gate Valve

- Hand-operated gate valves can be used, especially as fire control valves, requiring no electrical power to shutoff fuel flow when the emergency fire handle is pulled. The valves are typically positioned in the fuel feed line to each engine.

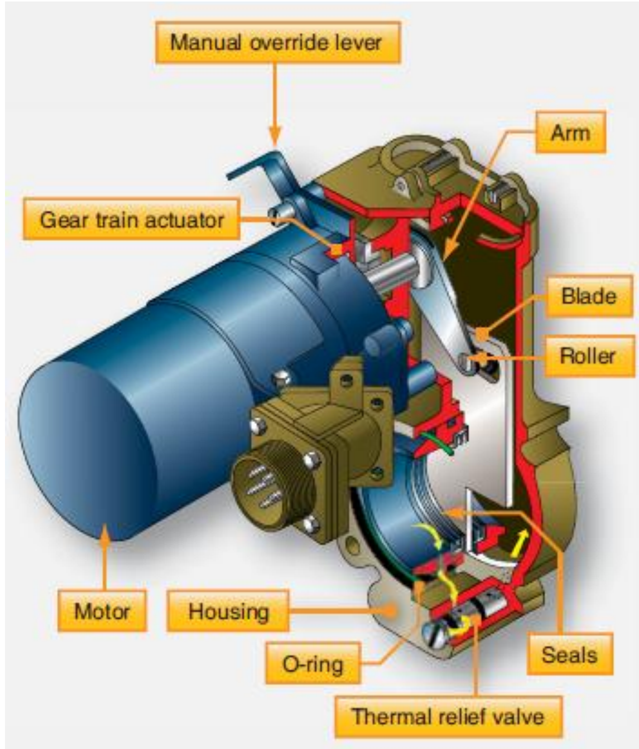
- Gate valves utilize a sealed gate or blade that slides into the path of the fuel, blocking its flow when closed.



- When the handle is rotated, the actuating arm inside the valve moves the gate blade down between seals and into the fuel flow path.
- A thermal relief bypass valve is incorporated to relieve excess pressure buildup against the closed gate due to temperature increases.

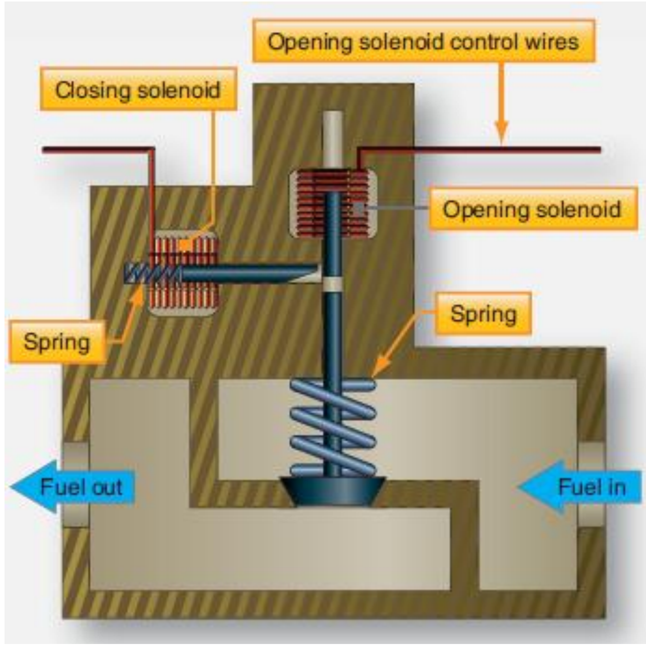
Motor Operated Valve

- The use of electric motors to operate fuel system valves is common on large aircraft due to the remote location from the cockpit of fuel system components. In this electric motors are used to actuate the units.
- The motor-operated gate valve uses a geared, reversible electric motor to turn the actuating arm of the valve that moves the fuel gate into or out of the path of the fuel. As with the manually operated gate valve, the gate or blade is sealed.



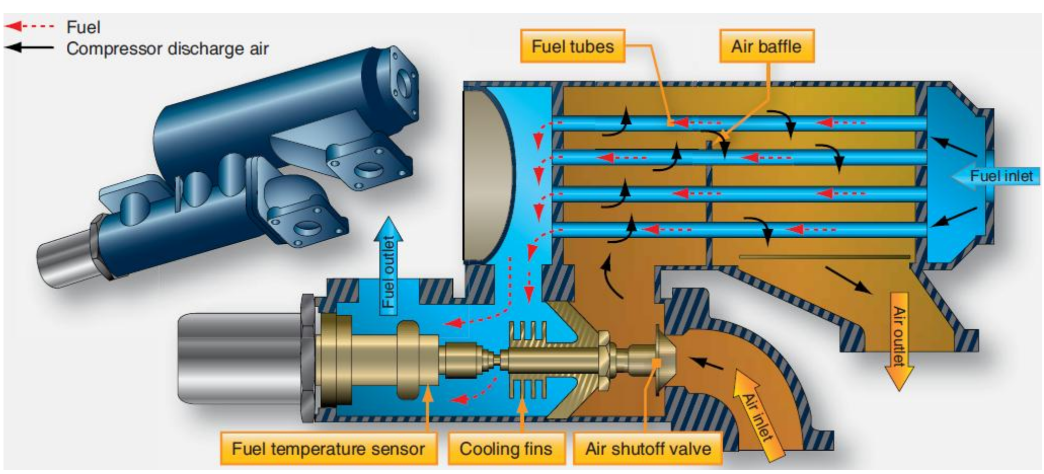
Solenoid Operated Valve

- In this poppet-type valve is opened via the magnetic pull developed when an opening solenoid is energized. A spring forces a locking stem into a notch in the stem of the poppet to lock the valve in the open position. Fuel then flows through the opening vacated by the poppet.
- To close the poppet and shut off fuel flow, a closing solenoid is energized. Its magnetic pull overcomes the force of the locking stem spring and pulls the locking stem out of the notch in the poppet stem. A spring behind the poppet forces it back onto its seat.



Fuel Heaters

- Turbine powered aircraft operate at high altitude where the temperature is very low. As the fuel in the fuel tanks cools, water in the fuel condenses and freezes.
- The formation of ice on the filter element blocks the flow of fuel through the filter.
- Fuel heaters are used to warm the fuel so that ice does not form.
- The most common types of fuel heaters are air/fuel heaters and oil/fuel heaters.
- An air/fuel heater uses warm compressor bleed air to heat the fuel. An oil/fuel exchanger heats the fuel with hot engine oil.
- Fuel heaters can also be automatic. A built-in thermostatic device opens or closes a valve that permits the hot air or hot oil to flow into the unit to cool the fuel.



Filler Caps

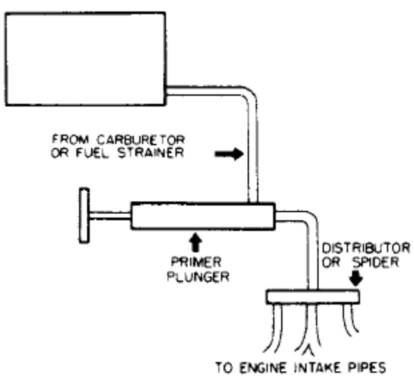
- The filler cap must provide a tight seal and be designed so that it cannot come off in flight.
- Fuel-tank venting may be provided through the fuel cap.

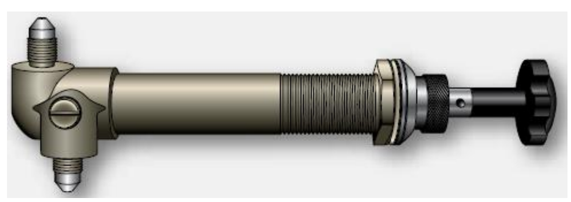
Fuel Lines and Fittings

- In an aircraft fuel system, the various components are connected by means of aluminum alloy, copper, or other types of tubing and flexible hose assemblies with approved connecting fittings.

Fuel Primers

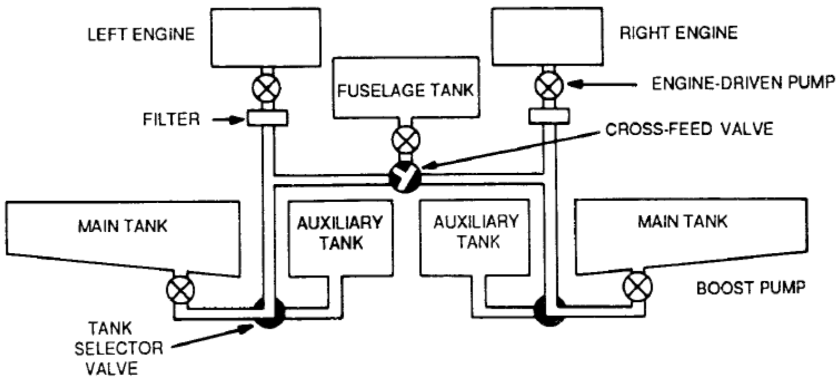
- Used to pump fuel directly into the intake system prior to engine start.
- Useful in cold weather when fuel in the carburetor is difficult to vaporize.





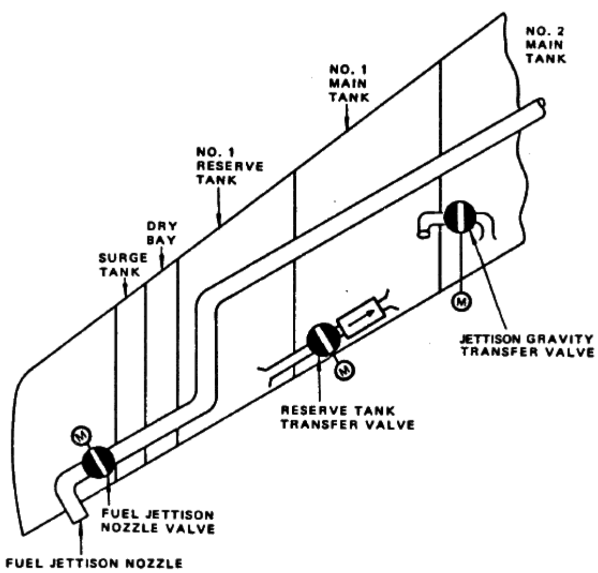
Fuel Cross-feed System

- On most multiengine aircraft, the fuel manifolds are connected in such a manner that any fuel tank may supply fuel to any engine. Should an engine fail, its fuel is immediately available to supply the demand of the other engine.
- It also makes it possible to transfer fuel from any tank to any other tank for the purpose of balancing the weight distribution and to maintain an acceptable position for the airplane's center of gravity.



Fuel Jettison System

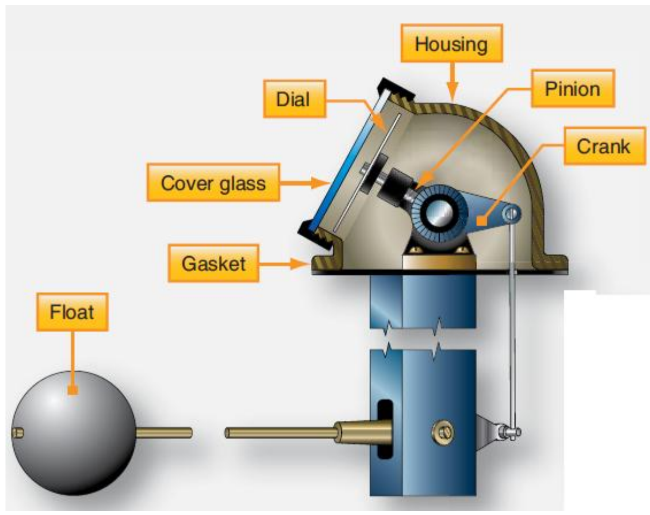
- The fuel jettison (Fuel Dumping) system comprises a combination of fuel lines, valves, and pumps provided to dump fuel overboard during an in-flight emergency to reduce the weight of the airplane to allowable landing weight or to dump all the fuel except the reserve quantity required for landing.



Fuel Quantity Indicating Systems

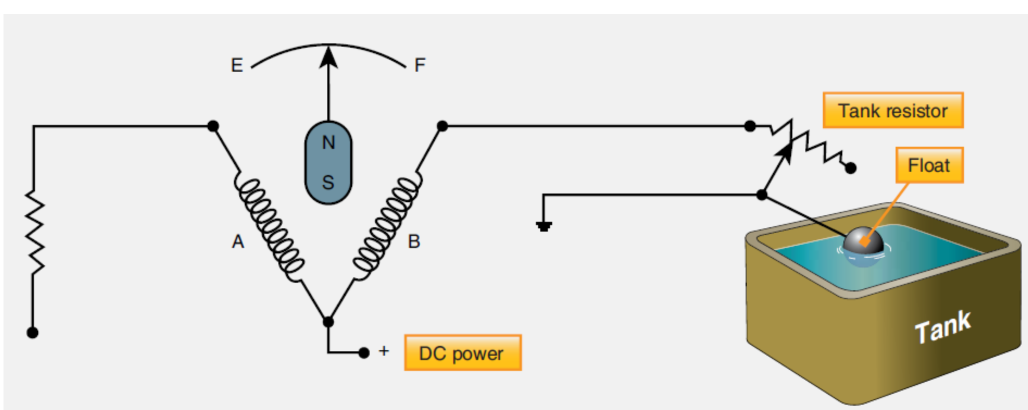
- The use of these direct reading indicators is possible only on light aircraft in which the fuel tanks are in close proximity to the cockpit.
- Other light aircraft and larger aircraft require electric indicators or electronic capacitance type indicators.

- 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.
- In mechanical type, 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.



Simple mechanical fuel indicator used on light aircraft

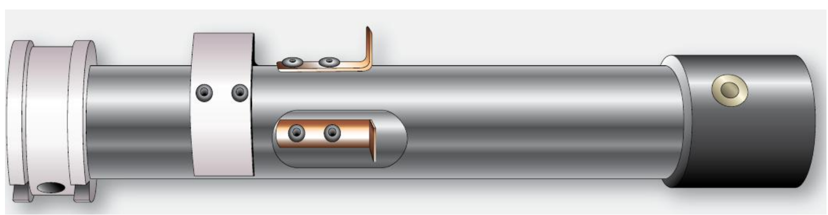
- In electric type, the movement of a float in the tank moves a connecting arm to the wiper on a variable resistor in the tank unit. This resistor is wired in series with one of the coils of the ratiometer-type fuel gauge in the instrument panel.
- Changes to the current flowing through the tank unit 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.



A DC electric fuel quantity indicator

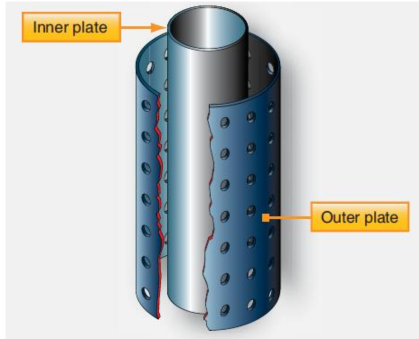
- Digital indicators are available that work with the same variable resistance signal from the tank unit.
- They convert the variable resistance into a digital display in the cockpit instrument head

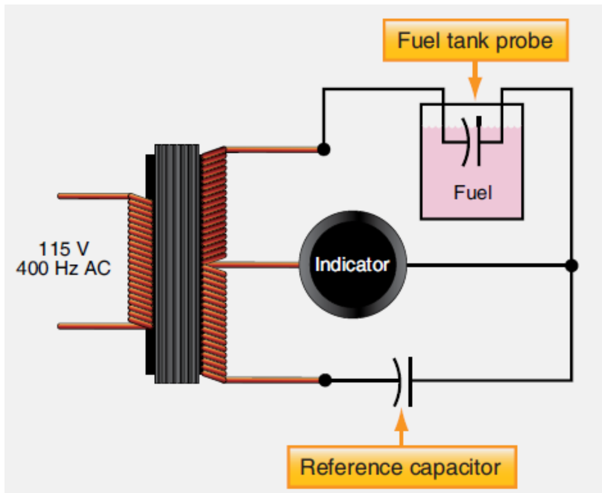
- Large and high-performance aircraft typically utilize electronic fuel quantity systems. Variable capacitance transmitters are installed in the fuel tanks extending from the top to the bottom of each tank.



Fuel tank transmitter for a capacitance type fuel quantity indicating system

- The amount of charge storage in a capacitor depends on three factors: the area of its plates, the distance between the plates, and the dielectric constant of the material separating the plates.
- A fuel tank unit contains two concentric plates that are a fixed distance apart. Therefore, the capacitance of a unit can change if the dielectric constant of the material separating the plates varies.
- The units are open at the top and bottom so they can assume the same level of fuel as is in the tanks. Therefore, the material between the plates is either fuel (if the tank is full), air (if the tank is empty), or some ratio of fuel and air depending on how much fuel remains in the tank.



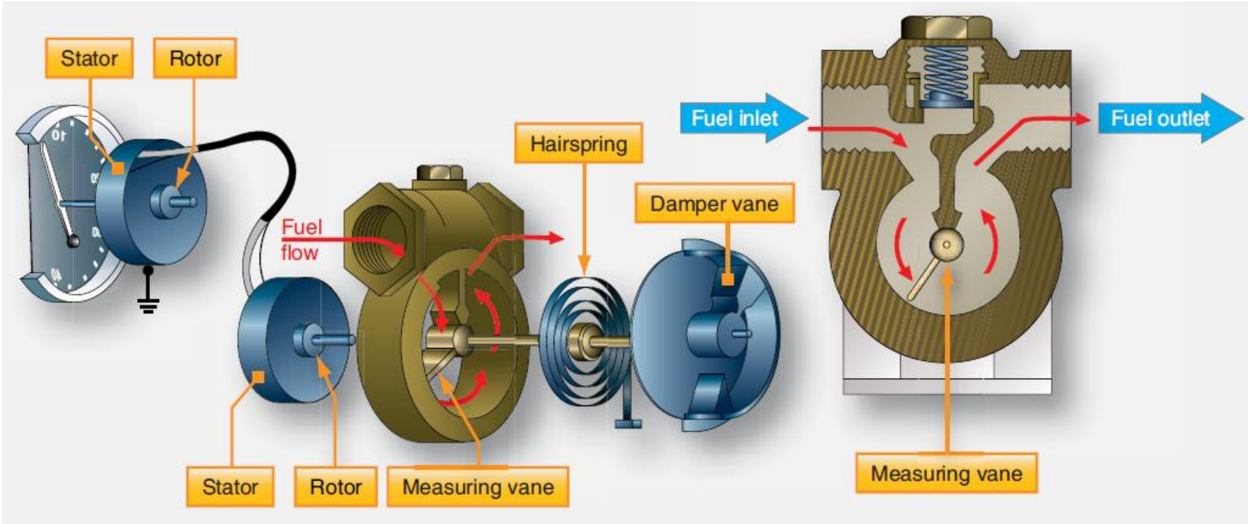


A simplified capacitance bridge for a fuel quantity system

- The bridge circuit that measures the capacitance of the tank units uses a reference capacitor for comparison.
- When voltage is induced into the bridge, the capacitive reactance of the tank probes and the reference capacitor can be equal or different. The magnitude of the difference is translated into an indication of the fuel quantity in the tank.

Fuel Flow meters

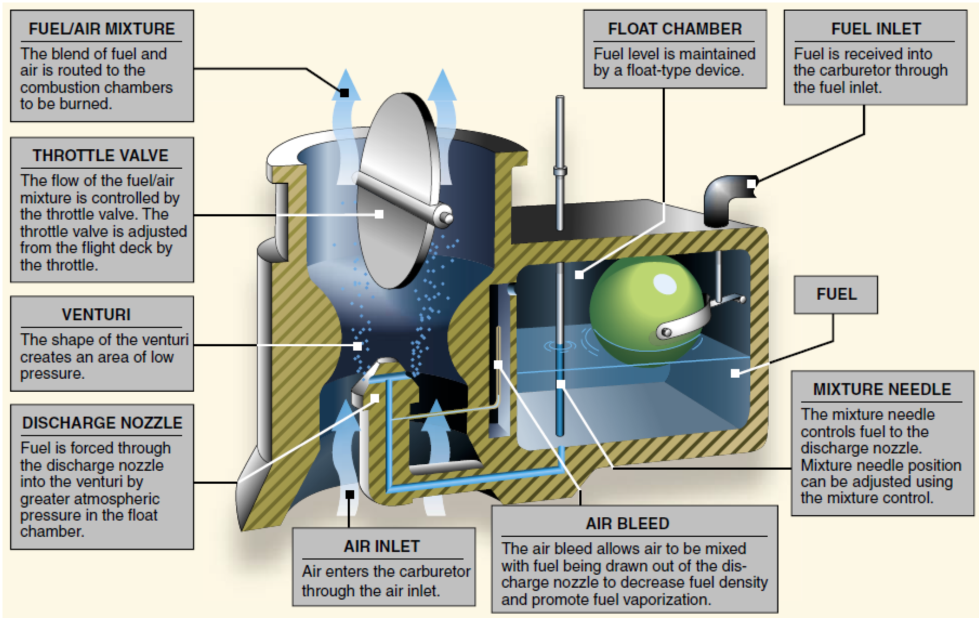
A fuel flow meter indicates an engine's fuel use in real time. This can be useful to the pilot for ascertaining engine performance and for flight planning calculations.



Vane-type fuel flow meter

Carburetor

- The carburetor must measure the airflow through the induction system and use this measurement to regulate the amount of fuel discharged into the airstream.
- The air measuring unit is the venturi, which makes use of a basic law of physics: ***as the velocity of a gas or liquid increases, the pressure decreases.***
- As the air speeds up to get through the narrow portion, its pressure drops. Note that the pressure in the throat is lower than that in any other part of the venturi.
- This pressure drop is proportional to the velocity and is, therefore, a measure of the airflow. The basic operating principle of most carburetors depends on the differential pressure between the inlet and the venturi throat.



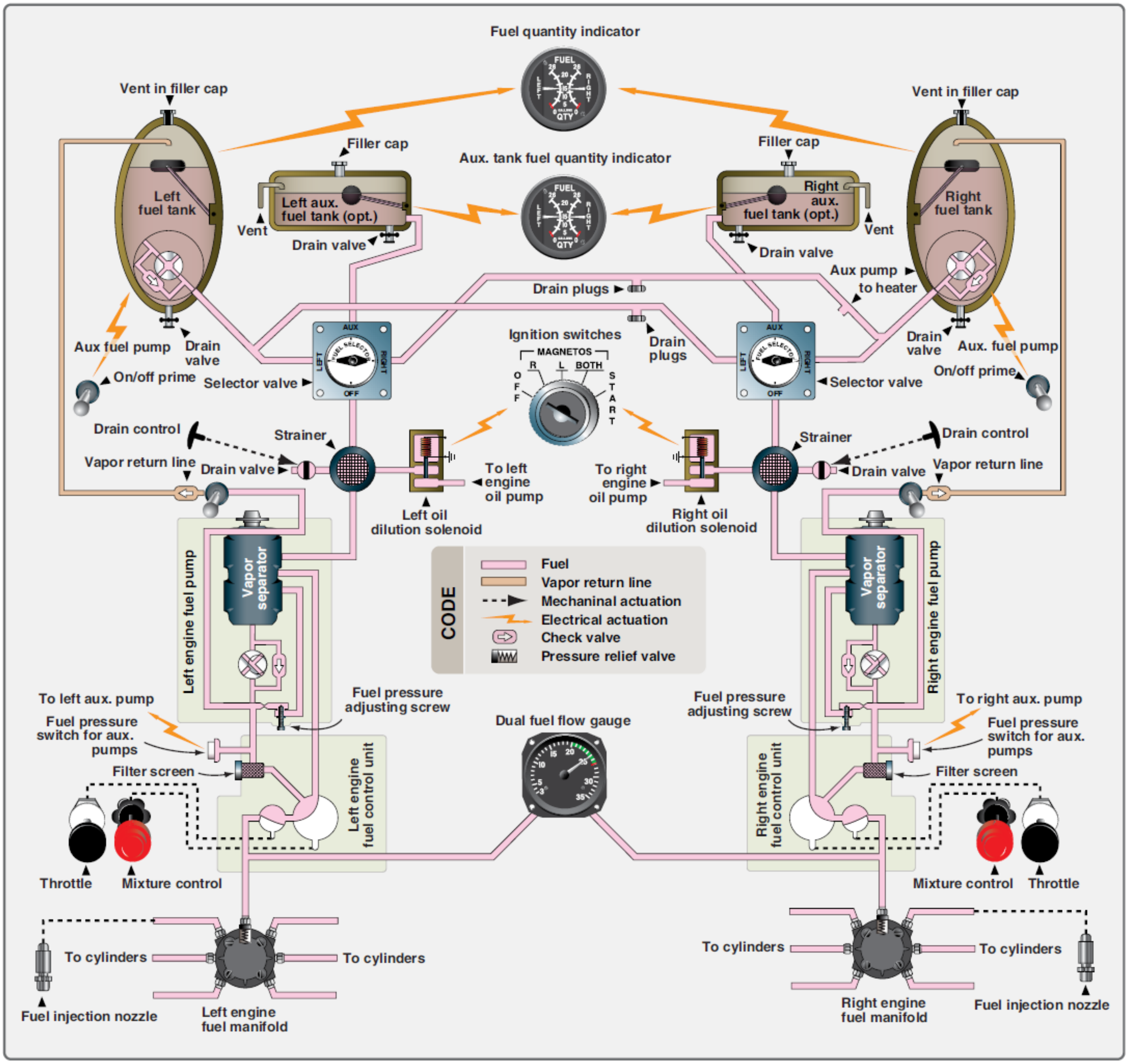
- Fuel enters the carburetor from the engine-driven pump. The float-operated needle valve regulates the flow through the inlet, which maintains the correct level in the fuel float chamber.
- This level must be slightly below the outlet of the discharge nozzle to prevent overflow when the engine is not running.
- The discharge nozzle is located in the throat of the venturi at the point where the lowest drop in pressure occurs as air passes through the carburetor to the engine cylinders.
- There are two different pressures acting on the fuel in the carburetor—a low pressure at the discharge nozzle and a higher (atmospheric) pressure in the float chamber.
- The higher pressure in the float chamber forces the fuel through the discharge nozzle into the airstream. If the throttle is opened wider to increase the airflow to the engine, there is a greater drop in pressure at the venturi throat.
- Because of the higher differential pressure, the fuel discharge increases in proportion to the increase in airflow.
- If the throttle is moved toward the “closed” position, the airflow and fuel flow decrease.
- The fuel must pass through the metering jet to reach the discharge nozzle.
- It is a certain size hole that the fuel passes through. The size of this jet determines the rate of fuel discharge at each differential pressure. I

- f the jet is replaced with a larger one, the fuel flow increases, resulting in a richer mixture. If a smaller jet is installed, there is a decrease in fuel flow and a leaner mixture.

VAPOR LOCK

- Normally the fuel remains in a liquid state until it is discharged into the air stream and then instantly changes to a vapor.
- Under certain conditions, however, the fuel may vaporize in the lines, pumps, or other units. The vapor pockets formed by this premature vaporization restrict the fuel flow through units which are designed to handle liquids rather than gases. The resulting partial or complete interruption of the fuel flow is called vapor lock.
- The three general causes of vapor lock are the lowering of the pressure on the fuel, high fuel temperatures, and excessive fuel turbulence.
- At high altitudes, the pressure on the fuel in the tank is low. This lowers the boiling point of the fuel and causes vapor bubbles to form. This vapor trapped in the fuel may cause vapor lock in the fuel system.
- Vapor lock can become serious enough to block the fuel flow completely and stop the engine. Even small amounts of vapor in the inlet line restrict the flow to the engine-driven pump and reduce its output pressure.
- To reduce the possibility of vapor lock, fuel lines are kept away from sources of heat; also, sharp bends and steep rises are avoided. In addition, the volatility of the fuel is controlled in manufacture so that it does not vaporize too readily.
- The major improvement in reducing vapor lock, however, is the incorporation of booster pumps in the fuel system. These pumps keep the fuel in the lines to the engine-driven pump under pressure. The slight pressure on the fuel reduces vapor formation. The booster pump also releases vapor from the fuel as it passes through the pump.

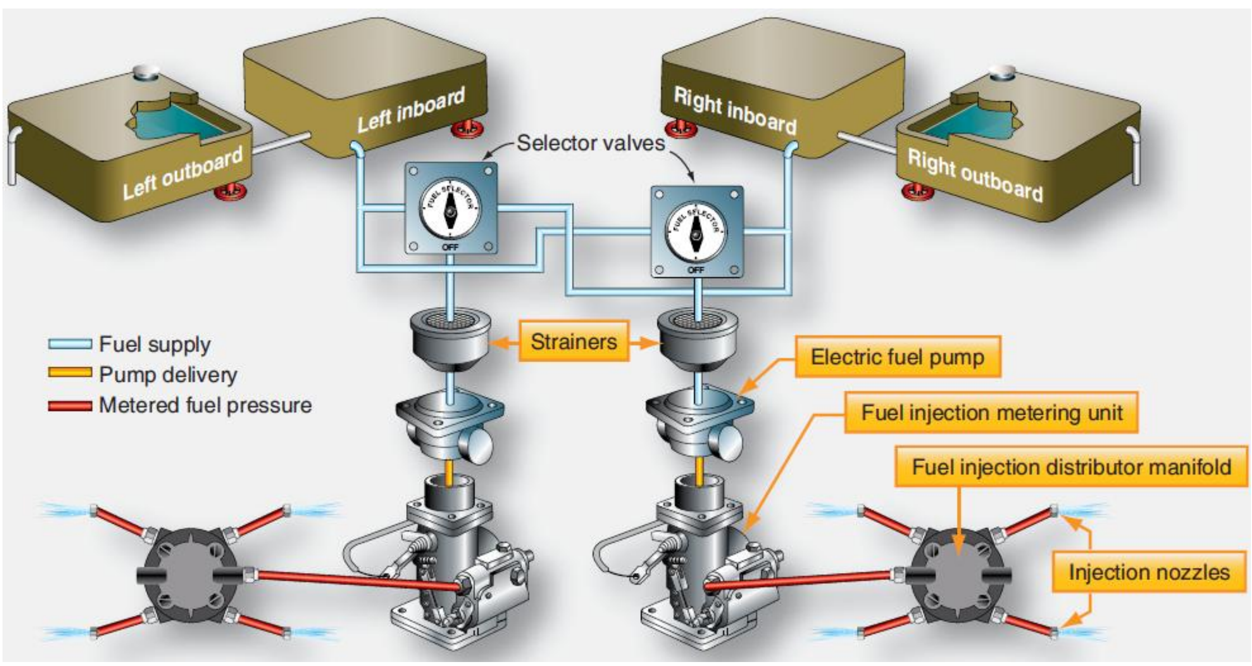
RECIPROCATING ENGINE FUEL SYSTEMS



Low-Wing Twin Engine Light Aircraft Fuel System

- It features the main fuel tanks in the wing tips and auxiliary tanks in the wing structure.
- A boost pump is located at the outlet of each main tank. This pressurizes the entire fuel system from the tank to the injectors.
- Two selector valves are required on twin-engine aircraft, one for each engine. The right selector valve receives fuel from a main tank on either side of the aircraft and directs it to the right engine. The left selector valve also receives fuel from either main tank and directs it to the left engine.

- On some aircraft, the strainer is built into the selector valve unit. From the strainer, fuel flows to the engine-driven fuel pump.
- The engine-driven fuel pump is an assembly that also contains a vapor separator and a pressure regulating valve with an adjustment screw.
- The pump supplies pressurized fuel to the fuel control. The fuel control, one for each engine, responds to throttle and mixture control settings from the cockpit and supplies the proper amount of fuel to the fuel manifold.
- The manifold divides the fuel and sends it to an injector in each cylinder.
- A fuel pressure gauge is placed between the fuel control unit outlet and the manifold to monitor the injector-applied pressure that indicates engine power.



High-Wing Twin Engine Fuel System

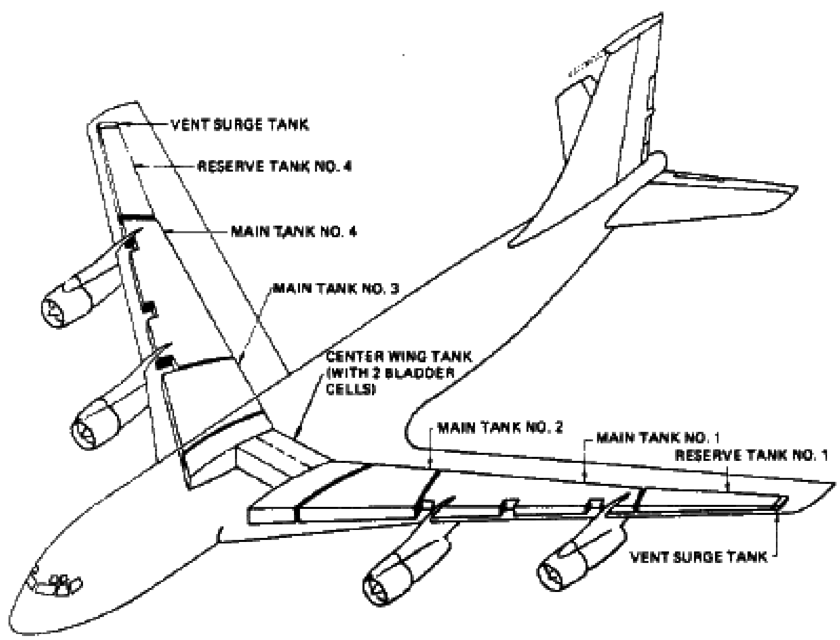
- A simplified system on a high-wing, twin-engine aircraft that combines gravity feed with an electric fuel pump is illustrated.
- The pump draws fuel from the selected tank and sends it under pressure to the inlet side of the fuel injection metering unit.

- The metering unit for each engine provides the proper flow of fuel to the distribution manifold which feeds the injectors.

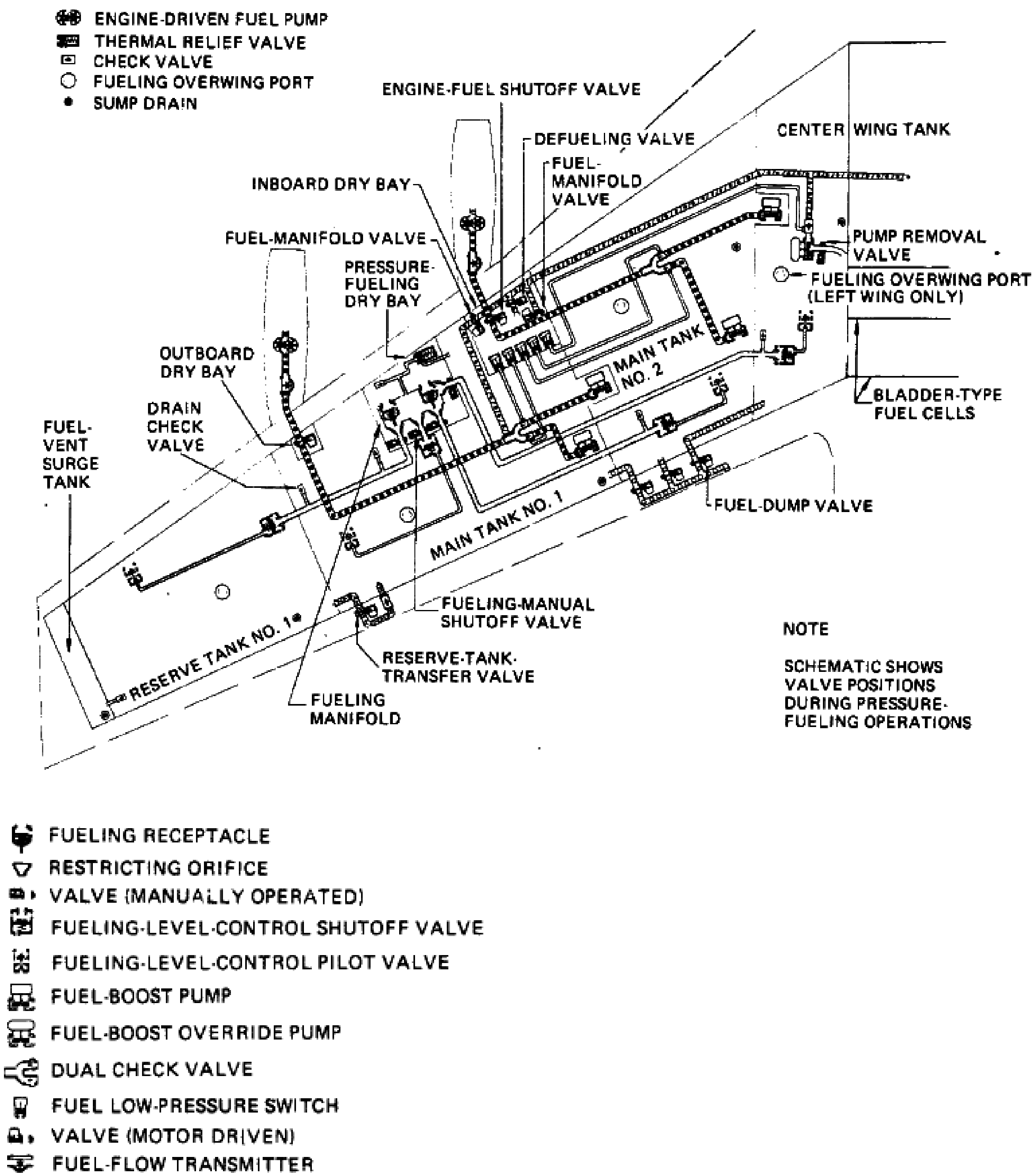
JET ENGINE FUEL SYSTEMS

Jet transport fuel systems include fuel subsystems as follows:

1. Storage
2. Vent
3. Distribution
4. Feed
5. Indicating

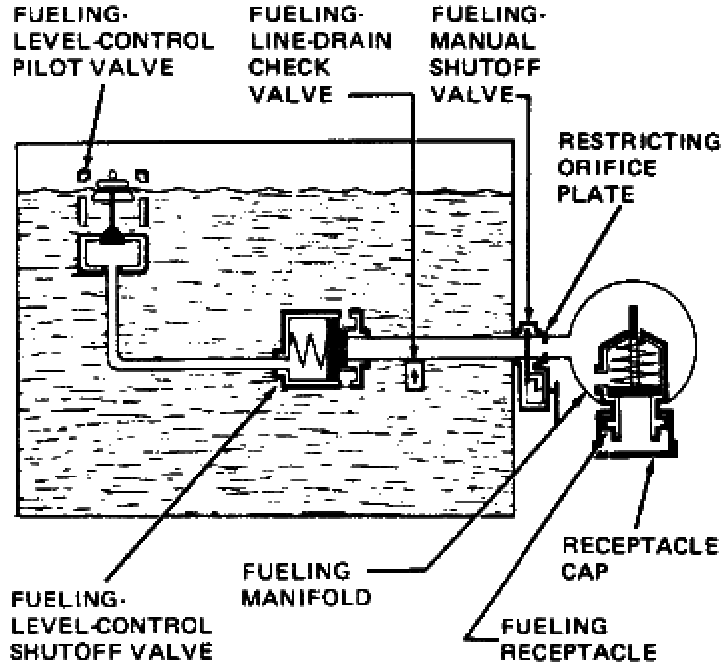


Fuel-tank arrangement for a four-engine turbine aircraft



- **Fueling receptacle:** The attachment for the pressure fueling hose. The receptacle is fitted with a valve that is automatically closed when the fueling hose is disconnected.
- **Restricting orifice:** A flow-limiting device to prevent excessive fuel flow during pressure fueling.

- **Manually operated shutoff valves:** Valves that are provided at the pressure-fueling station to permit a positive closing of fuel lines.



- **Fueling level control shutoff valve:** A valve that automatically closes the fueling line to a tank when that tank is filled to its maximum level.

- **Fueling level control pilot valve:** A valve that closes during pressure fueling when the full fuel level is reached. The closing of this valve causes pressure to be applied to the **f**ueling level control shutoff valve, thus closing it.

- **Motor-driven valve:** Slide valves operated by electric motors. They are used for fuel control throughout the system.

- **Fuel-flow transmitter:** The electrically operated unit that senses the rate of fuel flow to each engine.

- The fuel is distributed in four main tanks, two outboard reserve tanks, and a center-wing tank.

- A **fuel vent system** provides positive venting to the atmosphere of all fuel tanks, fuel cells, and cavities, thereby preventing excessive internal or external pressures across the tank walls during all flight maneuvers.

- The **engine fuel-feed system** consists of fuel lines, pumps, and valves, which distribute the fuel to the engines.

- The fuel-feed line from each main tank is pressurized by two **boost pumps** that are controlled by separate switches and independent circuits.
- The center-wing-tank boost pumps, known as the **fuel-boost-override** pumps, will override the main-tank boost pumps to supply fuel through the manifold to the engines.
- The distribution of fuel to the engines is controlled by electric-motor-driven slide valves in the fuel lines.

The valves are classified into three groups:

(1) **Engine fuel-shutoff valves,** which shut-off fuel to the engines.

(2) Fuel-manifold valves, which control manifold distribution.

(3) Reserve tank transfer valves, which control fuel from the reserve tanks to main tanks 1 and 4.

- The **fuel quantity indicating system** incorporates electric capacitance tank probes mounted internally in each fuel tank.
- The **fuel temperature indicating system** is required to tell when there may be danger of ice crystals forming in the fuel.
- **Pressure defueling** of the main tanks or center-wing tank is accomplished through a defueling valve located in the inboard dry bay of each wing.

2. LUBRICATING SYSTEMS

- The primary purpose of a lubricant is to reduce friction between moving parts.
- As oil circulates through the engine, it absorbs heat from the parts, which provides cooling.
- The oil also aids in forming a seal between the piston and the cylinder wall to prevent leakage of the gases from the combustion chamber.

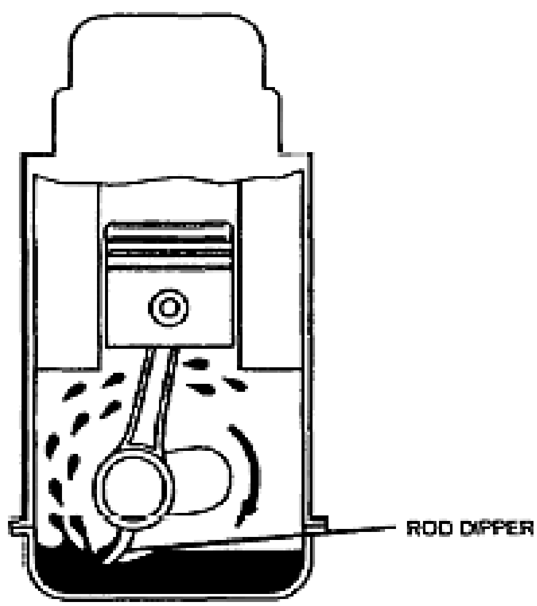
Properties of Reciprocating Engine Lubricants

- **Viscosity**

- **Viscosity Index** (change of viscosity with variations in temperature)
- **Flash Point**
- **Fire Point**
- **Cloud Point**(the temperature below which wax in diesel or biowax in biodiesels form a cloudy appearance)
- **Pour Point** (the temperature at which liquid becomes semi solid and loses its flow characteristics)
- **Specific Gravity(**ratio of the density of a substance to the density of a reference substance)

Reciprocating Engine Lubrication Systems

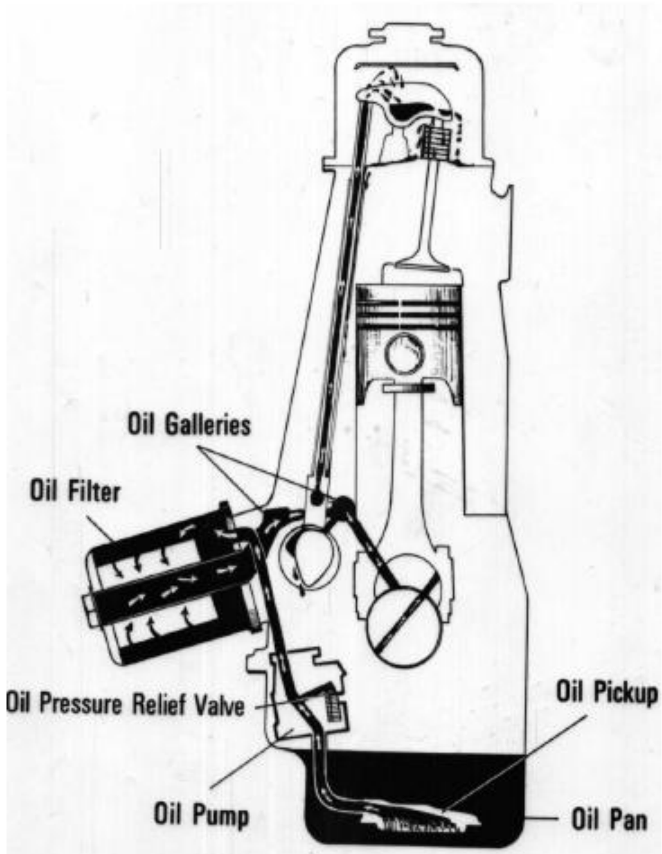
- The **pressure lubrication** system is the principal method of lubricating aircraft engines.
- **Splash lubrication** may be used in addition to pressure lubrication on aircraft engines, but it is never used by itself; aircraft-engine lubrication systems are always either the pressure type or the combination pressure and splash type, usually the latter.



Splash Lubrication system

Pressure Lubrication system

- It uses an oil pump to push oil through oil galleries (passages holes drilled throughout the engine block and components) to all engine parts that need lubrication.



The advantages of pressure lubrication are:

1. Positive introduction of oil to the bearings.

2. Cooling effect caused by the large quantities of oil that can be pumped, or circulated, through a bearing.

3. Satisfactory lubrication in various attitudes of flight.

- Aircraft reciprocating engine pressure lubrication systems can be divided into two basic classifications:

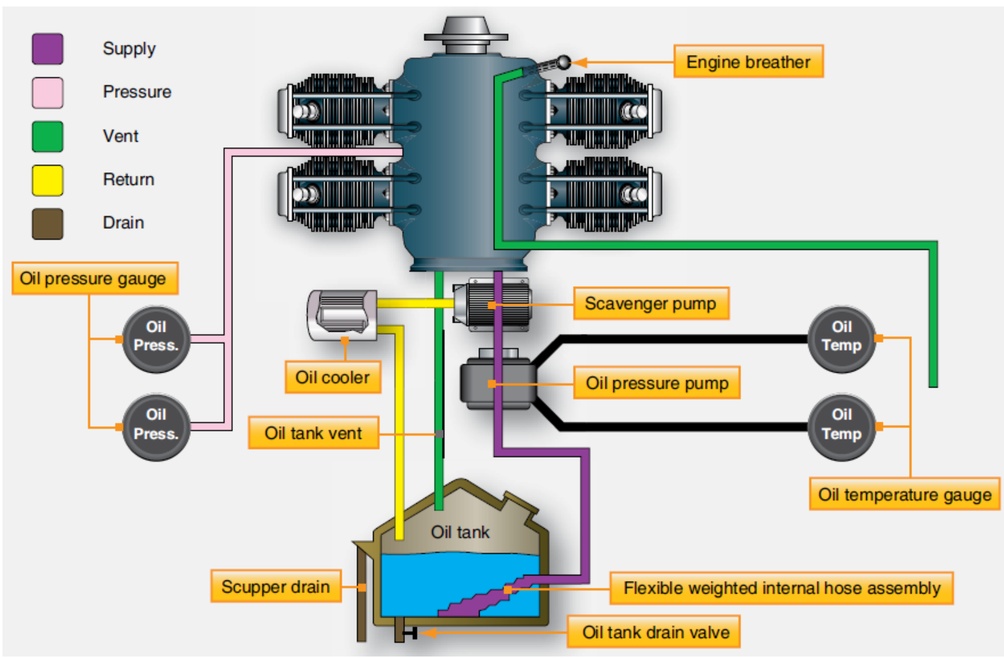
1. **Dry Sump System**
2. **Wet Sump System**

- The wet sump system stores oil in a reservoir inside the engine. After the oil is circulated through the engine, it is returned to this crankcase based reservoir.

- A dry sump engine pumps the oil from the engine's crankcase to an external tank that stores the oil.

DRY SUMP LUBRICATION SYSTEM

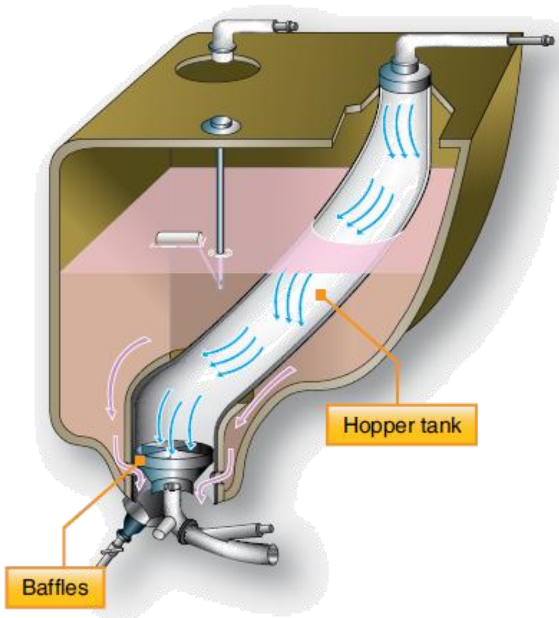
- The oil supply in this type of system is carried in a tank. A pressure pump circulates the oil through the engine. Scavenger pumps then return it to the tank as quickly as it accumulates in the engine sumps.
- A typical reciprocating engine dry sump oil system include an oil supply tank, an engine-driven pressure oil pump, a scavenger pump, an oil cooler with an oil cooler control valve, oil tank vent, necessary tubing, and pressure and temperature indicators.



Oil Tank

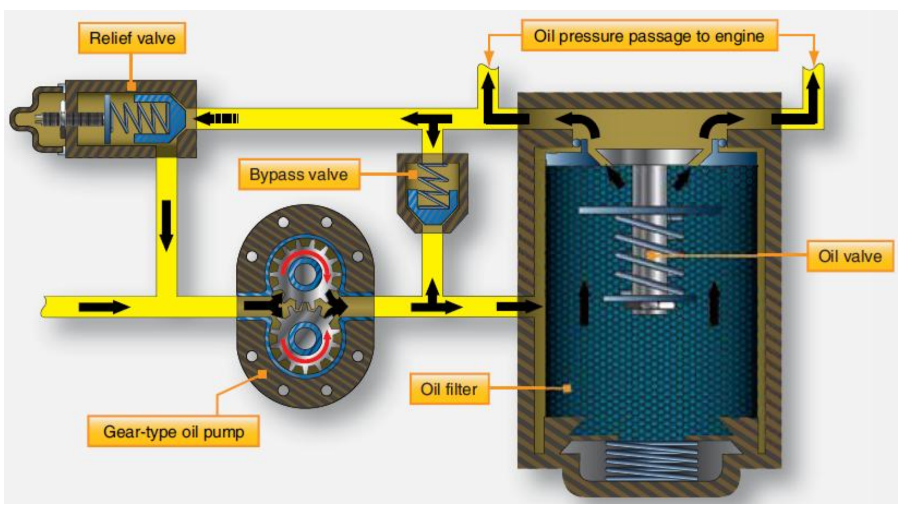
- Oil tanks are usually constructed of aluminum alloy and must withstand any vibration, inertia, and fluid loads expected in operation.
- Oil tank vent lines are provided to ensure proper tank ventilation in all attitudes of flight. These lines are usually connected to the engine crankcase to prevent the loss of oil through the vents.
- To help with engine warm up, some oil tanks had a built in hopper or temperature accelerating well. This well extended from the oil return fitting on top of the oil tank to the outlet fitting in the sump in the bottom of the tank.

- Most aircraft oil systems are equipped with the dipstick-type quantity gauge, often called a bayonet gauge.



Oil Pump

- Oil entering the engine is pressurized, filtered, and regulated by units within the engine.



- As oil enters the engine, it is pressurized by a gear-type pump.
- The pressurized oil flows to the oil filter, where any solid particles suspended in the oil are separated from it. Oil under pressure then opens the oil filter check valve mounted in the top of the filter.

- The spring loading on the bypass valve allows the valve to open before the oil pressure collapses the filter.

Oil Filters

- The oil filters used on aircraft engines are usually three types:

  (1) Screen filters

  (2) Cuno filters

  (3) Air-Maze filters

- A **screen-type** filter with its double-walled construction provides a large filtering area in a compact unit.
- As oil passes through the fine-mesh screen, dirt, sediment, and other foreign matter are removed and settle to the bottom of the housing.
- The **Cuno oil filter** has a cartridge made of disks and spacers.

- A cleaner blade fits between each pair of disks. The cleaner blades are stationary, but the disks rotate when the shaft is turned.
- Oil from the pump enters the cartridge well that surrounds the cartridge and passes through the spaces between the closely spaced disks of the cartridge, then through the hollow center, and on to the engine.
- Any foreign particles in the oil are deposited on the outer surface of the cartridge.
- **The Air-Maze filter** contains a series of round, fine-meshed screens mounted on a hollow shaft.

- The oil from the pump enters the well, surrounds the screens, and then passes through them and the shaft before entering the engine.
- The carbon deposits that collect on the screens actually improve their filtering efficiency.

Oil Pressure Relief Valve

- An oil pressure relief valve limits oil pressure to a predetermined value, depending on the installation.
- The oil pressure must be sufficiently high to ensure adequate lubrication of the engine and its accessories at high speeds and powers.

Oil Pressure Gauge

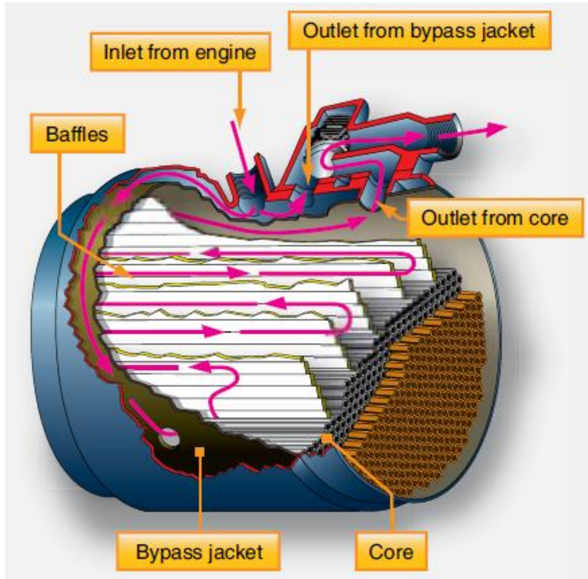
- The oil pressure gauge indicates the pressure that oil enters the engine from the pump. This gauge warns of possible engine failure caused by an exhausted oil supply, failure of the oil pump, burned-out bearings, ruptured oil lines, or other causes that may be indicated by a loss of oil pressure.
- One type of oil pressure gauge uses a Bourdon-tube mechanism that measures the difference between oil pressure and cabin, or atmospheric, pressure.

Oil Temperature Indicator

- Oil systems for wet-sump engines have the temperature bulb located where it senses oil temperature after the oil passes through the oil cooler.

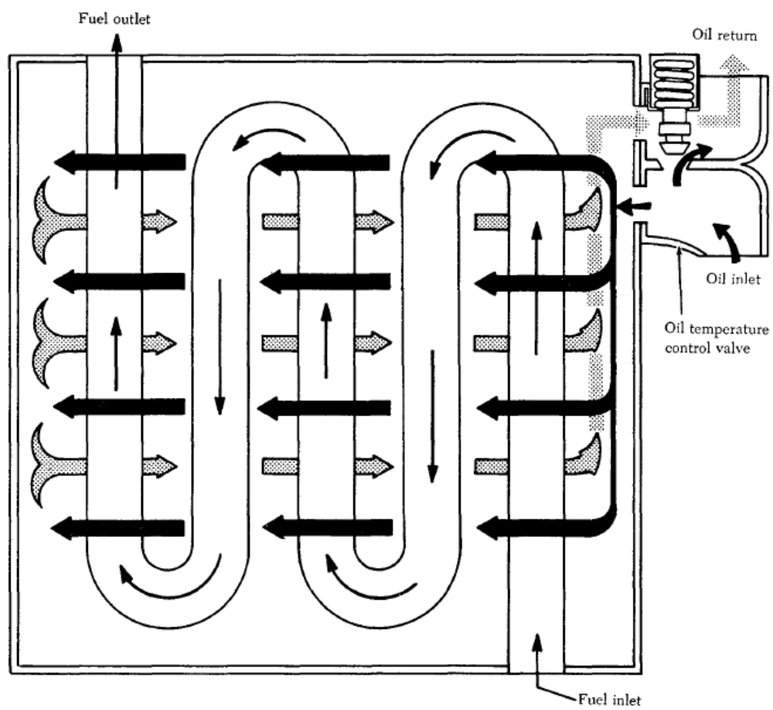
Oil Cooler

- The cooler, either cylindrical or elliptical shaped, consists of a core enclosed in a double-walled shell.



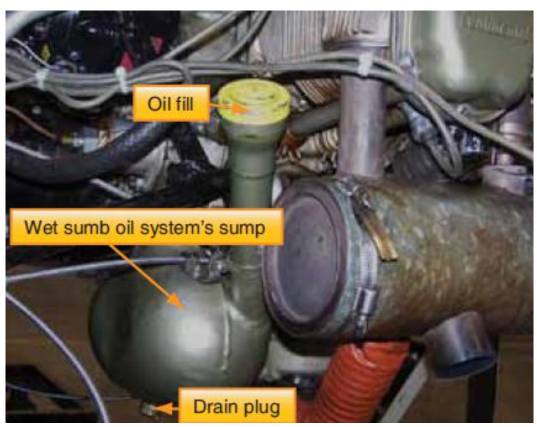
- The core is built of copper or aluminum tubes with the tube ends formed to a hexagonal shape and joined together in the honeycomb effect.
- The tubes touch only at the ends so that a space exists between them along most of their lengths.
- This allows oil to flow through the spaces between the tubes while the cooling air passes through the tubes.

Fuel/Oil Heat Exchanger



WET SUMP LUBRICATION SYSTEM

- Wet sump system consists of a sump or pan in which the oil supply is contained. The oil supply is limited by the sump (oil pan) capacity.
- In the bottom of the sump, there is a screen strainer having a suitable mesh, or series of openings, to strain undesirable particles from the oil.



- The rotation of the pump, which is driven by the engine, causes the oil to pass around the outside of the gears.
- This develops a pressure in the crankshaft oiling system (drilled passage holes).

- The parts oiled by pressure throw a lubricating spray into the cylinder and piston assemblies.
- After lubricating the various units it sprays, the oil drains back into the sump and the cycle is repeated.

The main disadvantages of the wet-sump system are:

(1)The oil supply is limited by the sump (oil pan) capacity.

(2) Provisions for cooling the oil are difficult to arrange because the system is a self-contained unit.

(3) Oil temperatures are likely to be higher on large engines because the oil supply is so close to the engine and is continuously subjected to the operating temperatures.

(4) The system is not readily adaptable to inverted flying since the entire oil supply will flood the engine.

TURBINE ENGINE LUBRICATION SYSTEM

Requirements of Turbine Engine Lubricants

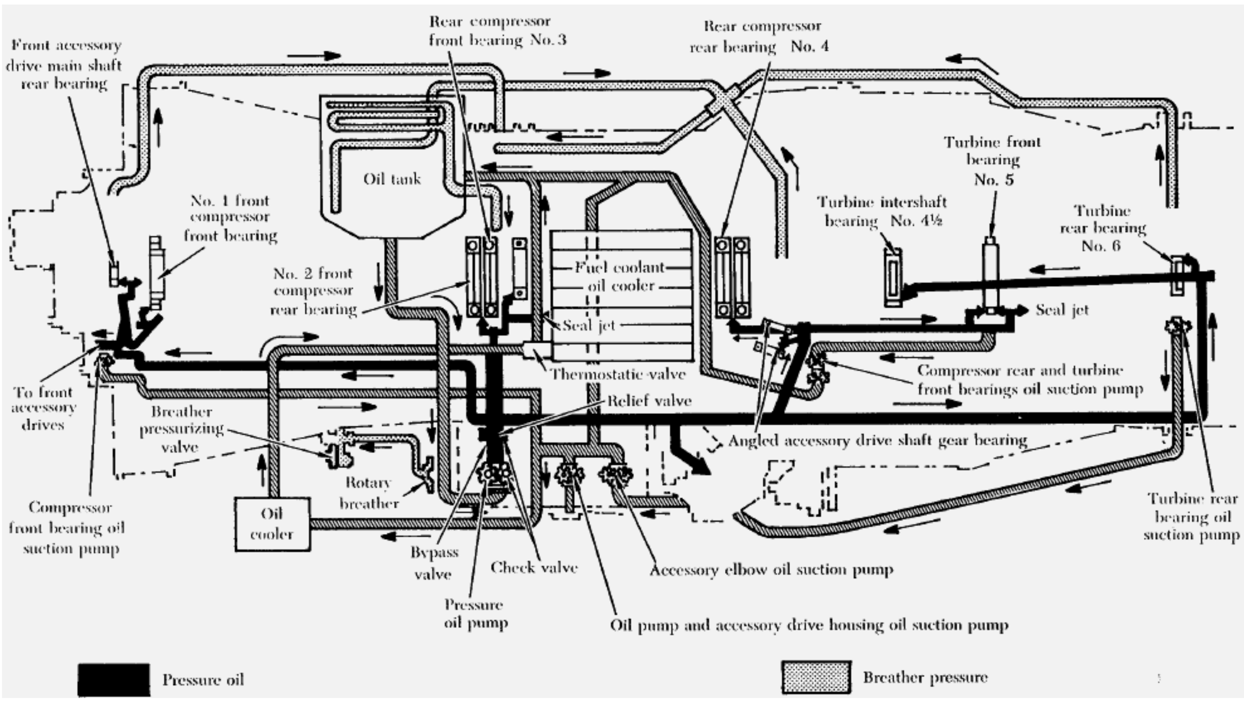
- Due to the absence of reciprocating motion and the presence of ball and roller bearings, the turbine engine **uses a less viscous lubricant**.
- The **turboprop engine**, while using essentially the same type of oil as the turbojet, must **use a higher viscosity oil** because of the higher bearing pressures introduced by the highly loaded propeller reduction gearing.
- Synthetic oil has two principal advantages over petroleum oil. It has less tendency to deposit lacquer and coke and less tendency to evaporate at high temperature.

Both wet- and dry-sump lubrication systems are used in gas turbine engines. Wet-sump engines store the lubricating oil in the engine proper. while dry-sump engines utilize an external tank mounted most generally on the engine or somewhere in the aircraft structure near the engine. The use of cooling air on bearings and turbines eliminates the necessity of using oil coolers in the wet-sump lubrication systems

Turbojet Dry Sump Lubrication System

- Although the dry-sump systems use an oil tank which contains most of the oil supply: a small sump usually is included on the engine to hold a small supply of oil.

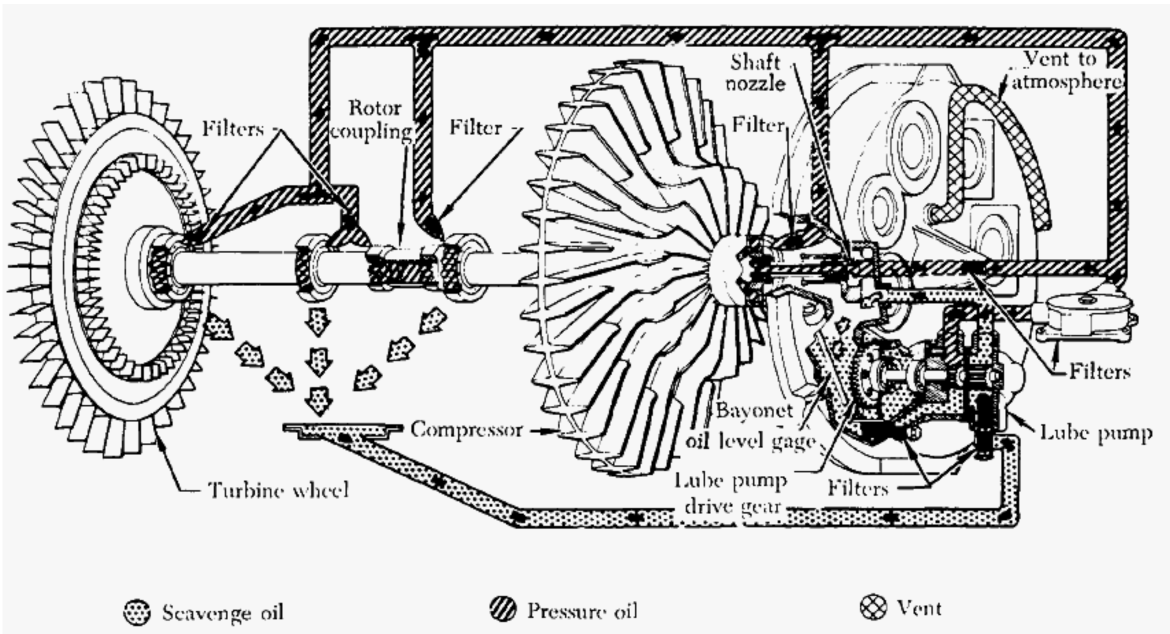
- It usually contains the oil pump, the scavenge and pressure inlet strainers, scavenge return connection, pressure outlet ports, an oil filter, and mounting bosses for the oil pressure gage and temperature bulb connections.
- An oil cooler is usually included in a dry-sump oil system This cooler may be air cooled or fuel cooled.



- **Oil Pumps-** gear, gerotor or piston type
- **Filters-** common type of oil filter uses a replaceable laminated paper element
- **Oil Pressure Relief Valve**
- **Oil Jets-** oil from these nozzles is delivered in the form of an atomized spray to the bearing compartments and rotor shaft couplings
- **Gauge Connections-** To measure Pressure and temperature
- **System Vents**
- **Check Valve**
- **Thermostatic Bypass Valves**
- **Oil Coolers**

Turbine Engine Wet Sump Lubrication System

- There are relatively few engines using a wet-sump type of oil system, because only a few models of centrifugal-flow engines are in operation.
- The reservoir for the wet-sump oil system may be either the **accessory gear case**, or it may be a sump mounted on the bottom of the accessory case.



Components:

(1) A bayonet-type gauge indicates the oil level in the sump.

(2) Two or more finger strainers (filters) are inserted in the accessory case for straining pressure and scavenged oil just before it leaves or enters the sump.

(3) A vent or breather equalizes pressure within the accessory casing.

(4) A magnetic drain plug may be provided to drain the oil and also to trap any ferrous metal particles in the oil.

(5) Provision may also be made for a temperature bulb and an oil pressure fitting.

(6) The bearing and drive gears in the accessory drive casing are lubricated by a splash system.

(7) The oil for the remaining points of lubrication leaves the pump under pressure and passes through a filter to jet nozzles that direct the oil into the rotor bearings and couplings.

(8) The scavenged oil is returned to the reservoir (sump) by gravity and by pump suction.

3. STARTING SYSTEMS

- Most aircraft engines are started by a device called a starter.
- A starter is a mechanism capable of developing large amounts of mechanical energy that can be applied to an engine, causing it to rotate.
- Reciprocating engines need only to be turned through at a relatively slow speed until the engine starts and turns on its own.
- Once the reciprocating engine has fired and started, the starter is disengaged and has no further function until the next start.
- In the case of a turbine engine, the starter must turn the engine up to a speed that provides enough airflow through the engine for fuel to be ignited. Then, the starter must continue to help the engine accelerate to a self-sustaining speed.

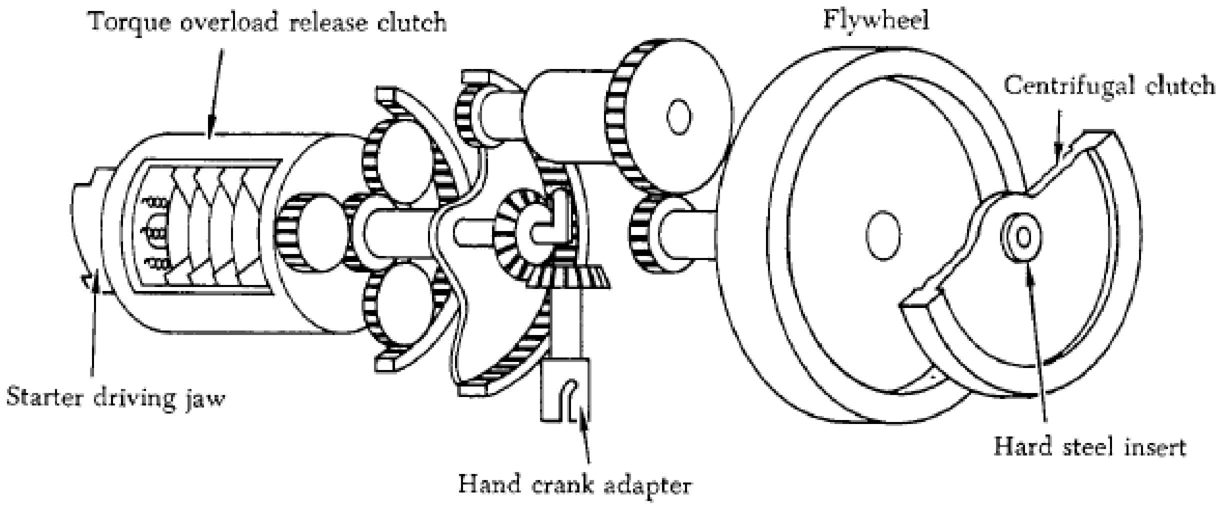
Reciprocating Engine Starting System

- **Inertia Starters**
    - Hand
    - Electric
    - Combination hand and electric
- **Direct Cranking Electric Starter**

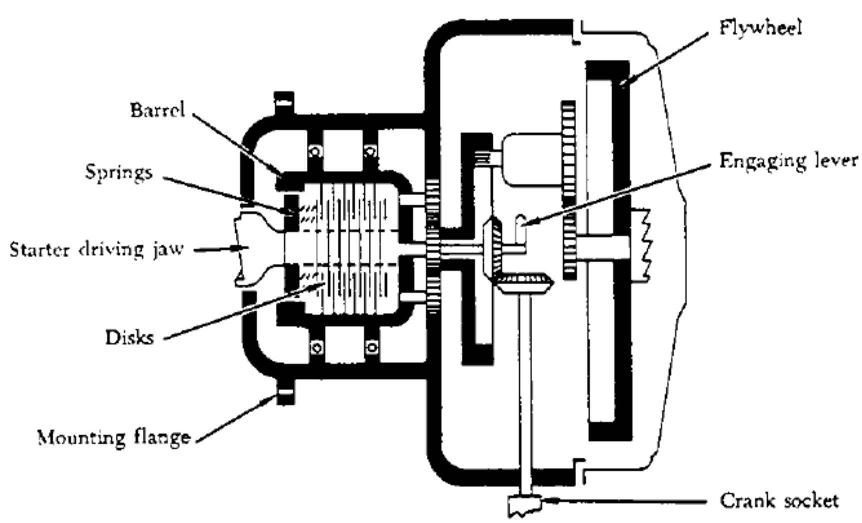
Inertia Starters

- The operation of all types of inertia starters depends on the kinetic energy stored in a rapidly rotating flywheel for cranking ability.
- In the inertia starter, energy is stored slowly during an energizing process by a manual hand crank or electrically with a small motor.
- During the energizing of the starter, all movable parts within it, including the flywheel, are set in motion.

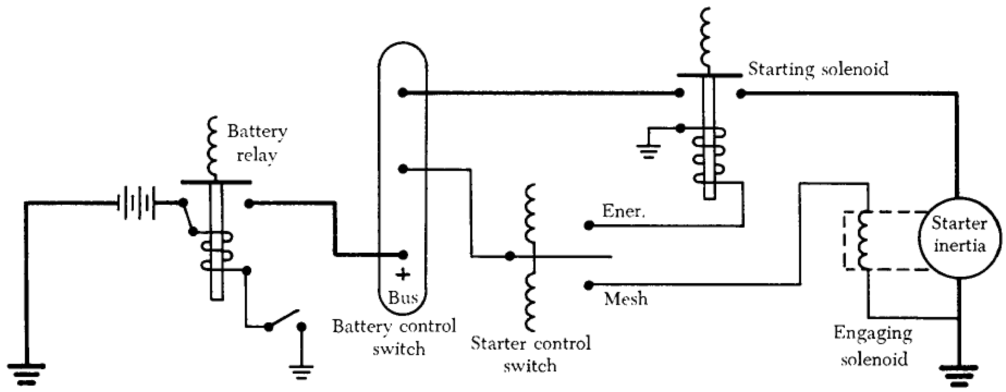
- After the starter has been fully energized, it is engaged to the crankshaft of the engine by a cable pulled manually or by a meshing solenoid that is energized electrically.
- When the starter is engaged, or meshed, flywheel energy is transferred to the engine through sets of reduction gears and a torque overload release clutch.



The flywheel and movable gears of a combination hand electric inertia starter.



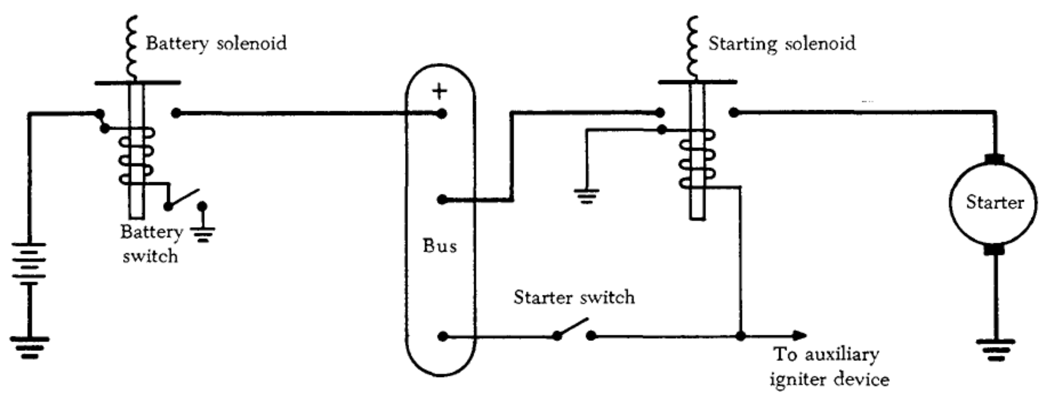
Torque overload release clutch



The electrical circuit for an electric inertia starter

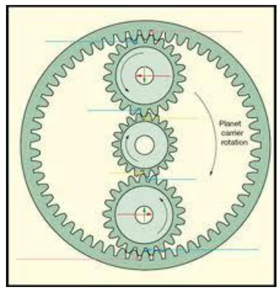
Direct Cranking Electric Starter

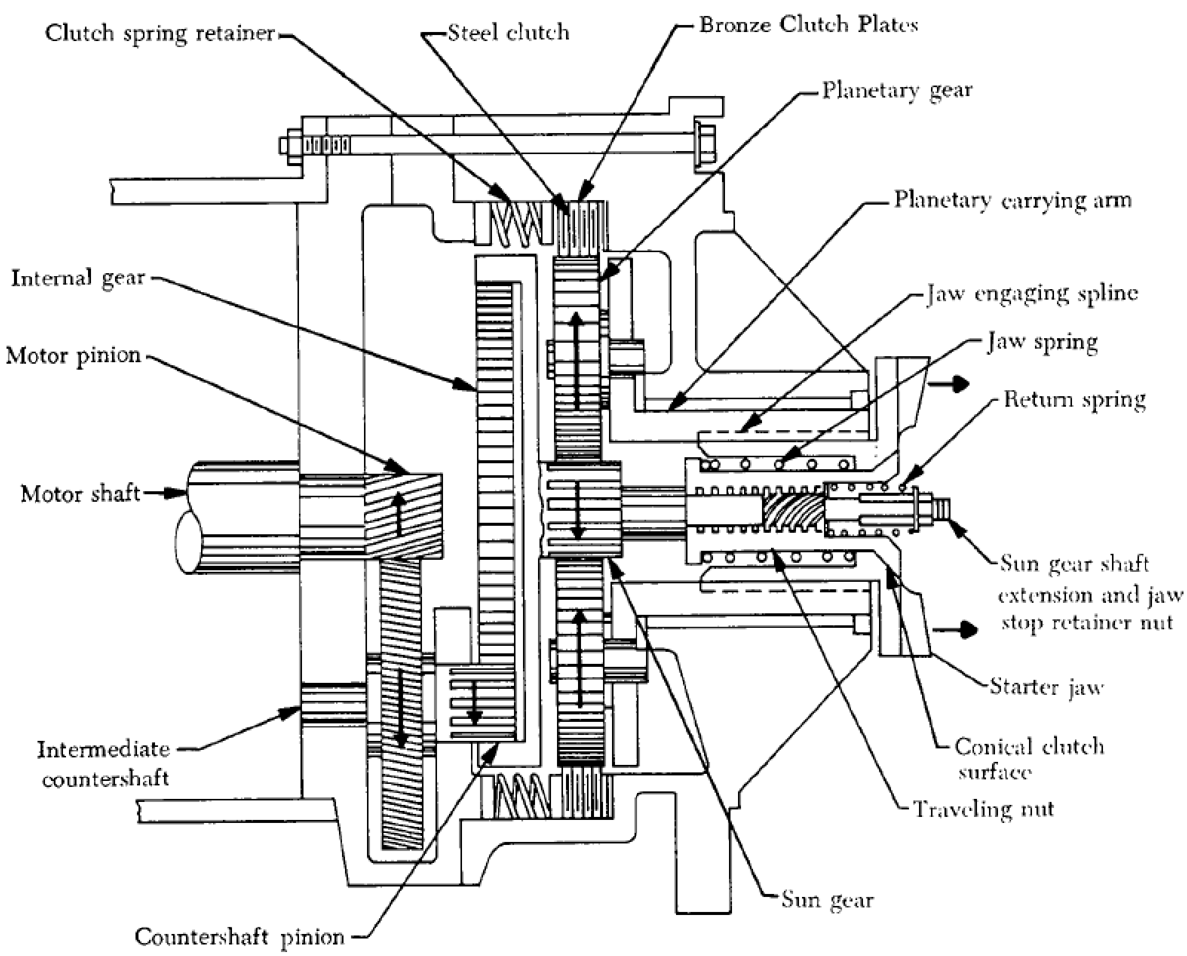
- The most widely used starting system on all types of reciprocating engines utilizes the direct cranking electric starter.
- It consists basically of an electric motor, reduction gears, and an automatic engaging and disengaging mechanism that is operated through an adjustable torque overload release clutch.



- The engine is cranked directly when the starter solenoid is closed.
- The typical starter motor is a 12- or 24-volt, series-wound motor that develops high starting torque.
- The torque of the motor is transmitted through reduction gears to the overload release clutch.
- Typically, this action actuates a helically splined shaft moving the starter jaw outward to engage the engine cranking jaw before the starter jaw begins to rotate. After the engine reaches a predetermined speed, the starter automatically disengages.
- In a typical high horsepower reciprocating engine starting system, the direct cranking electric starter consists of two basic components: **a motor assembly** and **a gear section**.

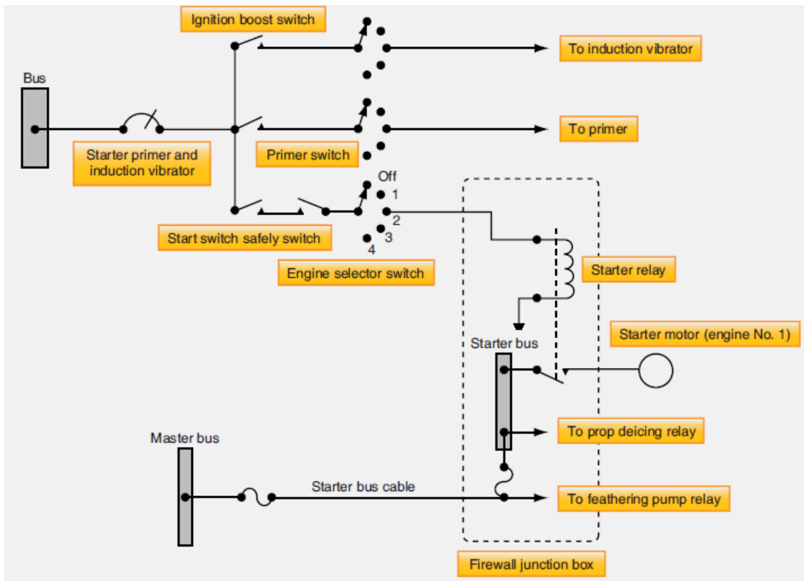
- The gear section is bolted to the drive end of the motor to form a complete unit.
- The motor assembly consists of the armature and motor pinion assembly, the end bell assembly, and the motor housing assembly. The motor housing also acts as the magnetic yoke for the field structure.
- The starter motor is a nonreversible and its speed varies directly with the applied voltage and inversely with the load.
- The starter gear section consists of an external housing with an integral mounting flange, planetary gear reduction, a sun and integral gear assembly, a torque-limiting clutch, and a jaw and cone assembly.





Starter gear section

- When the starter circuit is closed, the torque developed in the starter motor is transmitted to the starter jaw through the reduction gear train and clutch.
- The starter gear train converts the high speed low torque of the motor to the low speed high torque required to crank the engine.
- The pinion of the countershaft engages the internal gear which is rigidly attached to the sun gear shaft.



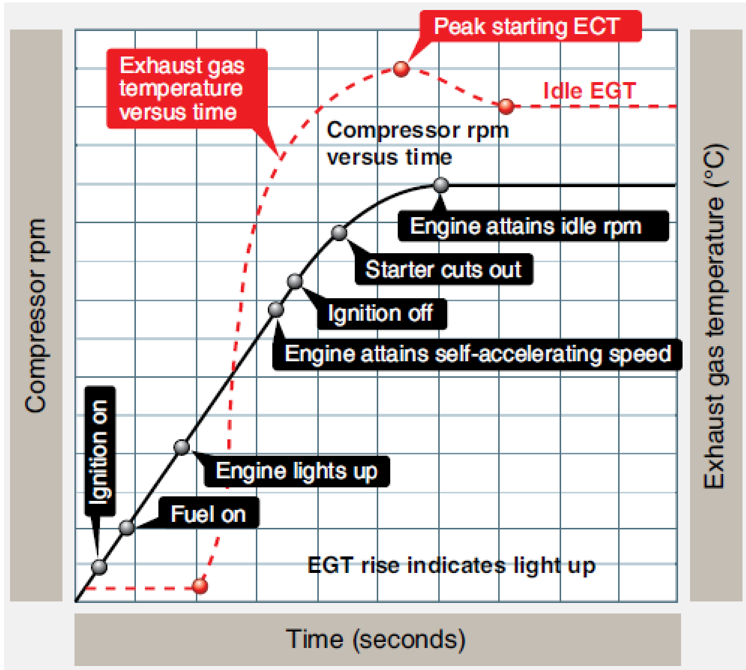
Starter control circuit

- The engine selector switch must be positioned and the starter switch and the safety switch—wired in series—must be closed before the starter can be energized.
- Current is supplied to the starter control circuit through a circuit breaker labeled "Starter, Primer, and Induction Vibrator."
- When the engine selector switch is in position for the engine start, closing the starter energizes the starter relay and completes the power circuit to the starter motor.

Gas Turbine Engine Starting System

- Gas turbine engines are started by rotating the compressor. On dual-axial-compressor engines, the high-pressure compressor is the only one rotated by the starter.
- To start a gas turbine engine it is necessary to accelerate the compressor to provide sufficient air to support combustion in the burners.

- Once fuel has been introduced and the engine has fired, the starter must continue to assist the engine to reach a speed above the self-accelerating speed of the engine.



Typical gas turbine engine starting sequence

- **Electric starting system**
  - **Direct cranking electrical systems**
  - **Starter generator systems**
- **Air turbine starters**
- **Cartridge / pneumatic turbine engine starter**
- **Fuel/air combustion turbine starter**

Electric starting system

- The starter generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct cranking starter must employ some means of disengaging the starter from the shaft after the engine has started.

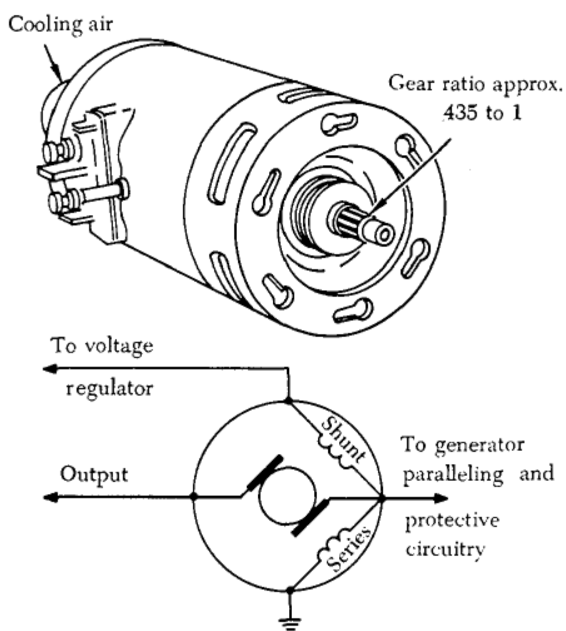
Direct Cranking Electrical System

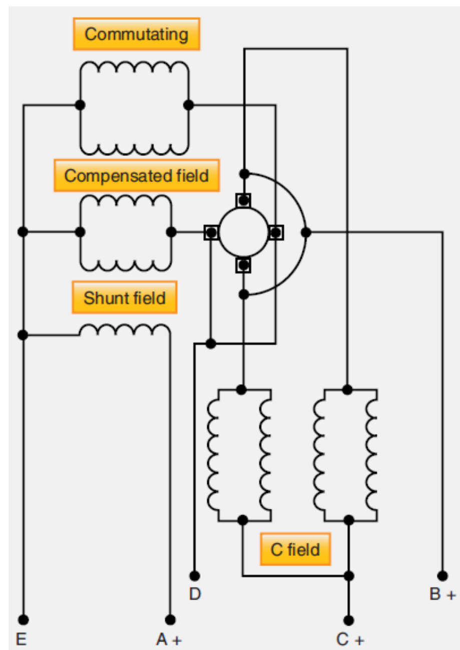
- On some direct-cranking starters used on gas turbine engines, no overload release clutch or gear reduction mechanism is used.

- This is because of the low torque and high speed requirement for starting gas turbine engines.

Starter generator systems

- These starting systems use a combination starter-generator which operates as a starter motor to drive the engine during starting; and, after the engine has reached a self-sustaining speed, operates as a generator to supply the electrical system power.
- The starter-generator unit is basically a shunt generator with an **additional heavy series winding**. This series winding is electrically connected to produce a strong field and a resulting high torque for starting.
- It is economic since one unit performs the functions of both starter and generator. Additionally, the total weight of starting system components is reduced.





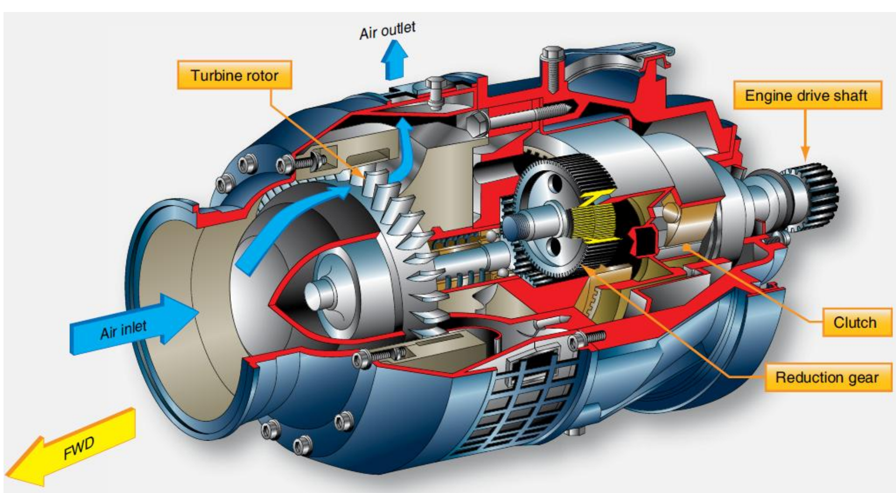
Internal circuit

- During starting, the series ("C" field), compensating, and commutating windings are used.
- While acting as a starter, the unit makes no practical use of its shunt field. A source of 24 volts and 1,500 amperes is usually required for starting.
- When operating as a generator, the shunt, compensating, and commutating windings are used.
- The "C" field is used only for starting purposes.
- The shunt field is connected in the conventional voltage control circuit for the generator.

- Compensating and commutating windings provide almost sparkless commutation from no load to full load.

Air Turbine Starters

- The air turbine starters are designed to provide high starting torque from a small, lightweight source.
- The typical air turbine starter weighs from one-fourth to one-half as much as an electric starter capable of starting the same engine. It is capable of developing twice as much torque as the electric starter.
- The typical air turbine starter consists of an axial flow turbine which turns a drive coupling through a reduction gear train and a starter clutch mechanism.
- The air to operate an air turbine starter is supplied from ground-operated compressor, APU or the bleed air from another engine.
- Auxiliary compressed-air bottles are available on some aircraft for operating the air turbine starter.
- The starter is operated by introducing air of sufficient volume and pressure into the starter inlet.
- The air passes into the starter turbine housing, where it is directed against the rotor blades by the nozzle vanes, causing the turbine rotor to turn.
- As the rotor turns, it drives the reduction gear train and clutch arrangement, which includes the rotor pinion, planet gears and carrier, clutch assembly, output shaft assembly, and drive coupling.

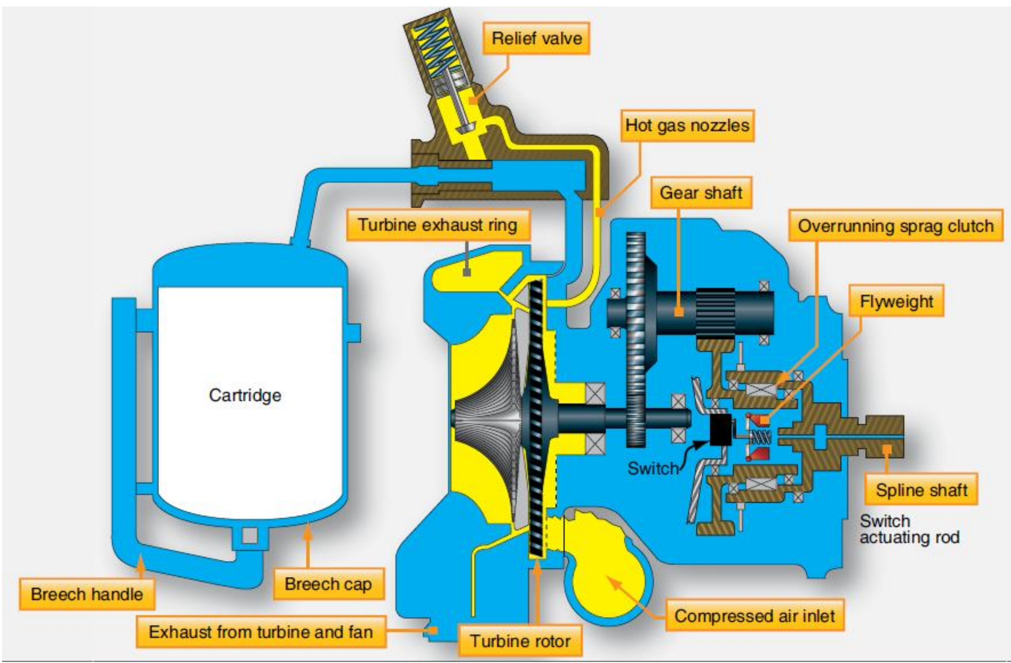


- The sprag clutch assembly engages automatically as soon as the rotor starts to turn, but disengages as soon as the drive coupling turns more rapidly than the rotor side.

- A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when the starter reaches cutout speed.
- Opening the turbine switch interrupts an electrical signal to the pressure-regulating valve. This closes the valve and shuts off the air supply to the starter.

Cartridge / Pneumatic Turbine Engine Starter

- The turbine engine cartridge starter, sometimes called the solid-propellant starter, is used on some large turbine engines.
- must be constructed to withstand the high temperatures resulting from burning a solid-propellant charge to supply the energy for starting.
- Protection is also provided, against excessive torque pressures and over speeding of the starter turbine.

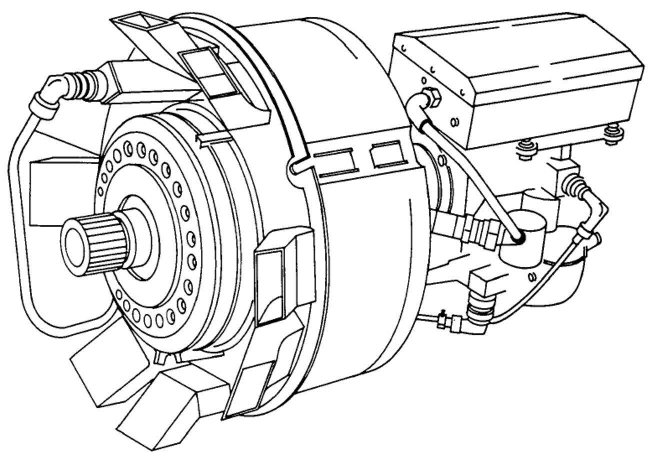


- To accomplish a cartridge start, a cartridge is first placed in the breech cap.
- The breech is then closed on the breech chamber by means of the breech handle and then rotated a partial turn to engage the lugs between the two breech sections.
- The cartridge is ignited by applying voltage through the connector at the end of the breech handle.

- Upon ignition, the cartridge begins to generate gas. The gas is forced out of the breech to the hot gas nozzles that are directed toward the buckets of the turbine rotor by vanes placed around the ring, and rotation is produced via the overboard exhaust collector.

Fuel/Air Combustion Turbine Starter

- The fuel/air combustion starter is used to start both turbojet and turboprop engines by using the combustion energy of conventional jet engine fuel and compressed air.
- The starter consists of a turbine-driven power unit and auxiliary fuel, air, and ignition systems.
- The combustion starter is a gas turbine engine which delivers its power through a high-ratio reduction gear system.
- The compressed air is normally stored in a shatter-proof cylinder near the combustion gas turbine.



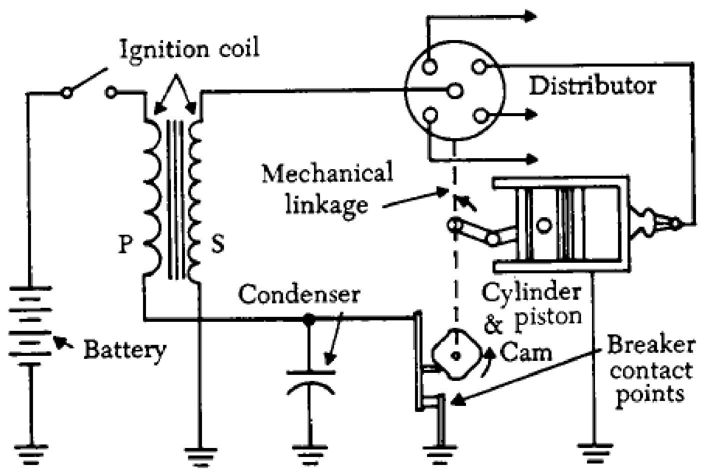
4. IGNITION SYSTEMS

Reciprocating Engine Ignition System

- All ignition systems must deliver a high-tension to each cylinder of the engine in firing order at a predetermined number of degrees ahead of the top dead center position of the piston.
- The voltage output of the system must be such that the spark will jump the gap in the spark plug under all operating conditions.
- Ignition systems can be divided into two classifications: battery-ignition or magneto-ignition systems.

Battery Ignition System

- In this system, the source of energy is a battery or generator.
- This system is similar to that used in most automobiles. A cam driven by the engine opens a set of points to interrupt the flow of current in a primary circuit.
- And because of more turns of the secondary, the resulting collapsing magnetic field induces a high voltage in the secondary of the ignition coil, which is directed by a distributor to the proper cylinder.



Magneto Ignition System

- The magneto, a special type of engine-driven a.c. generator, uses a permanent magnet as a source of energy.
- The magneto develops the high voltage which forces a spark to jump across the spark plug gap in each cylinder.
- Aircraft magneto ignition systems can be classified as either high tension or low tension.

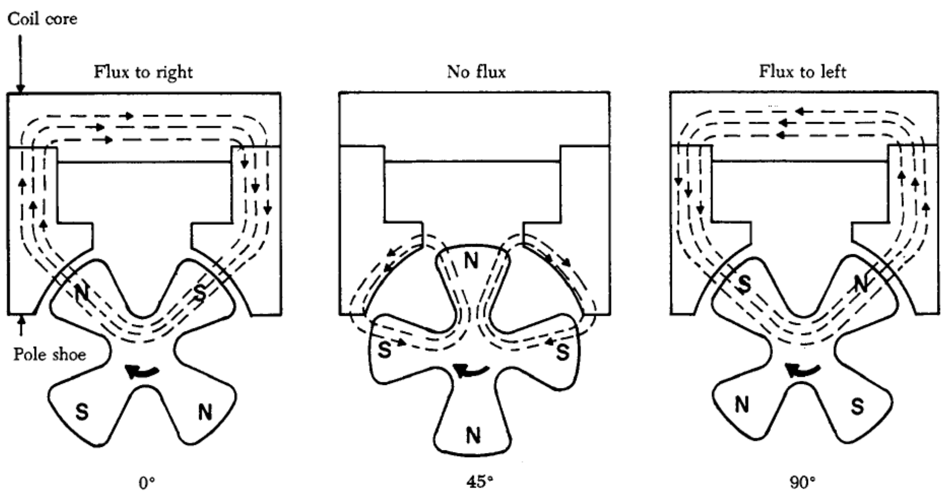
High Tension Magneto System

The high-tension magneto system can be divided into three distinct circuits:

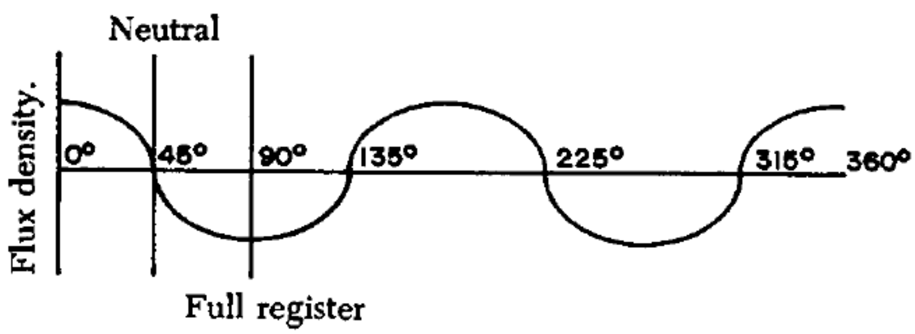
- Magnetic circuit
- Primary electrical circuit
- Secondary electrical circuit

Magnetic Circuit

- The magnetic circuit consists of a permanent multi-pole rotating magnet, a soft iron core, and pole shoes.
- The magnet is geared to the aircraft engine and rotates in the gap between two pole shoes to furnish the magnetic lines of force (flux) necessary to produce an electrical voltage.



Magnetic flux at three positions of the rotating magnet.

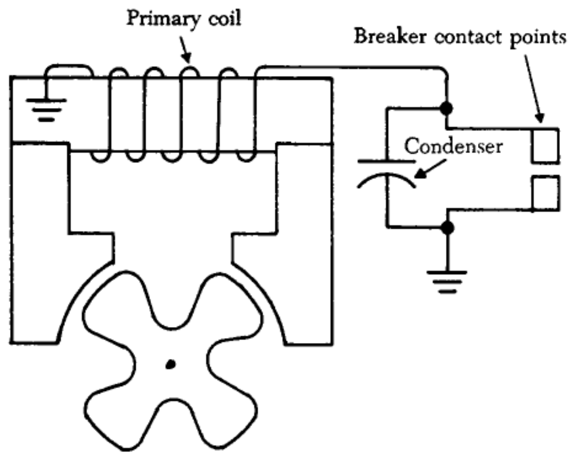


Change in flux density as magnet rotates

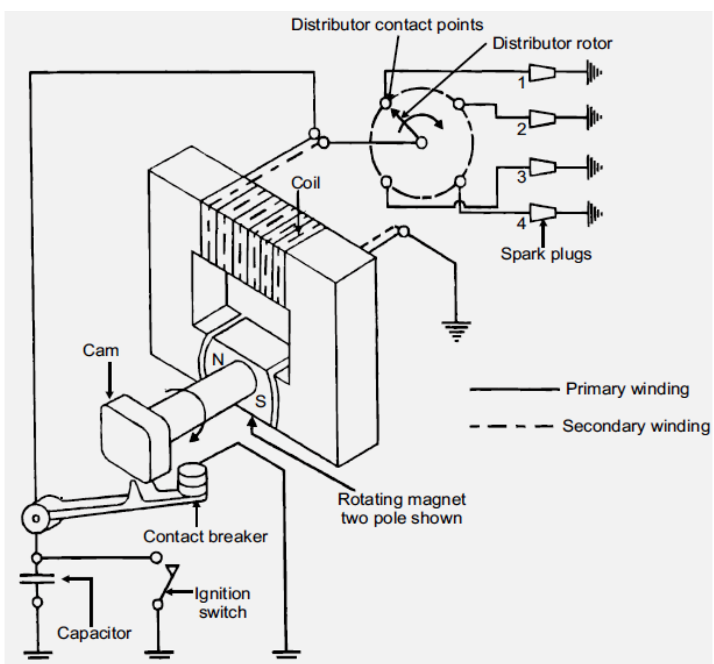
Primary Electric Circuit

- The primary electrical circuit consists of a set of breaker contact points, a condenser, and an insulated coil.
- The coil is made up of a few turns of heavy copper wire, one end of which is grounded to the coil core, and the other end to the ungrounded side of the breaker points.
- The primary circuit is complete only when the ungrounded breaker point contacts the grounded breaker point.

- The condenser (capacitor), is wired in parallel with the breaker points. It prevents arcing at the points when the circuit is opened, and hastens the collapse of the magnetic field about the primary coil.



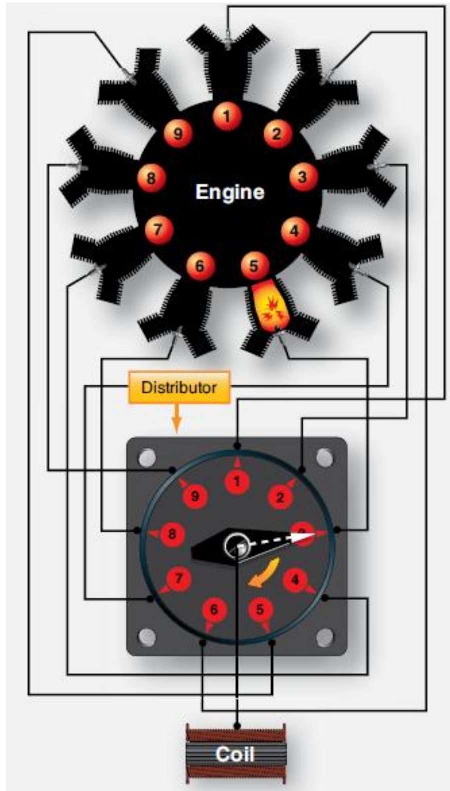
- The primary breaker closes at approximately full-register position. When the breaker points are closed, the rotating magnet will induce current flow in the primary circuit.
- This current flow generates its own magnetic field, which is in such a direction that it opposes any change in the magnetic flux of the permanent magnet's circuit (by Lenz's law).
- Thus, the current flowing in the primary circuit holds the flux in the core at a high value in one direction until the rotating magnet has time to rotate through the neutral position to a point a few degrees beyond neutral (E-gap position).



- With the magnetic rotor in E-gap position and the primary coil holding the magnetic field of the magnetic circuit in the opposite polarity, a very high rate of flux change can be obtained by opening the primary breaker points.
- Opening the breaker points stops the flow of current in the primary circuit, and allows the magnetic rotor to quickly reverse the field through the coil core.
- This sudden flux reversal produces a high rate of flux change in the core, which cuts across the secondary coil of the magneto, inducing the pulse of high-voltage current in the secondary needed to fire a spark plug.
- As the rotor continues to rotate to approximately full-register position, the primary breaker points close again and the cycle is repeated to fire the next spark plug in firing order.

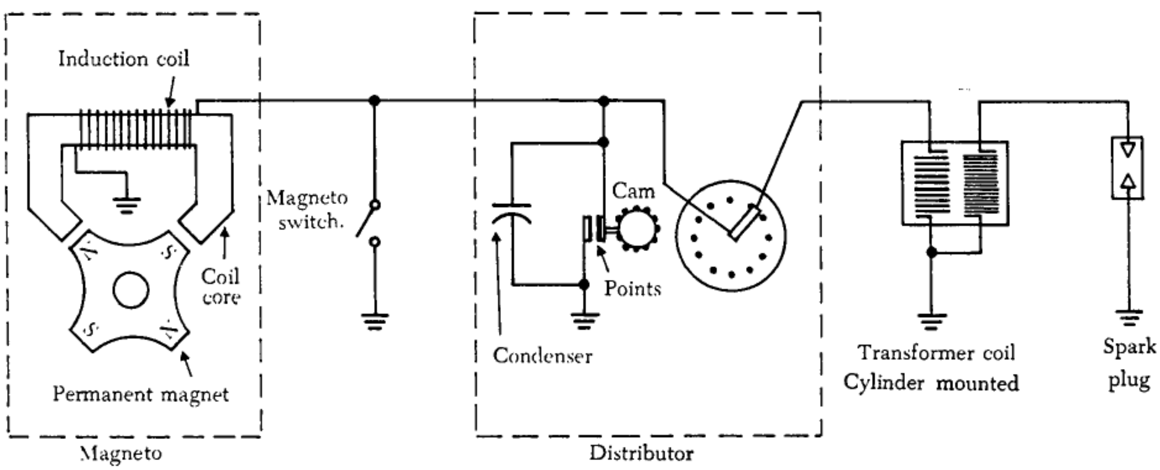
Secondary Electric Circuit

- The secondary circuit contains the secondary windings of the coil, distributor rotor, distributor cap, ignition lead, and spark plug.
- The secondary coil is made up of a winding containing approximately 13,000 turns of fine, insulated wire; one end of which is electrically grounded to the primary coil or to the coil core and the other end connected to the distributor rotor.
- The primary and secondary coils are encased in a non-conducting material. The whole assembly is then fastened to the pole shoes with screws and clamps.
- The high voltage induced in the secondary coil is directed to the distributor, which consists a rotating part, which may take the shape of a disk made of a non-conducting material with an embedded conductor.
- The stationary part consists of a block also made of non-conducting material that contains terminals and terminal receptacles into which the wiring that connects the distributor to the spark plug is attached.



Low Tension Magneto System

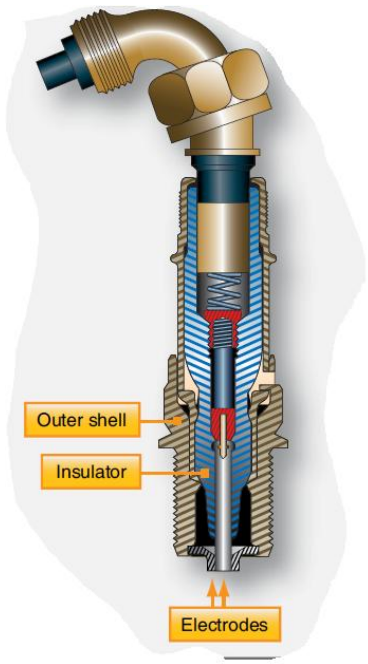
- In the low-tension system, low-voltage is generated in the magneto and flows to the primary winding of a transformer coil located near the spark plug. There the voltage is increased to a high voltage by transformer action and conducted to the spark plug.

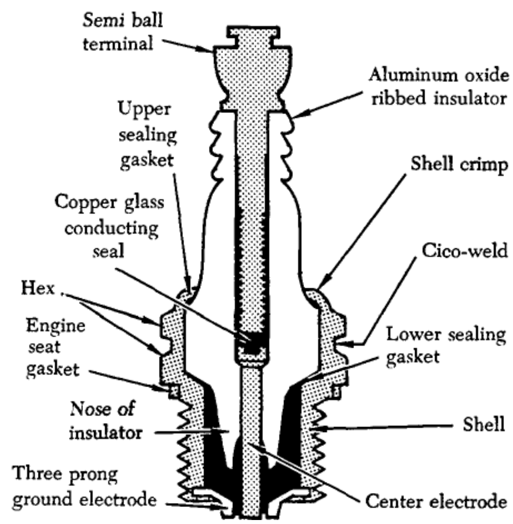


Spark Plugs

- The function of the spark plug in an ignition system is to conduct a short impulse of high voltage current through the wall of the combustion chamber.

- Inside the combustion chamber it provides an air gap across which this impulse can produce an electric spark to ignite the fuel/air charge.
- The three main components of a spark plug are the electrode, insulator, and outer shell.



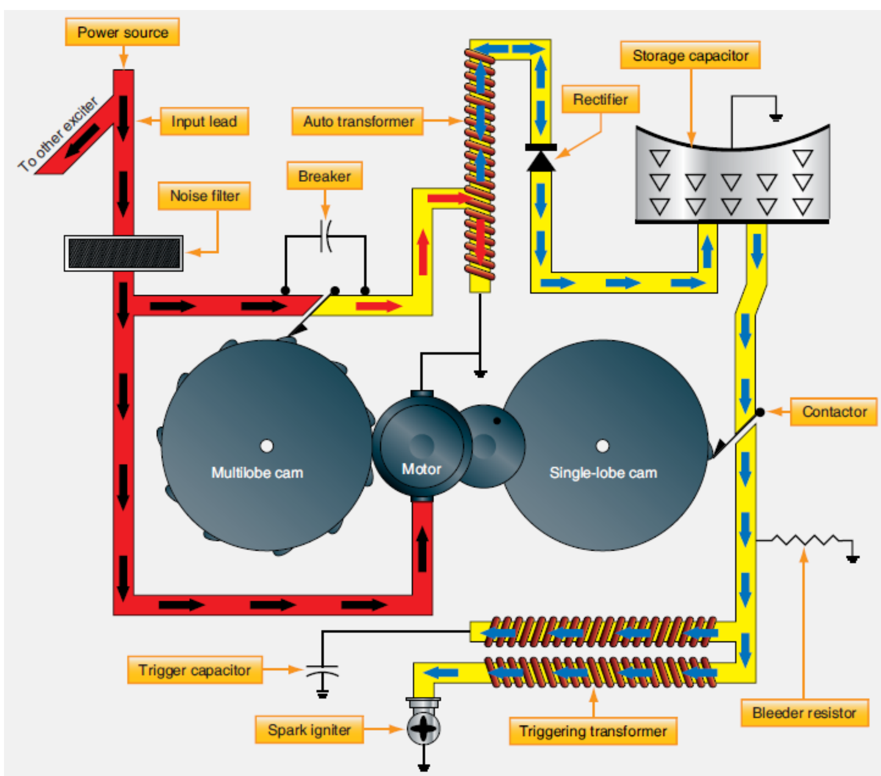


- The outer shell, threaded to fit into the cylinder, is usually made of finely machined steel and is often plated to prevent corrosion from engine gases
- Close-tolerance screw threads and a copper gasket prevent cylinder gas pressure from escaping around the plug.
- Pressure that might escape through the plug is retained by inner seals between the outer metal shell and the insulator, and between the insulator and the center electrode assembly.
- The insulator provides a protective core around the electrode. In addition to affording electrical insulation, the ceramic insulator core also transfers heat from the ceramic tip, or nose, to the cylinder.
- The electrodes can be of several designs from massive electrodes or Nickel-base alloy to fine wire electrodes.
- The massive electrode material has a lower melting point Fine wire iridium and platinum electrodes have a very high melting point.
- The iridium electrode allows for a larger spark gap, which creates a more intense spark that increases performance.

Turbine Engine Ignition System

- Since turbine ignition systems are operated mostly for a brief period during the engine-starting cycle. It is used to ignite the fuel in the combustor and then it is switched off.
- Continuous ignition is used in case the engine were to flame out. This ignition could relight the fuel and keep the engine from stopping.
- Examples of critical flight modes that use continuous ignition are takeoff, landing, and some abnormal and emergency situations.
- Most turbojet engines are equipped with a high-energy, capacitor-type ignition system.
- Both turbojet and turboprop engines may be equipped with an electronic-type ignition system

Capacitor Discharge Ignition System



- A 24-volt d.c. input voltage is supplied to the input receptacle of the exciter unit.
- Before the electrical energy reaches the exciter unit, it passes through a filter which prevents noise voltage from being induced into the aircraft electrical system.

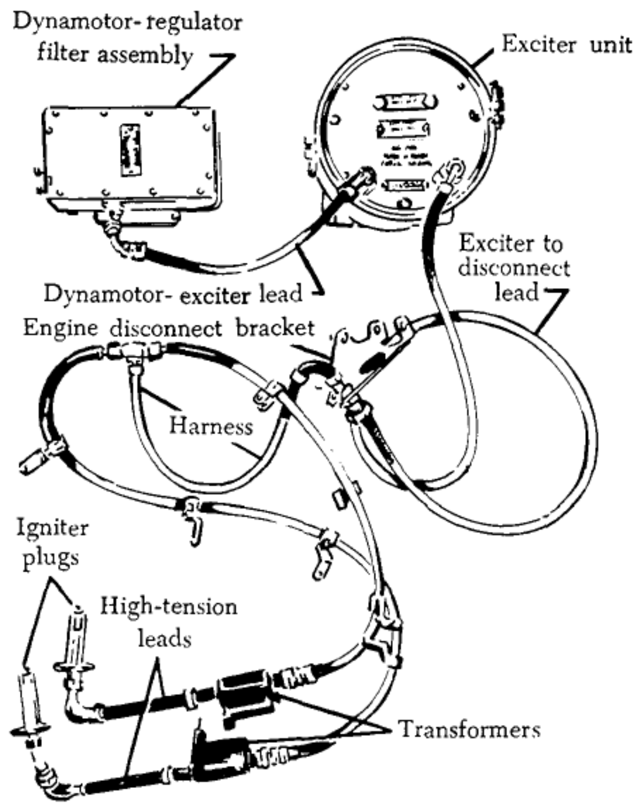
- The low-voltage input power operates a d.c. motor, which drives one multi-lobe cam and one single-lobe cam.
- At the same time, input power is supplied to a set of breaker points that are actuated by the multi-lobe cam.
- From the breaker points, a rapidly interrupted current is delivered to an auto transformer. When the breaker closes, the flow of current through the primary winding of the transformer establishes a magnetic field.
- When the breaker opens, the flow of current stops, and the collapse of the field induces a voltage in the secondary of the transformer.
- This voltage causes a pulse of current to flow into the storage capacitor through the rectifier, which limits the flow to a single direction. With repeated pulses the storage capacitor thus assumes a charge.
- The storage capacitor is connected to the spark igniter through the triggering transformer and a contactor, normally open.
- When the charge on the capacitor has built up, the contactor is closed by the mechanical action of the single-lobe cam.
- A portion of the charge flows through the primary of the triggering transformer and the capacitor connected in series with it.
- This current induces a high-voltage in the secondary, which ionizes the gap at the spark igniter.

Electronic Ignition System

- The system consists of a dynamotor/regulator/ filter assembly, an exciter unit, two high-tension transformer units. two high-tension leads, and two igniter plugs.
- The dynamotor is used to step up the direct current of the aircraft battery or the external power supply to the operating voltage of the exciter unit.
- This voltage is used to charge two storage capacitors(located in the exciter unit) which store the energy to be used for ignition purposes.

- The voltage across these capacitors is stepped up by transformer units. At the instant of igniter plug firing, the resistance of the gap is lowered sufficiently to permit the larger capacitor to discharge across the gap.

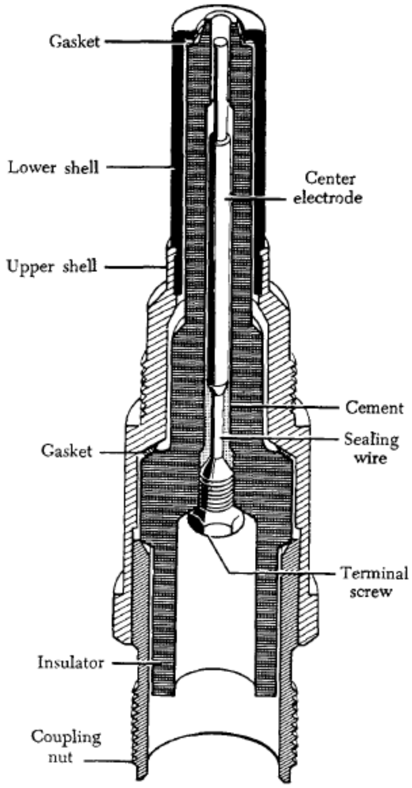
- A continuous series of sparks is produced until the engine starts. The battery current is then cut off, and the plugs do not fire while the engine is operating.



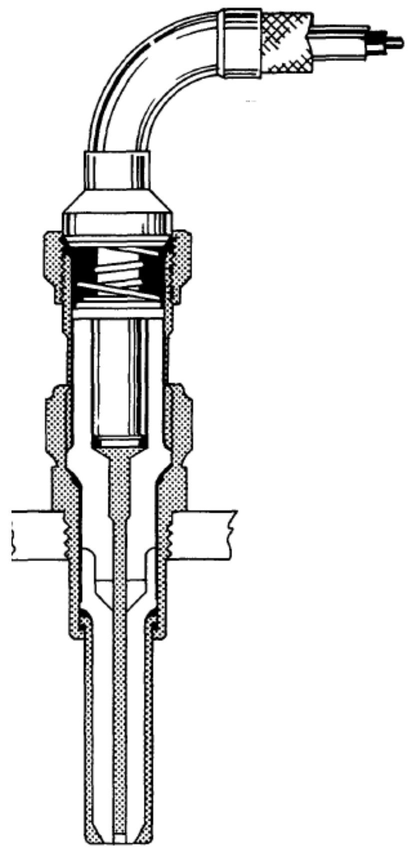
Igniter Plugs

- The igniter plug of a turbine engine ignition system differs considerably from the spark plug of a reciprocating engine ignition system.

- Its electrode must be capable of withstanding a current of much higher energy than the electrode of a conventional spark plug.



Annular gap igniter plug



Constrained gap igniter plug

- Annular-gap igniter plug, sometimes referred to as a "long reach" igniter because it projects slightly into the combustion-chamber liner to produce a more effective spark.
- The constrained-gap plug is used in some types of turbine engines. It operates at a much cooler temperature because it does not project into the combustion-chamber liner.
- This is possible because the spark does not remain close to the plug, but arcs beyond the face of the combustion-chamber liner.

AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 5

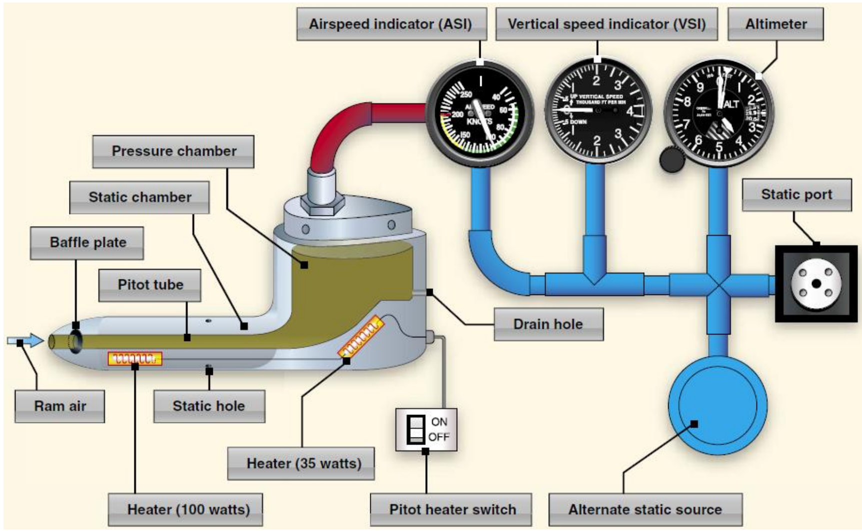
FLIGHT INSTRUMENTS

- The instruments used in controlling the aircraft's flight attitude are known as the flight instruments.
- There are basic flight instruments, such as the altimeter that displays aircraft altitude; the airspeed indicator; and the magnetic direction indicator, a form of compass. Additionally, an artificial horizon, turn coordinator, and vertical speed indicator are flight instruments present in most aircraft.
- Original analog flight instruments are operated by air pressure and the use of gyroscopes.

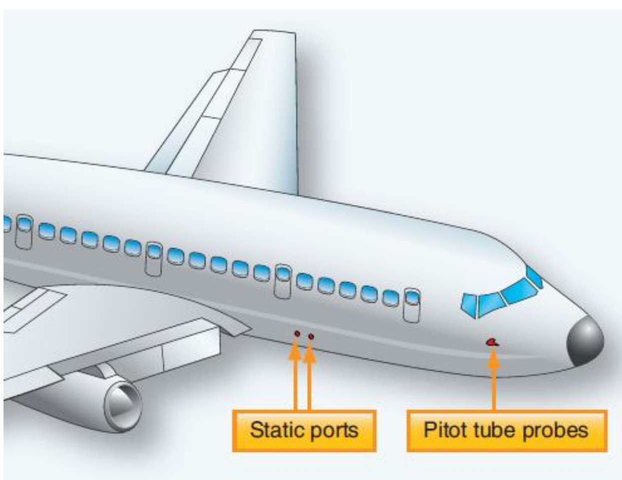
The basic T arrangement of analog flight instruments

<u>Pitot-Static Systems</u>

- Some of the most important flight instruments derive their indications from measuring air pressure. Gathering and distributing various air pressures for flight instrumentation is the function of the pitot-static system.
- The altimeter, airspeed indicator, and vertical speed indicator are the three most common pitot-static instruments.
- It is open and faces into the airstream to receive the full force of the impact air pressure as the aircraft moves forward.
- Pitot tube measures the total air pressure.



- The pitot-static tube is mounted on the outside of the aircraft at a point where the air is least likely to be turbulent.
- It is pointed in a forward direction parallel to the aircraft's line of flight. The location may vary. Some are on the nose of the fuselage and others may be located on a wing.
- Most aircraft equipped with a pitot-static tube have an alternate source of static air pressure provided for emergency Use.



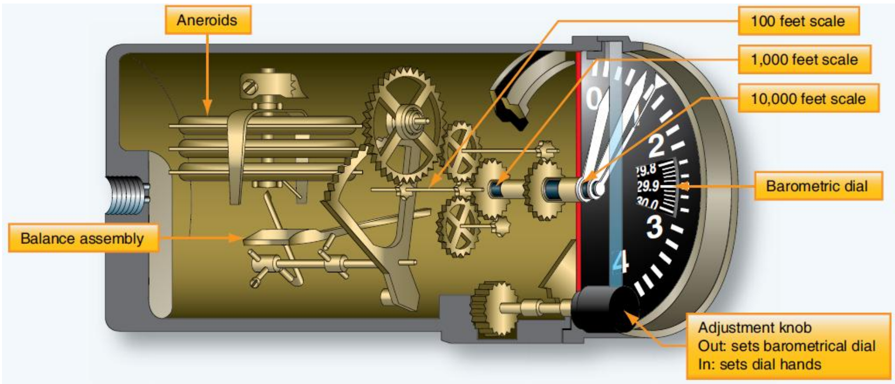
Air Data Computers (ADC)

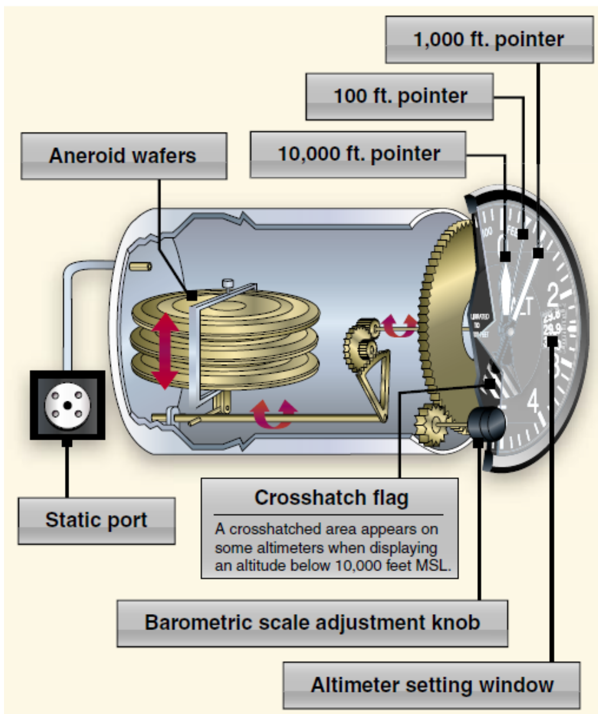
- High performance and jet transport category aircraft pitot-static systems may be more complicated.
- The compressibility of air is also altered at high speeds and at high altitudes. Airflow around the fuselage changes, making it difficult to pick up consistent static pressure inputs.

- The pilot must compensate for all factors of air temperature and density to obtain accurate indications from instruments.
- ADC provides accurate information that has compensated for the many variables encountered.

ALTIMETER

- An altimeter is an instrument that is used to indicate the height of the aircraft above a predetermined level, such as sea level or the terrain beneath the aircraft.
- A pressure altimeter is made to measure the ambient air pressure at any given location and altitude. In aircraft, it is connected to the static vent(s) via tubing in the pitot-static system.



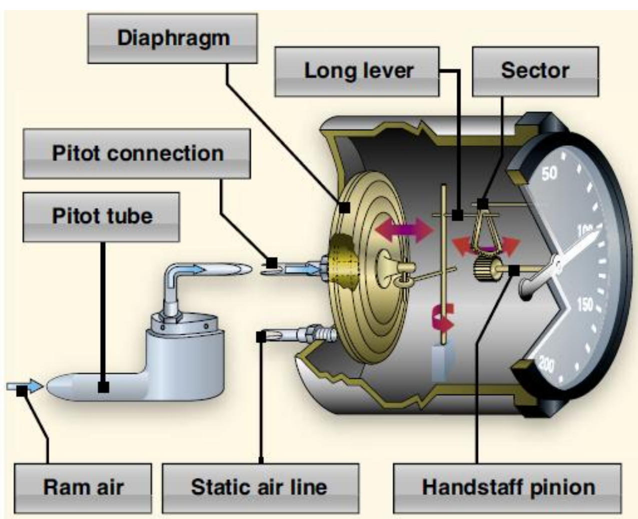


The internal arrangement of a sealed diaphragm pressure altimeter

- A stack of sealed aneroid wafers comprise the main component of the altimeter.
- An aneroid wafer is a sealed wafer that is evacuated to an internal pressure of 29.92 inches of mercury (29.92 "Hg).
- These wafers are free to expand and contract with changes to the static pressure.
- A higher static pressure presses down on the wafers and causes them to collapse.
- A lower static pressure (less than 29.92 "Hg) allows the wafers to expand.
- A mechanical linkage connects the wafer movement to the needles on the indicator face, which translates compression of the wafers into a decrease in altitude and translates an expansion of the wafers into an increase in altitude.

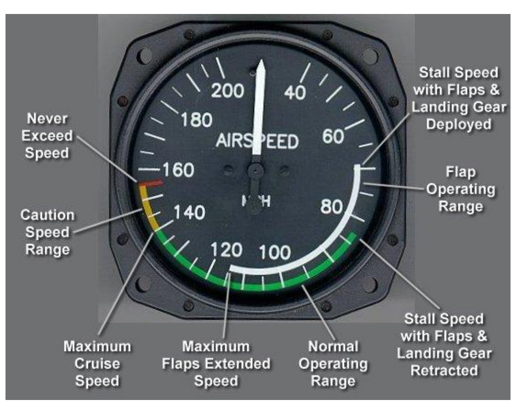
AIRSPEED INDICATOR

- The ASI is a sensitive, differential pressure gauge which measures and promptly indicates the difference between pitot (impact/dynamic pressure) and static pressure.
- These two pressures are equal when the aircraft is parked on the ground in calm air.
- When the aircraft moves through the air, the pressure on the pitot line becomes greater than the pressure in the static lines.



- Ram air pressure from the aircraft's pitot tube is directed into a diaphragm in an analog airspeed instrument case.
- Static air pressure from the aircraft static vent(s) is directed into the case surrounding the diaphragm.

- As the speed of the aircraft varies, the ram air pressure varies, expanding or contracting the diaphragm.
- Linkage attached to the diaphragm causes a pointer to move over the instrument face, which is calibrated in knots or miles per hour (mph)
- **Indicated airspeed (IAS)—**the direct instrument reading obtained from the ASI, uncorrected for variations in atmospheric density, installation error, or instrument error. Manufacturers use this airspeed as the basis for determining aircraft performance.
- **Calibrated airspeed (CAS)—**IAS corrected for installation error and instrument error. In the cruising and higher airspeed ranges, IAS and CAS are approximately the same.
- **True airspeed (TAS)—**CAS corrected for altitude and nonstandard temperature. Because air density decreases with an increase in altitude, an aircraft has to be flown faster at higher altitudes to cause the same pressure difference between pitot impact pressure and static pressure. Therefore, for a given CAS, TAS increases as altitude increases.
- **Groundspeed (GS)—**the actual speed of the airplane over the ground. It is TAS adjusted for wind.
- **Equivalent airspeed (EAS)-** The speed at sea level that would produce the same incompressible dynamic pressure as the true airspeed at the altitude at which the vehicle is flying.
- At standard sea level pressure, calibrated airspeed and equivalent airspeed are equal.
- Up to about 200 knots CAS and 10,000 ft (3,000 m) the difference is negligible, but at higher speeds and altitudes CAS must be corrected for compressibility error to determine EAS.



MACHMETER

- Since the speed of sound depends on atmospheric pressure and density and also with altitude, this suggests that for an aircraft to operate within speed limits commensurate with structural safety, a different speed would have to be maintained for each altitude.

- This obviously is not a practical solution and so it is therefore necessary to have a means of common base which is the mach number.

- Many high performance aircraft are equipped with a Machmeter.

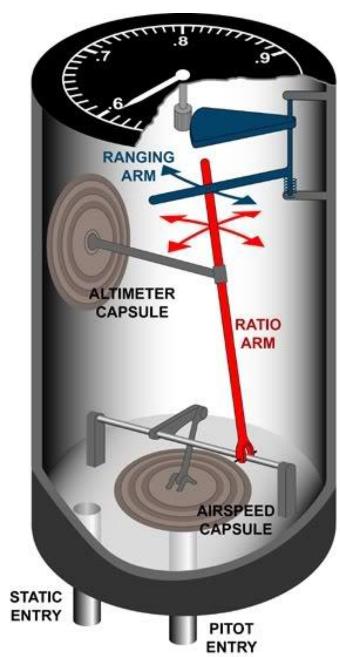
- It is essentially an airspeed instrument that is calibrated in relation to Mach on the dial. Various scales exist for subsonic and supersonic aircraft.

- In addition to the ram air/static air diaphragm arrangement, Machmeters also contain an **altitude sensing diaphragm**. It adjusts the input to the pointer so changes in the speed of sound due to altitude are incorporated into the indication.

- A Mach meter is a compound air data instrument which accepts two variables and uses them to compute the required ratio.

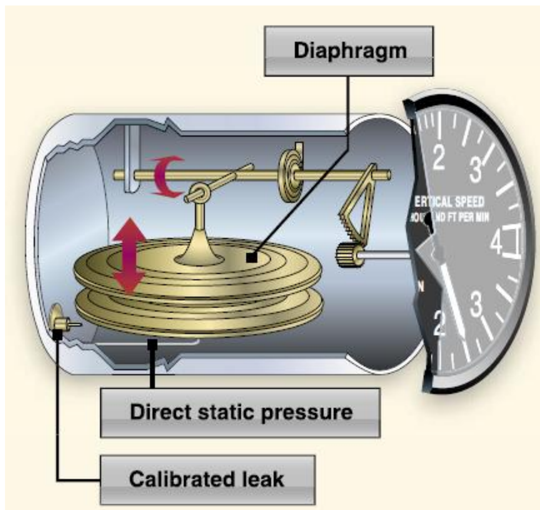
- The first variable is airspeed- computed by a mechanism based on conventional airspeed indicator by measuring the difference between $p_t - p_s$

- The second variable is altitude – computed by a mechanism based on an aneroid capsule sensitive to p_s

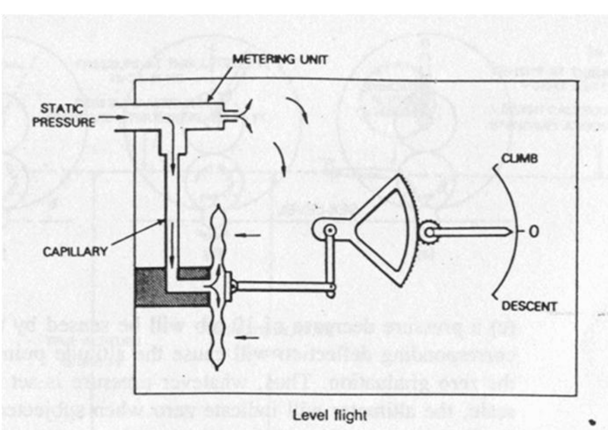


VERTICAL SPEED INDICATOR (VSI)

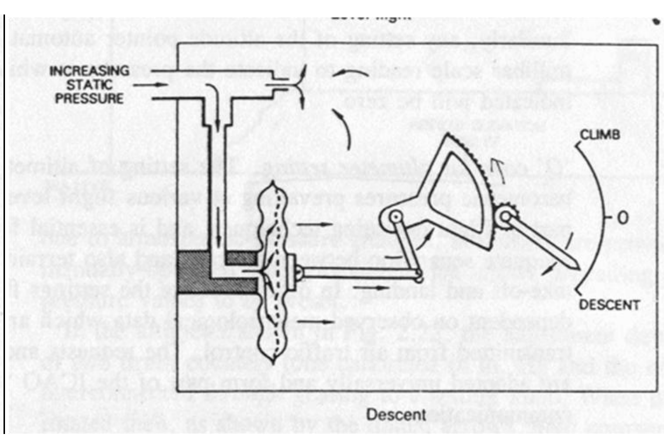
- The VSI, which is sometimes called a vertical velocity indicator (VVI), indicates whether the aircraft is climbing, descending, or in level flight.
- The rate of climb or descent is indicated in feet per minute (fpm). If properly calibrated, the VSI indicates zero in level flight.
- VSI operates solely from static pressure.



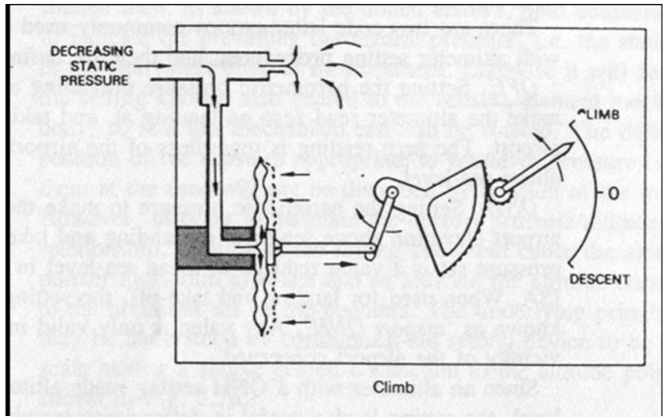
- It contains a diaphragm with connecting linkage and gearing to the indicator pointer inside an airtight case.
- The inside of the diaphragm is connected directly to the static line of the pitot-static system.
- The area outside the diaphragm, which is inside the instrument case, is also connected to the static line, but through a restricted orifice (calibrated leak).



Level flight



Descent



- Both the diaphragm and the case receive air from the static line at existing atmospheric pressure.
- The diaphragm receives unrestricted air while the case receives the static pressure via the metered leak.
- When the aircraft is on the ground or in level flight, the pressures inside the diaphragm and the instrument case are equal and the pointer is at the zero indication.
- When the aircraft climbs or descends, the pressure inside the diaphragm changes immediately, but due to the metering action of the restricted passage, the case pressure remains higher or lower for a short time, causing the diaphragm to contract or expand.
- This causes a pressure differential that is indicated on the instrument needle as a climb or descent.

NAVIGATION INSTRUMENTS

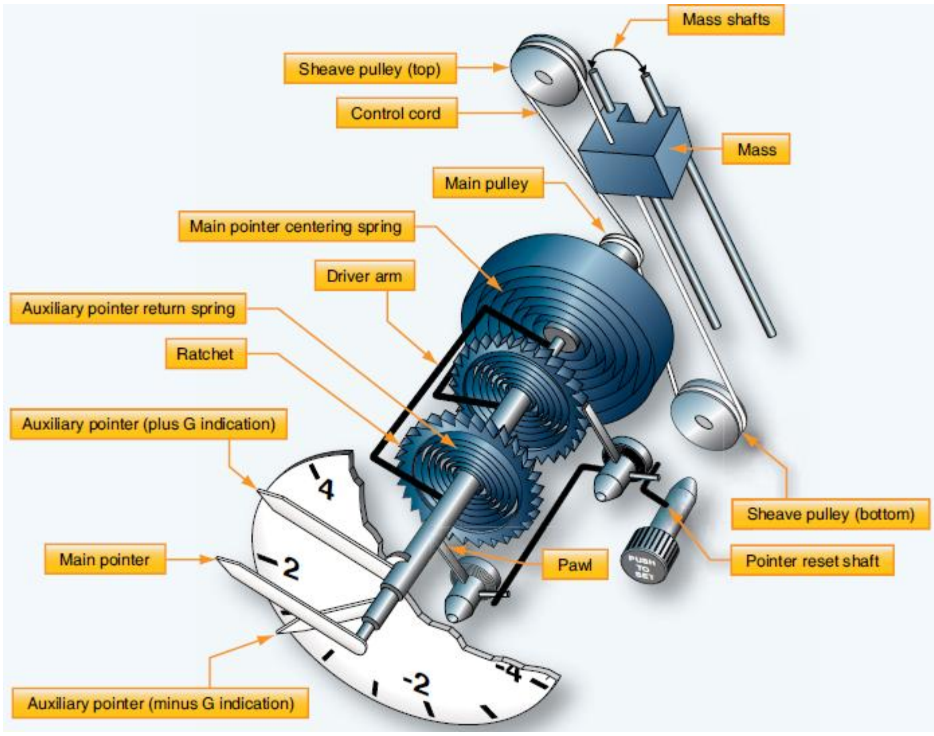
- Navigation instruments are those that contribute information used by the pilot to guide the aircraft along a definite course.
- Traditional navigation instruments include a clock and a magnetic compass. Along with the airspeed indicator and wind information, these can be used to calculate navigational progress.
- Other instruments depend on the use of gyroscopes and accelerometers.

ACCELEROMETERS

- An accelerometer is an instrument that measures acceleration.
- It is used to monitor the forces acting upon an airframe.
- Accelerometers are also used in inertial reference navigation systems.
- Simple accelerometers are mechanical, direct-reading instruments calibrated to indicate force in ‘g’s (force of gravity).
- When an aircraft initiates a rapid climb, positive g-force tends to push one back into one’s seat. Initiating a rapid decent causes a force in the opposite direction, resulting in a negative g-force.

Mass type accelerometer

- The accelerometer operates on the principle of inertia. A mass, or weight, inside is free to slide along a shaft in response to the slightest acceleration force.
- When a maneuver creates an accelerating force, the aircraft and instrument move, but inertia causes the weight to stay at rest in space.
- As the shaft slides through the weight, the relative position of the weight on the shaft changes. This position corresponds to the force experienced.
- Through a series of pulleys, springs, and shafts, the pointers are moved on the dial to indicate the relative strength of the acceleration force.
- Forces can act upon an airframe along the three axes of flight. Single and multi-axis accelerometers are available.



Mass type accelerometer

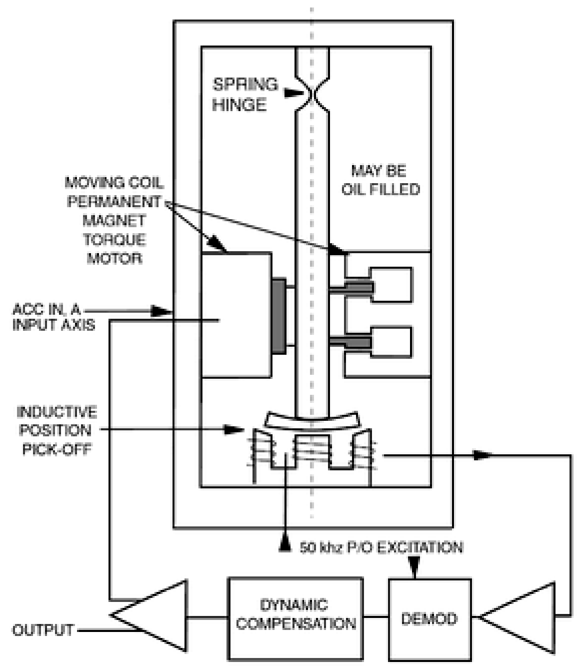
Pendulum Accelerometer

- The acceleration of a vehicle can be determined by measuring the force required to constrain a suspended mass so that it has the same acceleration as the vehicle on which it is suspended.
- The restoring force can be a magnetic field, electric field or mechanical force.

Magnetically Restrained Pendulum Accelerometer

- Pendulum has a leaf spring with mass at the end. A wire coil attaches to the end of the pendulum.
- The deflection from the neutral un accelerated position is measured to indicate acceleration.
- To make accelerometer independent of spring characteristics, the pendulum is restored to the undeflected position by a magnetic field.
- The mass of the pendulum is in a constant magnetic field.
- Current may pass through a wire coil around the pendulum, producing a field that interacts with the static magnetic field and generates a force between the pendulum and the static magnetic field.

- The force of acceleration is counterbalanced by the magnetic fields. A current passed through the coil counter acts the force due to acceleration, such that pendulum is restored to the undeflected position. The current is directly proportional to the acceleration.



Magnetically Restrained Pendulum Accelerometer

GYROSCOPES

- Several flight instruments utilize the properties of a gyroscope for their operation.
- The most common instruments containing gyroscopes are the turn coordinator, heading indicator, and the attitude indicator.

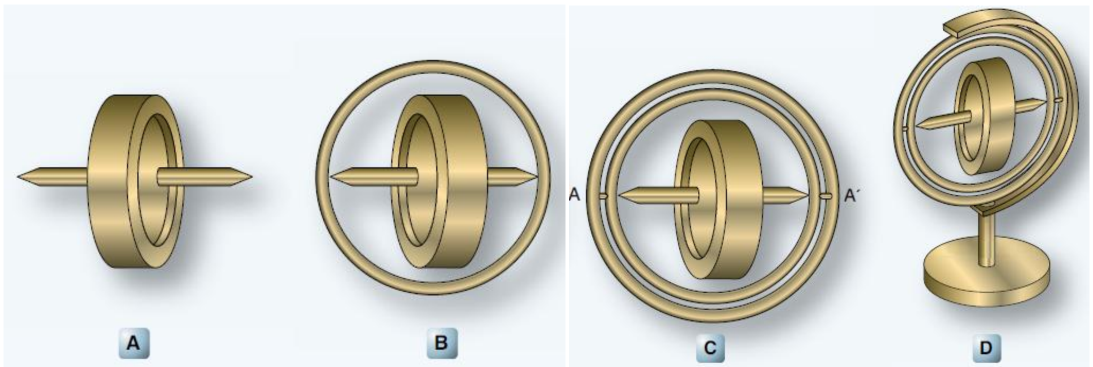
Types of Gyroscopes

- Mechanical
- Ring Laser
- Fibre-Optic

Mechanical Gyroscope

- A mechanical gyroscope, or gyro, is comprised of a wheel or rotor with its mass concentrated around its perimeter.
- The rotor has bearings to enable it to spin at high speeds.

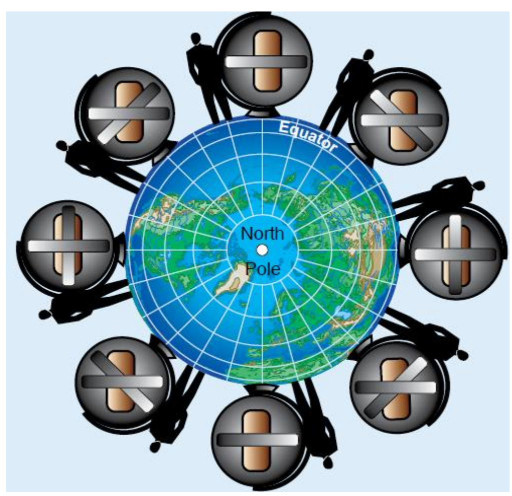
- The mounting configuration allows the rotor assembly to rotate about one or two axes perpendicular to its axis of spin.
- To suspend the rotor for rotation, the axle is first mounted in a supporting ring. If brackets are attached 90° around the supporting ring from where the spin axle attached, the supporting ring and rotor can both move freely 360°.



- Unless the rotor of a gyro is spinning, it has no unusual properties; it is simply a wheel universally mounted. When the rotor is rotated at a high speed, the gyro exhibits a couple of unique characteristics.

1) **Gyroscopic rigidity, or rigidity in space:**

- It refers to the principle that a gyroscope remains in a fixed position in the plane in which it is spinning.
- Thus, if the gimbal rings are tilted, twisted, or otherwise moved, the gyro remains in the plane in which it was originally spinning.



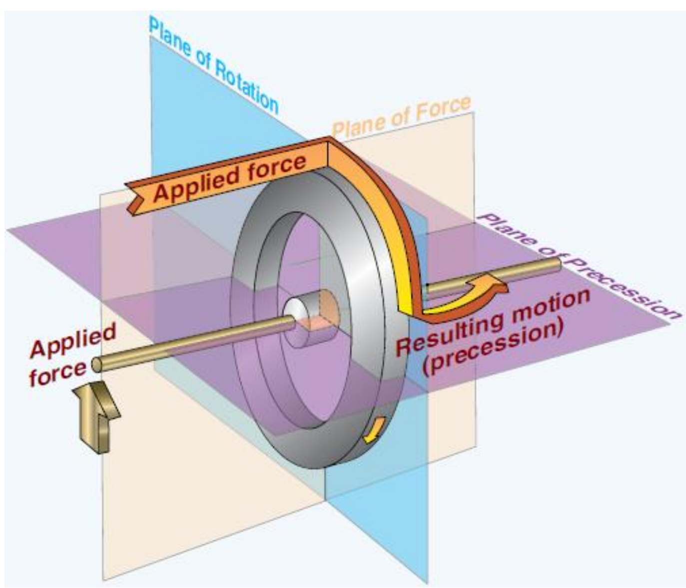
Once spinning, a free gyro rotor stays oriented in the same position in space despite the position or location of its base.

Gyroscopic rigidity depends upon several design factors:

- **Weight**—for a given size, a heavy mass is more resistant to disturbing forces than a light mass.
- **Angular velocity**—the higher the rotational speed, the greater the rigidity or resistance is to deflection.
- **Radius at which the weight is concentrated**— maximum effect is obtained from a mass when its principal weight is concentrated near the rim, rotating at high speed.
- **Bearing friction**—any friction applies a deflecting force to a gyro. Minimum bearing friction keeps deflecting forces at a minimum.

2) Gyroscopic Precession:

- It is the tilting or turning of a gyro in response to a deflective force. The reaction to this force does not occur at the point at which it was applied; rather, it occurs at a point that is 90° later in the direction of rotation.
- This principle allows the gyro to determine a rate of turn by sensing the amount of pressure created by a change in direction.

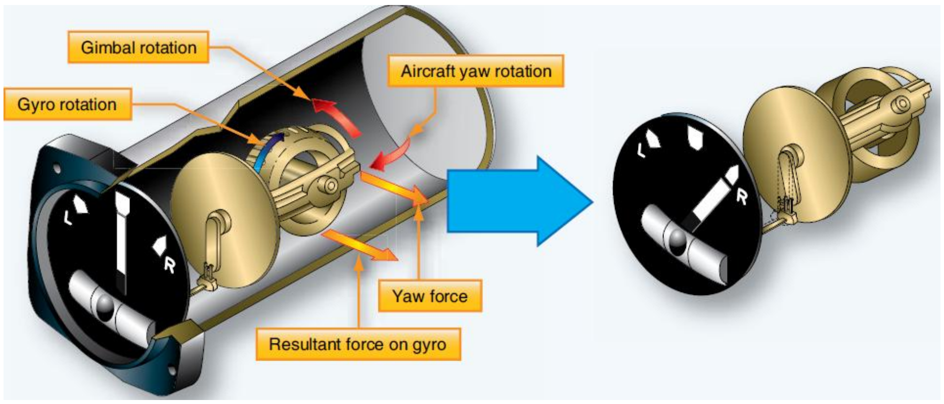


Precession of a gyroscope resulting from an applied deflective force

GYROSCOPIC INSTUMENTS

TURN AND SLIP INDICATOR

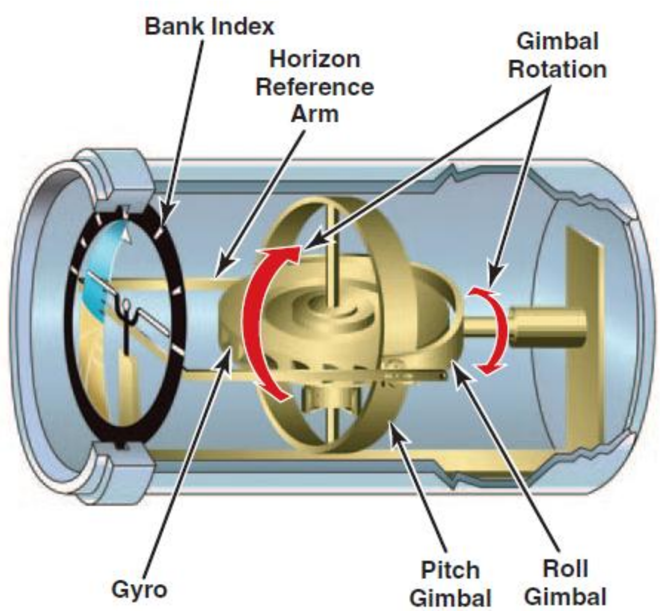
- It may also be referred to as the turn-and-bank indicator.
- It shows the correct execution of a turn while banking the aircraft and indicates movement about the vertical axis of the aircraft (yaw).



- The turn-and-slip indicator is actually two separate devices built into the same instrument housing: a turn indicator pointer and slip indicator ball.
- The turn pointer is operated by a gyro.
- The ball is a completely independent device. It is a round steel ball, in a glass tube filled with dampening fluid. It moves in response to gravity and centrifugal force experienced in a turn.
- The gyro spins in a vertical plane aligned with the longitudinal axis of the aircraft.
- When the aircraft rotates about its vertical axis during a turn, the force experienced by the spinning gyro is exerted about the vertical axis.
- Due to precession, the reaction of the gyro rotor is 90° further around the gyro in the direction of spin.
- This means the reaction to the force around the vertical axis is movement around the longitudinal axis of the aircraft.
- This causes the top of the rotor to tilt to the left or right. The pointer is attached with linkage that makes the pointer deflect in the opposite direction, which matches the direction of turn.
- So, the aircraft's turn around the vertical axis is indicated around the longitudinal axis on the gauge

GYRO HORIZON

- It is the attitude indicator. With its miniature aircraft and horizon bar, displays a picture of the attitude of the aircraft.
- The relationship of the miniature aircraft to the horizon bar is the same as the relationship of the real aircraft to the actual horizon.
- The instrument gives an instantaneous indication of even the smallest changes in attitude.
- The gyro in the attitude indicator is mounted in a horizontal plane and depends upon rigidity in space for its operation.
- The horizon bar represents the true horizon. This bar is fixed to the gyro and remains in a horizontal plane as the aircraft is pitched or banked about its lateral or longitudinal axis, indicating the attitude of the aircraft relative to the true horizon.
- The gyro spins in the horizontal plane and resists deflection of the rotational path. Since the gyro relies on rigidity in space, the aircraft actually rotates around the spinning gyro.



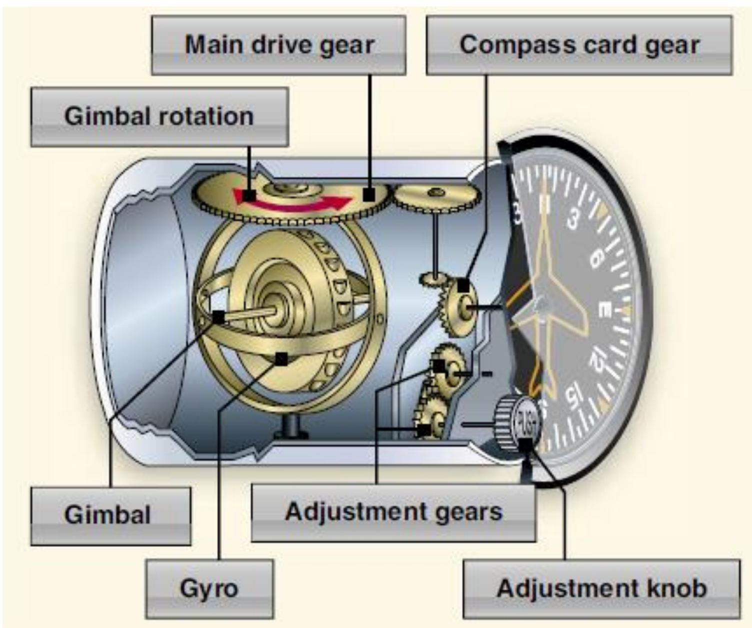
- An adjustment knob is provided with which the pilot may move the miniature aircraft up or down to align the miniature aircraft with the horizon bar to suit the pilot's line of vision.
- Normally, the miniature aircraft is adjusted so that the wings overlap the horizon bar when the aircraft is in straight-and-level cruising flight.

Attitude representation by the attitude indicator corresponds to the relation of the aircraft to the real horizon.

DIRECTIONAL GYRO/HEADING INDICATOR

- The **Directional (DG)** is a vacuum driven gyroscope. It looks much like a compass.

- A major difference it has with the compass is that it doesn't rely on the earth's magnetic field to operate.
- When the gyroscope is spinning it has a principle of remaining rigid in space. That is the spinning wheel will resist any change in position. The **DG** takes advantage of that principle.
- When an airplane is turning, the gyroscope will resist moving with the turn. The energy used to resist the turn instead moves the compass card which will indicate the heading of the airplane.
- **DG's** are used because they are not effected by magnetic disturbances or have turning errors inherent to the compass. They are susceptible to **gyroscopic precession** which are errors due to the mechanical friction imposed on the spinning gyroscope.

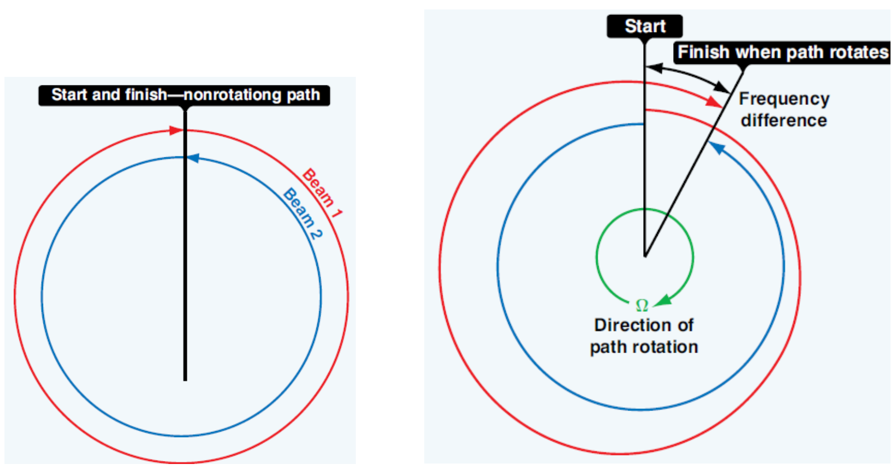


- The heading indicator is fundamentally a mechanical instrument designed to facilitate the use of the magnetic compass.
- Errors in the magnetic compass are numerous, making straight flight and precision turns to headings difficult to accomplish, particularly in turbulent air.
- A heading indicator, however, is not affected by the forces that make the magnetic compass difficult to interpret.
- The operation of the heading indicator depends upon the principle of rigidity in space.
- The rotor turns in a vertical plane and fixed to the rotor is a compass card.

- Since the rotor remains rigid in space, the points on the card hold the same position in space relative to the vertical plane of the gyro.
- The aircraft actually rotates around the rotating gyro, not the other way around.
- As the instrument case and the aircraft revolve around the vertical axis of the gyro, the card provides clear and accurate heading information.

RING LASER GYRO (RLG)

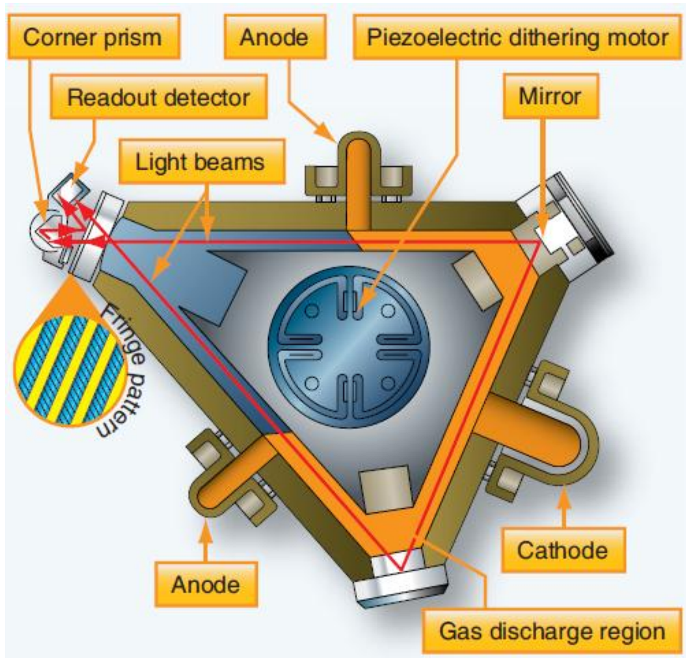
- The basis for RLG operation is that it takes time for light to travel around a stationary, non rotating circular path.
- Light takes longer to complete the journey if the path is rotating in the same direction as the light is traveling. And, it takes less time for the light to complete the loop if the path is rotating in the direction opposite to that of the light.
- The path is made longer or shorter by the rotation. This is known as the **Sagnac effect**.



Sagnac Effect

- A ring laser gyro produces laser beams that travel in opposite directions around a closed triangular cavity. The wavelength of the light traveling around the loop is fixed.
- As the loop rotates, the path the lasers must travel lengthens or shortens. The light wavelengths compress or expand to complete travel around the loop as the loop changes its effective length. As the wavelengths change, the frequencies also change.

- By examining the difference in the frequencies of the two counter rotating beams of light, the rate at which the path is rotating can be measured



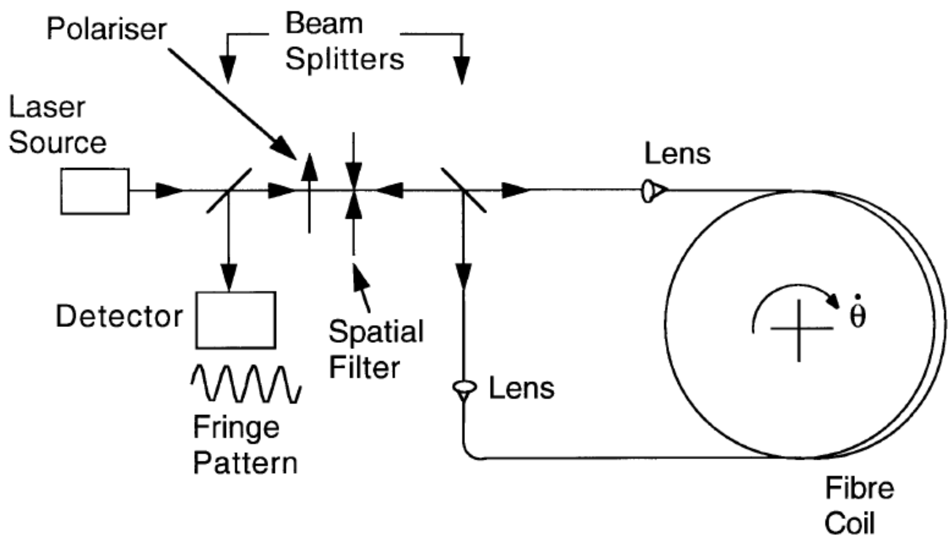
Ring Laser Gyro

- An RLG is remotely mounted so the cavity path rotates around one of the axes of flight. The rate of frequency phase shift detected between the counter rotating lasers is proportional to the rate that the aircraft is moving about that axis.
- On aircraft, an RLG is installed for each axis of flight.
- RLGs are very rugged and have a long service life with virtually no maintenance due to their lack of moving parts.
- They measure movement about an axis extremely quickly and provide continuous output. They are extremely accurate and generally are considered superior to mechanical gyroscopes.

FIBRE OPTIC GYRO (FOG)

- Light from the laser diode source is passed through a first beam splitter and a single optical mode is selected. The light passes through a second beam splitter and propagates in both directions around the fibre coil.

- In the absence of rotation, the transit times are identical so that when the light arrives back at the second beam splitter, perfect constructive interference occurs with accompanying fringe pattern.
- The gyro output signal is obtained by directing the returning light via the first beam splitter to a photo-detector.



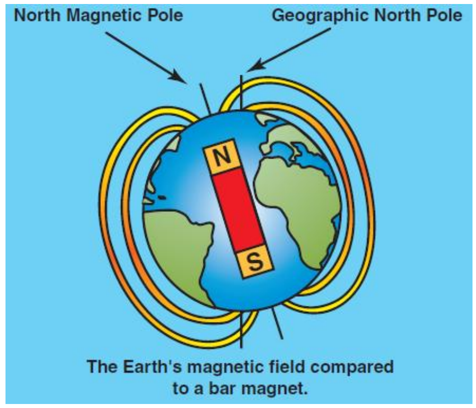
- An input rotation rate about an axis normal to the plane of the coil results in a difference in the transit times between the clockwise and anti-clockwise beams.
- This phase shift between the clockwise and anti-clockwise travelling light waves results in a reduction in the intensity of the light at the detector.

COMPASS

- A compass may be defined as an instrument that indicates direction over the earth's surface with reference to a known datum.
- Various types of compasses have been developed, each of which is distinguished by the particular datum used as the reference from which direction is measured.
- Two basic types of compasses are in current use: **the magnetic and gyrocompass.**
- The magnetic compass uses the lines of force of the earth's magnetic field as a primary reference.
- The gyrocompass uses as its datum an arbitrary fixed point in space determined by the initial alignment of the gyroscope axis.

MAGNETIC COMPASS

- The magnetic compass indicates direction in the horizontal plane with reference to the horizontal component of the earth's magnetic field.



Earth's magnetic field

- The **geographic north and south** poles form the axis for the Earth's rotation. These positions are also referred to as **true north and south.**
- Another axis is formed by the **magnetic north and south pole**s.
- Lines of magnetic force flow out from each pole in all directions, and eventually return to the opposite pole. A compass aligns itself with the magnetic axis formed by the north/south magnetic field of the Earth.

Magnetic compasses may be divided into two classes:

1. The **direct-indicating magnetic compass** in which the measurement of direction is made by a direct observation of the position of a pivoted magnetic needle.

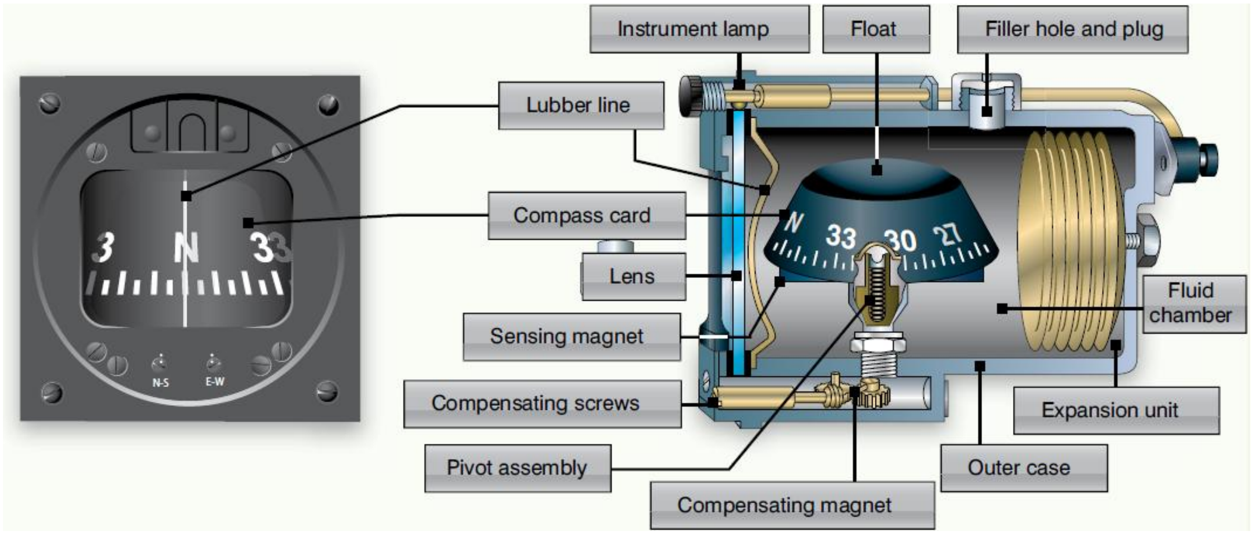
2. The **remote-indicating gyro-stabilized magnetic compass**.

DIRECT-INDICATING MAGNETIC COMPASS

- It contains two steel magnetized needles fastened to a float pivoted at its middle, around which is mounted a compass card.

- The needles are parallel, with their north-seeking ends pointing in the same direction.

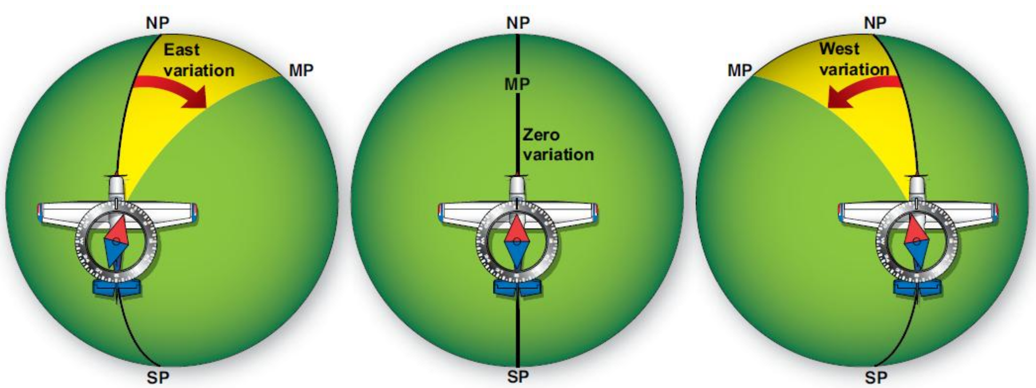
- The compass card has letters for cardinal headings, and each 30° interval is represented by a number, the last zero of which is omitted.



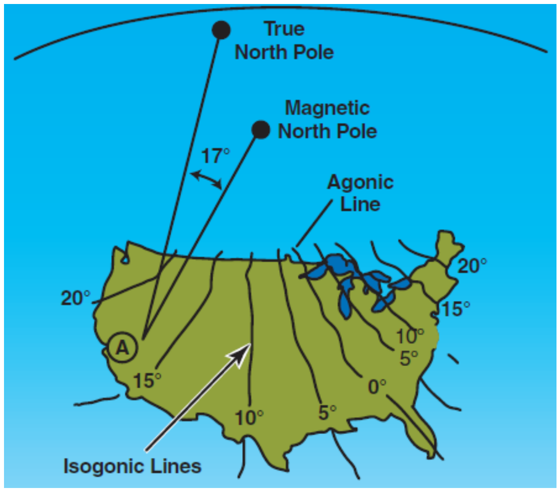
COMPASS ERRORS

Magnetic Variation

- The earth's magnetic poles are joined by irregular curves called magnetic meridians. The angle between the magnetic meridian and the geographic meridian is called the magnetic variation.
- Variation is listed on charts as east or west. When variation is east, magnetic north (MN) is east of true north (TN). Similarly, when variation is west, MN is west of TN.



- Lines connecting points having the same magnetic variation are called **isogonic lines**. Compensate for magnetic variation to convert a compass direction to true direction.

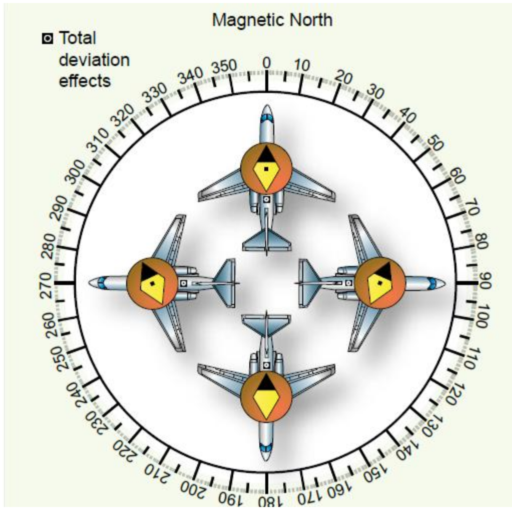


Variation at point A in the western United States is 17°. Since the magnetic north pole is located to the east of the true north pole in relation to this point, the variation is easterly. When the magnetic pole falls to the west of the true north pole, variation is westerly.

- The correction for variation and deviation is usually expressed as a plus or minus value and is computed as a correction to true heading (TH).
- If variation or deviation is east, the sign of the correction is minus; if west, the sign is plus.

Compass Deviation

- Besides the magnetic fields generated by the Earth, other magnetic fields are produced by metal and electrical accessories within the airplane. These magnetic fields distort the Earth's magnetic force, and cause the compass to swing away from the correct heading. This error is called deviation.
- Manufacturers install compensating magnets within the compass housing to reduce the effects of deviation. The magnets are usually adjusted while the engine is running and all electrical equipment is operating.
- However, it is not possible to completely eliminate deviation error; therefore, a compass correction card is mounted near the compass. This card corrects for deviation that occurs from one heading to the next as the lines of force interact at different angles.



Deviation changes with heading

Compass: Magnetic			
Swung: 12 APR 95		By: TTD	
To Fly	**Steer**	**To Fly**	**Steer**
N	001	180	179
15	016	195	194
30	131	210	209
45	046	225	224
60	062	240	238
75	077	255	253
90	092	270	268
105	107	285	283
120	122	300	298
135	135	315	314
150	149	330	330
165	164	345	346

Compass Correction Card

Magnetic Dip

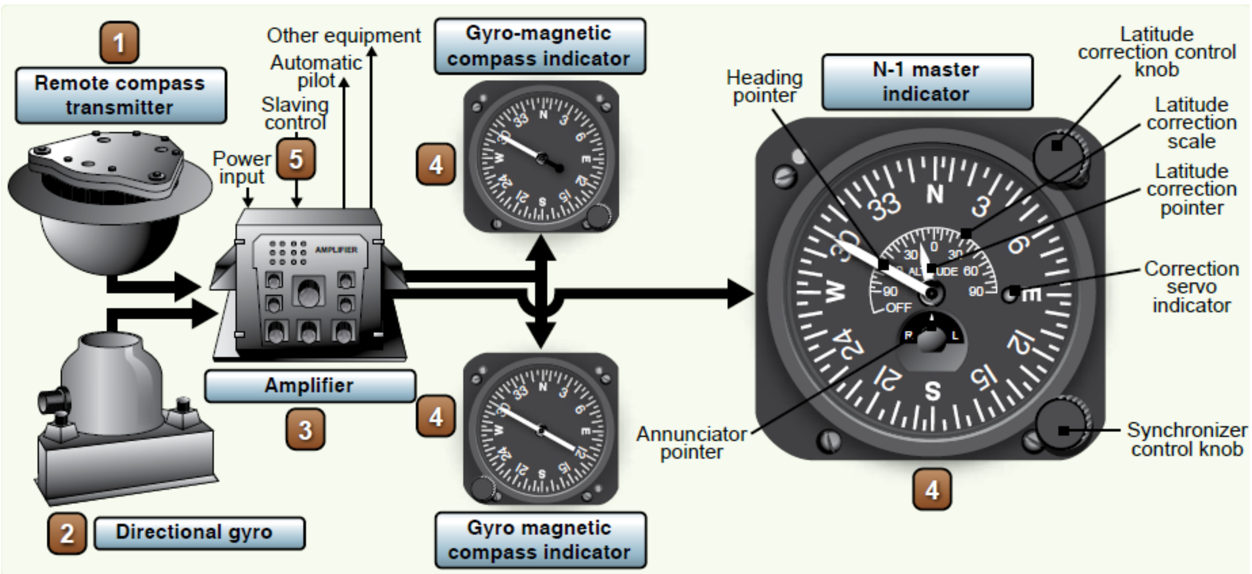
- Magnetic dip is the result of the vertical component of the Earth's magnetic field. This dip is virtually non-existent at the magnetic equator, since the lines of force are parallel to the Earth's surface and the vertical component is minimal.
- When a compass is moved toward the poles, the vertical component increases, and magnetic dip becomes more apparent at higher latitudes. Magnetic dip is responsible for compass errors during acceleration, deceleration, and turns

REMOTE-INDICATING MAGNETIC COMPASS

- A chief disadvantage of the simple magnetic compass is its susceptibility to deviation.
- In remote-indicating gyrostabilized compass systems, this difficulty is overcome by locating the compass direction-sensing device outside magnetic fields created by electrical circuits in the aircraft.
- This is done by installing the direction-sensing device in a remote part of the aircraft, such as the outer extremity of a wing or vertical stabilizer.

It uses the following five basic components:

- **Remote compass transmitter**
- **Directional gyro (DG)**
- **Amplifier**
- **Heading indicators**
- **Slaving control**



Remote Compass Transmitter

- The remote compass transmitter is the magnetic-direction sensing component of the compass system.
- The transmitter is located as far from magnetic disturbances of the aircraft as possible, usually in a wing tip or the vertical stabilizer.
- The transmitter senses the horizontal component of the earth's magnetic field and electrically transmits it to the master indicator.
- The compensator, an auxiliary unit of the remote compass transmitter, is used to eliminate most of the magnetic deviation.

Directional Gyro (DG)

- The DG is the stabilizing component of the compass system when the system is in magnetic-slaved operation.
- When the compass system is in DG operation, the gyro acts as the directional reference component of the system.

Amplifier

- The amplifier is the receiving and distributing center of the compass system. Azimuth correction and leveling signals originating in the components of the system are each received, amplified, and transmitted by separate channels in the amplifier.
- Primary power to operate the compass is fed to the amplifier and distributed to the systems components.

Master Indicator

- The master indicator is the heading-indicating component of the compass system.
- The mechanism in the master indicator integrates all data received from the directional gyro and the remote compass transmitter, corrects the master indicator heading pointer for azimuth drift of the DG due to the earth's rotation, and provides takeoff signals for operating remote indicators, radar, navigation computers, and directional control of the autopilot.
- The latitude correction control provides a means for selecting either magnetic-slaved operation or DG operation of the compass system, as well as the proper latitude correction rate.
- The latitude correction pointer is mechanically connected to the latitude correction control knob and indicates the latitude setting on the latitude correction scale at the center of the master indicator dial face.
- The synchronizer control knob at the lower right-hand corner of the master indicator face provides a means of synchronizing the master indicator heading pointer with the correct Magnetic Heading (MH) when the system is in magnetic-slaved operation.
- It also provides a means of setting the master indicator heading pointer on the desired gyro heading reference when the system is in DG operation.

- The annunciator pointer indicates the direction in which to rotate the synchronizer control knob to align the heading pointer with the correct MH.

Gyro-Magnetic Compass Indicators

- The gyro-magnetic compass indicators are remote-reading, movable dial compass indicators.
- They are intended for supplementary use as directional compass indicators when used with the compass system.
- The indicators duplicate the azimuth heading of the master indicator heading pointer. A setting knob is provided at the front of each indicator for rotating the dial 360° in either direction without changing the physical alignment of the pointer.

Slaving Control

- The slaving control is a gyro control rate switch that reduces errors in the compass system during turns.
- When the aircraft turns at a rate of 23° or more per minute, the slaving control prevents the remote compass transmitter signal from being transmitted to the compass system during magnetic-slaved operation.
- It also interrupts leveling action in the DG when the system is in magnetic-slaved or DG operation.

AO403 AIRCRAFT SYSTEMS AND INSTRUMENTS

MODULE 6

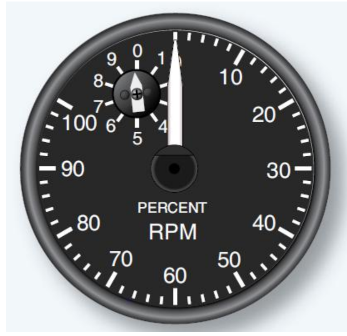
ENGINE INSTRUMENTS

- Engine instruments are those designed to measure operating parameters of the aircraft's engine(s).
- These are usually quantity, pressure, and temperature indications.
- They also include measuring engine speed(s). The most common engine instruments are the fuel and oil quantity and pressure gauges, tachometers, and temperature gauges.

TACHOMETER

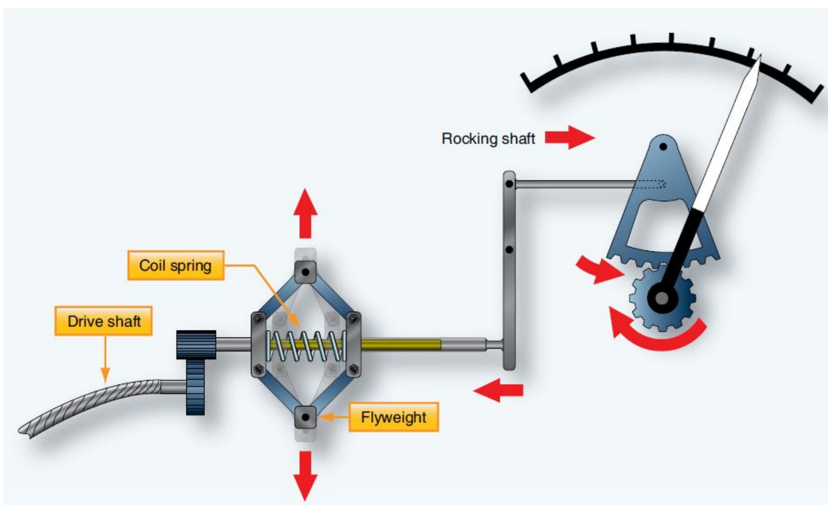
- The tachometer, or tach, is an instrument that indicates the speed of the crankshaft of a reciprocating engine.
- It can be a direct- or remote-indicating instrument, the dial of which is calibrated to indicate revolutions per minutes (rpm).
- On reciprocating engines, the tach is used to monitor engine power and to ensure the engine is operated within certified limits.

- Gas turbine engines tachometers are used to monitor the speed(s) of the compressor section(s) of the engine.
- Turbine engine tachometers are calibrated in percentage of rpm with 100 percent corresponding to optimum turbine speed.



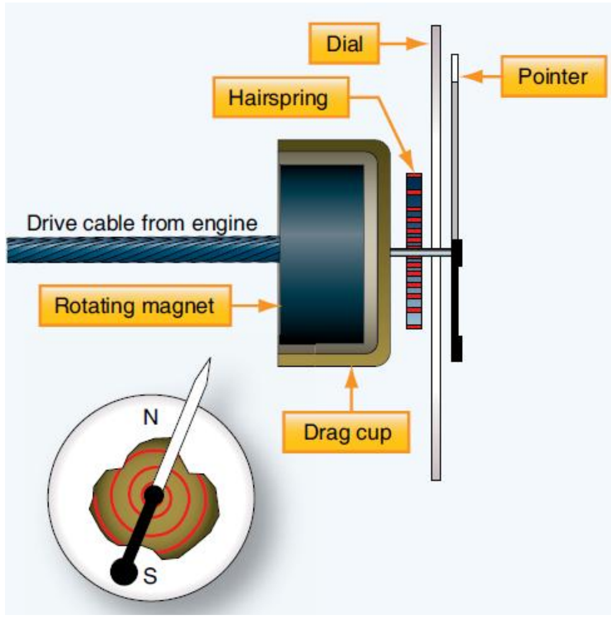
MECHANICAL TACHOMETERS

- Mechanical tachometer indicating systems are found on small, single-engine light aircraft in which a short distance exists between the engine and the instrument panel.
- They consist of an indicator connected to the engine by a flexible drive shaft. The drive shaft is geared into the engine so that when the engine turns, so does the shaft.
- The indicator contains a flyweight assembly coupled to a gear mechanism that drives a pointer.



- A more common variation of this type of mechanical tachometer uses a magnetic drag cup to move the pointer in the indicator.
- As the drive shaft turns, it rotates a permanent magnet in a close-tolerance aluminum cup. A shaft attached to the indicating point is attached to the exterior center of the cup.
- As the magnet is rotated by the engine flex drive cable, its magnetic field cuts through the conductor surrounding it, creating eddy currents in the aluminum cup.
- This current flow creates its own magnetic field, which interacts with the rotating magnet's flux field. The result is that the cup tends to rotate, and with it, the indicating pointer.

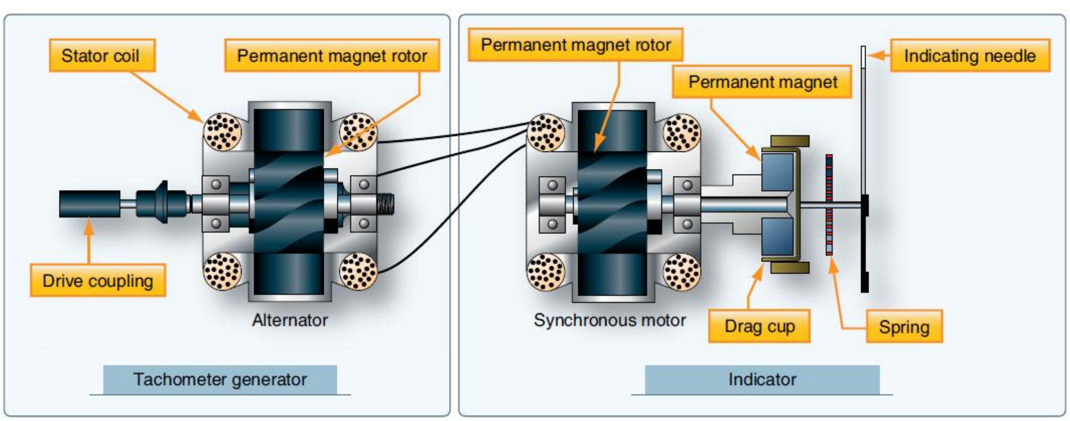
- A calibrated restraining spring limits the cup's rotation to the arc of motion of the pointer across the scale on the instrument face.



Magnetic drag cup tachometer indicating device

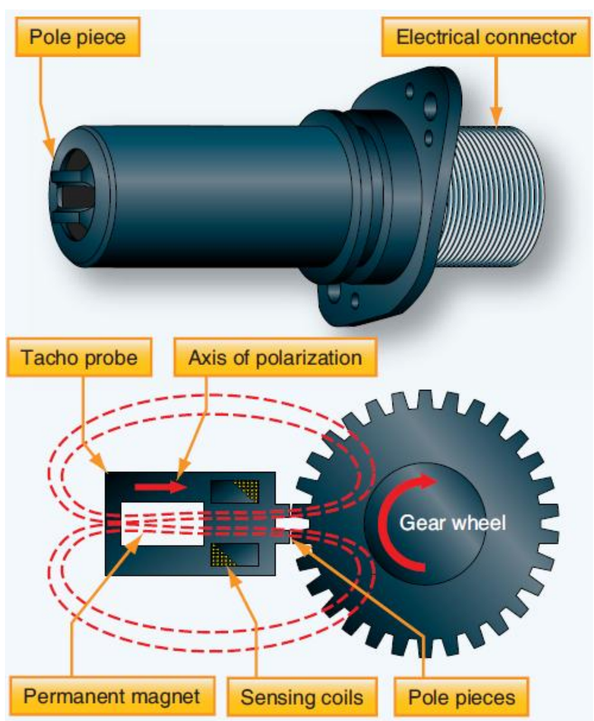
ELECTRIC TACHOMETERS

- Greater accuracy with lower maintenance is achieved through the use of electric tachometers.
- A popular electric tachometer system makes use of a small AC generator mounted to a reciprocating engine's gear case or the accessory drive section of a turbine engine.
- As the engine turns, so does the generator. The frequency output of the generator is directly proportional to the speed of the engine.



An electric tachometer system with synchronous motors and a drag cup indicator

- It is connected via wires to a synchronous motor in the indicator that mirrors this output. A drag cup, or drag disk link, is used to drive the indicator as in a mechanical tachometer.
- Some turbine engines use **tachometer probes** for rpm indication, rather than a tach generator system. They provide a great advantage in that there are no moving parts.
- They are sealed units that are mounted on a flange and protrude into the compressor section of the engine.
- A magnetic field is set up inside the probe that extends through pole pieces and out the end of the probe
- A rotating gear wheel, which moves at the same speed as the engine compressor shaft, alters the magnetic field flux density as it moves past the pole pieces at close proximity.
- This generates voltage signals in coils inside the probe. The amplitude of the EMF signals vary directly with the speed of the engine.



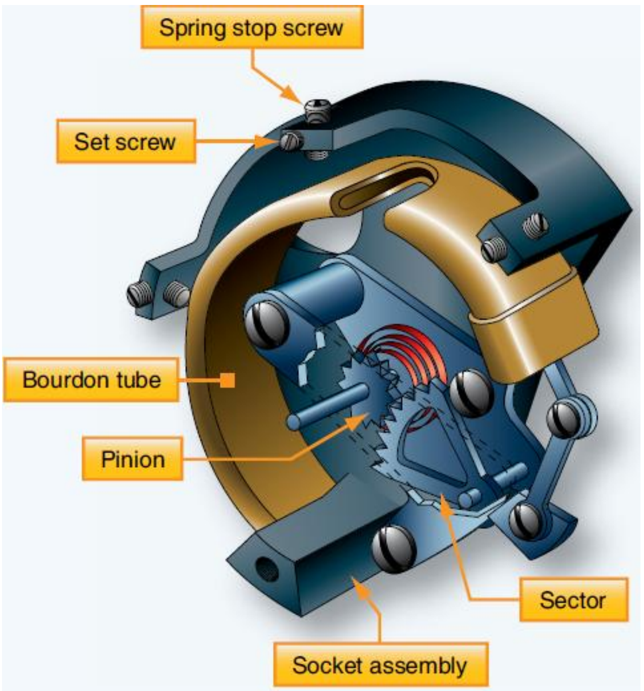
Tacho probe

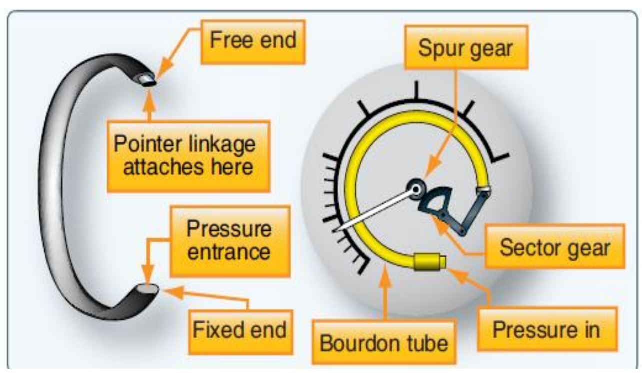
ENGINE PRESSURE GAUGES

- Pressure gages are used to indicate the pressure at which engine oil is forced through the bearings, oil passages, and moving parts of the engine and the pressure at which fuel is delivered to the carburetor or fuel control.
- Aircraft using analog instruments often use direct reading Bourdon tube oil pressure gauges

BOURDON TUBE

- The open end of this coiled tube is fixed in place and the other end is sealed and free to move.
- When a fluid that needs to be measured is directed into the open end of the tube, the unfixed portion of the coiled tube tends to straighten out.
- A pointer is attached to this moving end of the tube, usually through a linkage of small shafts and gears.





OIL PRESSURE GAUGES

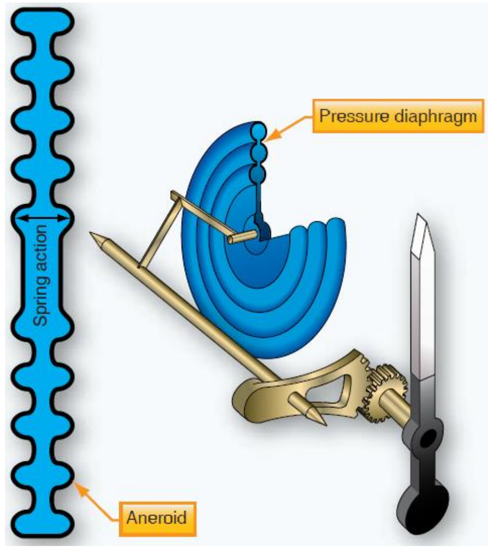
- The most important instrument used by the pilot to perceive the health of an engine is the engine oil pressure gauge.
- In reciprocating and turbine engines, oil is used to lubricate and cool bearing surfaces where parts are rotating or sliding past each other at high speeds.

- A loss of pressurized oil to these areas would rapidly cause excessive friction and over temperature conditions, leading to catastrophic engine failure.
- Oil pressure indicators can be mechanically operated or electrically powered.
- A mechanically operated gauge uses an oil-pressure line from the engine to the instrument to operate the bourdon tube and gear segment to position the indicator needle.
- Some aircraft use a light oil in the line between the gauge and the engine so that there will be no delay in oil pressure indication due to cold engine oil being in the line.

- Electric oil pressure gauge use a sensor on the engine, which varies in resistance as the pressure changes.
- The pressure is indicated by one of the electrical indication methods.

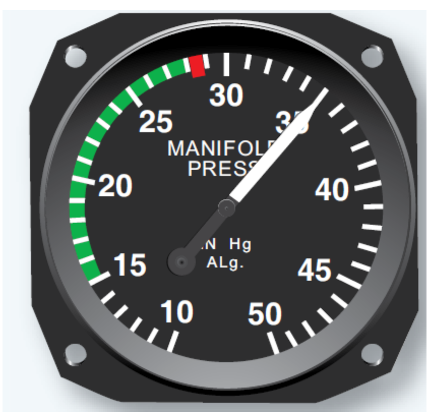
MANIFOLD PRESSURE GAUGES

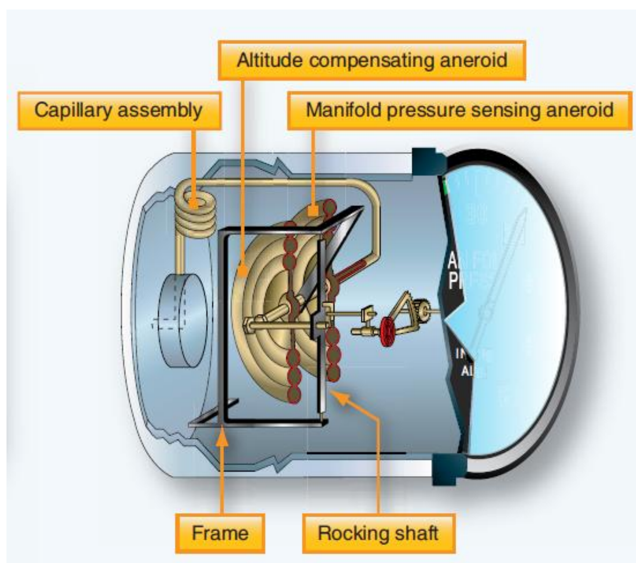
- In reciprocating engine aircraft, the manifold pressure gauge indicates the pressure of the air in the engine's induction manifold. This is an indication of power being developed by the engine. The higher the pressure of the fuel air mixture going into the engine, the more power it can produce.
- Most manifold pressure gauges are calibrated in **inches of mercury**, although digital displays may have the option to display in a different scale.
- A typical analog gauge makes use of an aneroid.



A diaphragm used for measuring pressure.

- When atmospheric pressure acts on the aneroid inside the gauge, the connected pointer indicates the current air pressure.
- A line running from the intake manifold into the gauge presents intake manifold air pressure to the aneroid, so the gauge indicates the absolute pressure in the intake manifold.

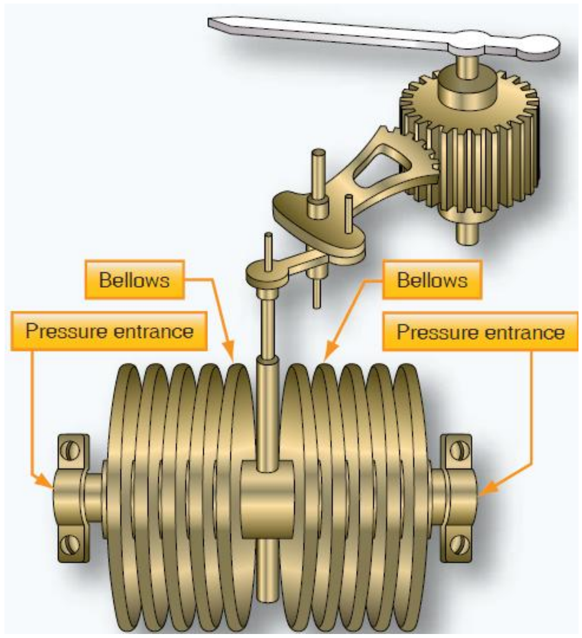




ENGINE PRESSURE RATIO (EPR) GAUGE

- Turbine engines have their own pressure indication that relates the power being developed by the engine. It is called the engine pressure ratio indicator.

- This gauge compares the total exhaust pressure to the pressure of the ram air at the inlet of the engine.
- With adjustments for temperature, altitude, and other factors, the EPR gauge presents an indication of the thrust being developed by the engine. Since the EPR gauge compares two pressures, it is a differential pressure gauge.



Bellows unit in a differential pressure gauge compares two different pressure values

FUEL PRESSURE GAUGE

- Fuel pressure gauges also provide critical information to the pilot.
- Typically, fuel is pumped out of various fuel tanks on the aircraft for use by the engines.
- A malfunctioning fuel pump, or a tank that has been emptied beyond the point at which there is sufficient fuel entering the pump to maintain desired output pressure, is a condition that requires the pilot’s immediate attention.
- Direct-sensing fuel pressure gauges using Bourdon tubes, diaphragms, and bellows sensing arrangements exist.

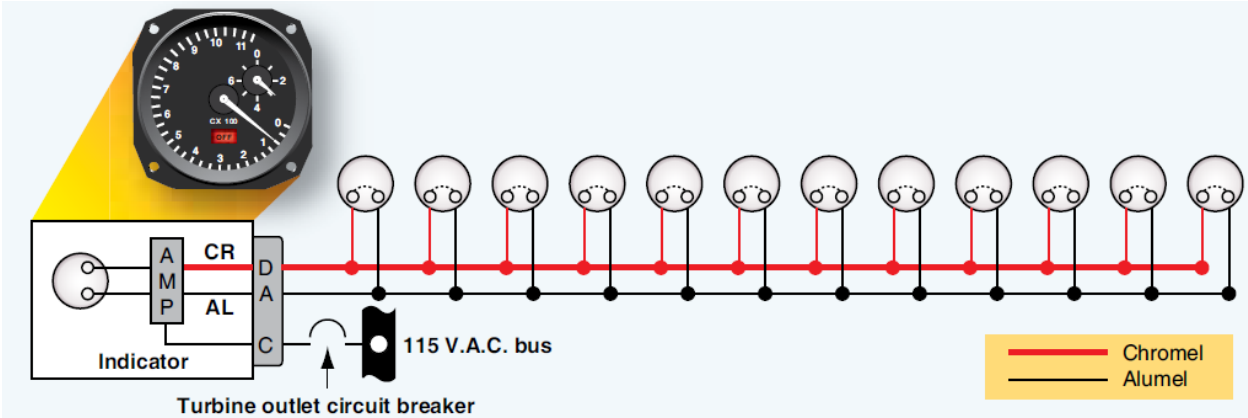
TEMPERATURE GAUGES

OIL TEMPERATURE GAUGES

- Oil temperature indicators can be electrical or mechanical.
- To operate electrically, a resistance probe is placed in the line where the oil enters the engine.
- The oil temperature is derived by the change in probe resistance due to temperature change.
- Another method used to measure oil temperature is with a **volatile liquid in a sealed sensor bulb and capillary rube.**
- The sensor bulb is placed in the line at the inlet to the engine. The temperature of the oil causes the volatile liquid to vaporize and it increase the pressure in the capillary tube.
- A bourdon tube can be used to measure this pressure.

EXHAUST GAS TEMPERATURE (EGT) GAUGE

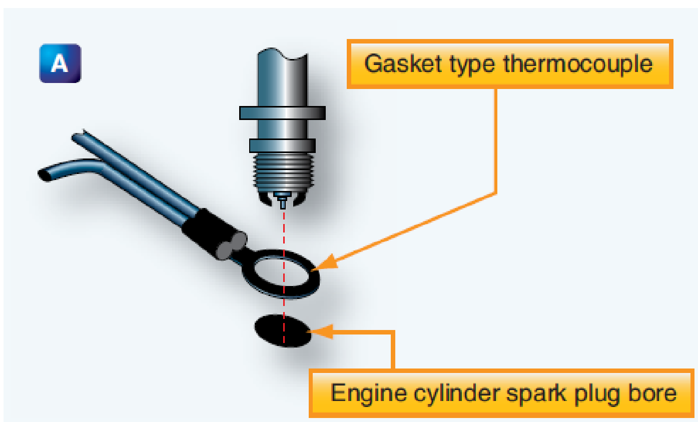
- EGT is a critical variable of turbine engine operation.
- The EGT indicating system provides a visual temperature indication in the cockpit of the turbine exhaust gases as they leave the turbine unit.
- Several thermocouples are used to measure EGT. They are spaced at intervals around the perimeter of the engine turbine casing or exhaust duct.
- The tiny thermocouple voltages are typically amplified and used to energize a servomotor that drives the indicator pointer.



A typical exhaust gas temperature thermocouple system

CYLINDER HEAD TEMPERATURE (CHT) GAUGE

- In the gasket type thermocouple system, two rings of the dissimilar metals are pressed together to form a gasket that can be installed under a spark plug or cylinder hold down nut.



SYNCHROSCOPE

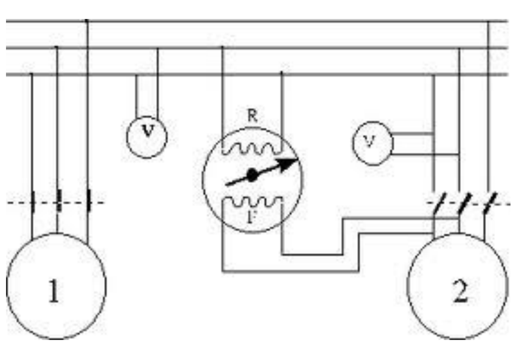
- A synchroscope is an instrument used to establish phase angle and frequency synchronization between alternating current (AC) power supplies.
- This is a critical safety measure when AC power networks or generator outputs are merged or connected together.
- For two electrical systems to be synchronized, both systems must operate at the same frequency, and the phase angle between the systems must be zero (and two polyphase systems must have the same phase sequence).
- Synchroscopes measure and display the frequency difference and phase angle between two power systems.
- Only when these two quantities are zero is it safe to connect the two systems together.
- Connecting two unsynchronized AC power systems together is likely to cause high currents to flow, which will severely damage any equipment not protected by fuses or circuit breakers.

There are two basic types of synchroscope.

- **Electro-mechanical synchroscope**
- **Electronic synchroscope**

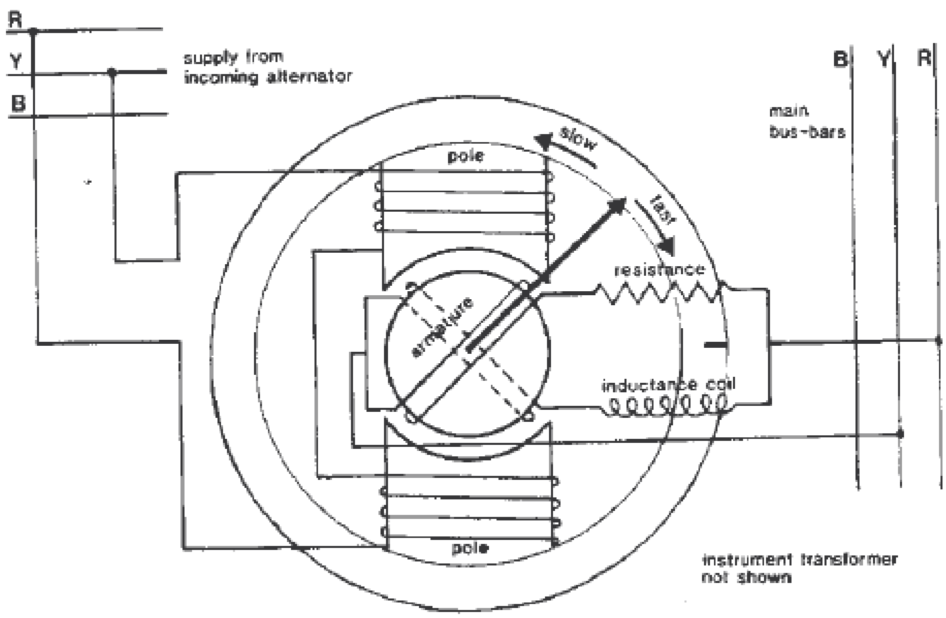
ELECTRO-MECHANICAL SYNCHROSCOPE

- The electro-mechanical type synchroscope indicates phase and frequency relationships with a pointer and dial indicator.

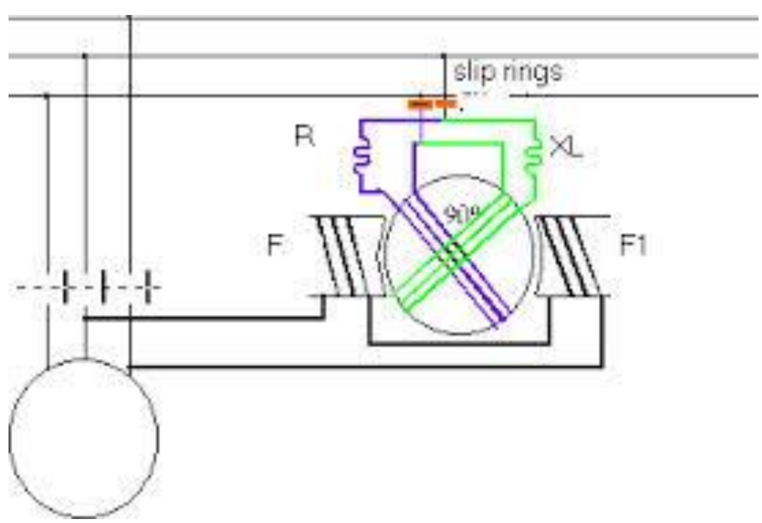


- The synchroscope consists of a small motor with coils on the two poles connected across two phases.

- Let's say it is connected in red and yellow phases of the incoming machine and armature windings supplied from red and yellow phases from the switchboard bus bars.
- The bus bar circuit consists of an inductance and resistance connected in parallel.
- The inductor circuit has the delaying current effect by 90 degrees relative to current in resistance.



- These dual currents are fed into the synchroscope with the help of slip rings to the armature windings which produces a rotating magnetic field.



- The polarity of the poles will change alternatively in north/south direction with changes in red and yellow phases of the incoming machine.

- The rotating field will react with the poles by turning the rotor either in clockwise or anticlockwise direction.
- If the rotor is moving in clockwise direction this means that the incoming machine is running faster than the bus bar and slower when running in anticlockwise direction.

ELECTRONIC SYNCHROSCOPE

- This type utilizes a microprocessor designed to sample and compare two AC power supplies for phase and frequency characteristics.
- Any differences between the two are then calculated and indicated on either a digital liquid crystal display (LCD) or by means of LEDs.
- In some type of synchroscope typically has a circle of LEDs on its front panel which illuminate in a set pattern to indicate the presence and magnitude of phase and frequency differences.

Before synchronization, following conditions must be satisfied:

Equality of Voltage

The terminal voltage of both the systems i.e. the incoming alternator and the bus bar voltage or other alternator must be same.

Phase Sequence

The phase sequence of both the systems must be same.

Equality of Frequency

The frequency of both the systems must be same.