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DOCUMENT TITLE

AIRCRAFT GENERAL KNOWLEDGE

CHAPTER 2 – HYDRAULIC SYSTEM

Version 1.0
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HYDRAULIC SYSTEM

2.1 Introduction

The flaps and undercarriage of this B747 are operated by means of hydraulic power.

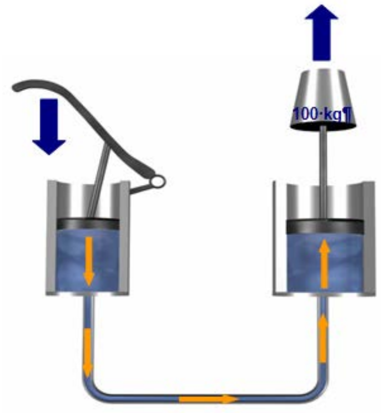
A hydraulic system is a high-powered, extremely accurate, remote control system. It affords a convenient way of transmitting power for the operation of devices such as retractable undercarriages, flaps, flight controls and wheel brakes.

Hydraulic systems are compact and robust and may therefore be placed in close proximity to the surface or piece of equipment they are to operate; this eliminates the need for large bulky mechanical systems.

The two large hydraulic actuators shown here at the rear of the strut provide steering for the B747 main body gear. Note the piping at the rear of the strut which carries the hydraulic fluid providing the power.

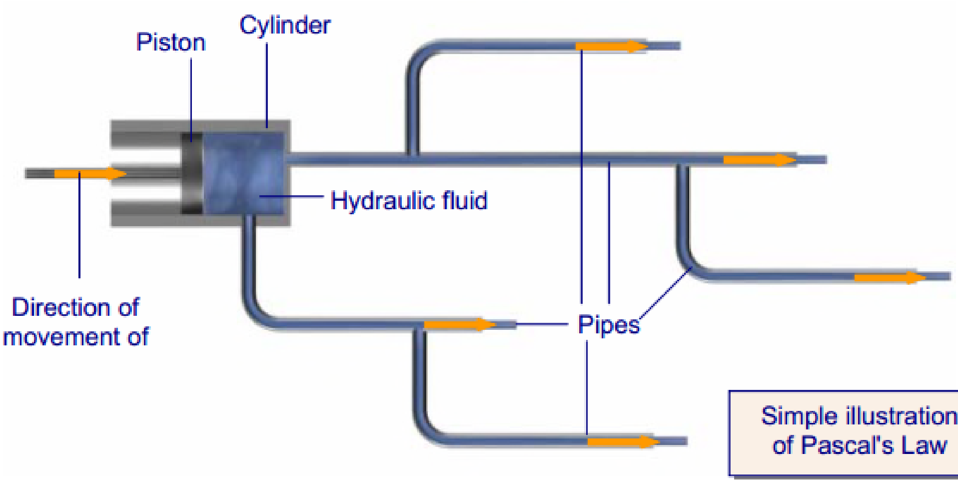
2.2 Principle of Operation

Hydraulic systems are used primarily to transmit and distribute forces. Fluids are able to do this because they are almost incompressible.



2.3 Pascal's Law

Pascal's Law states, "Pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part." Thus, if a number of passages exist in a system, pressure can be distributed through all of them by means of the fluid.



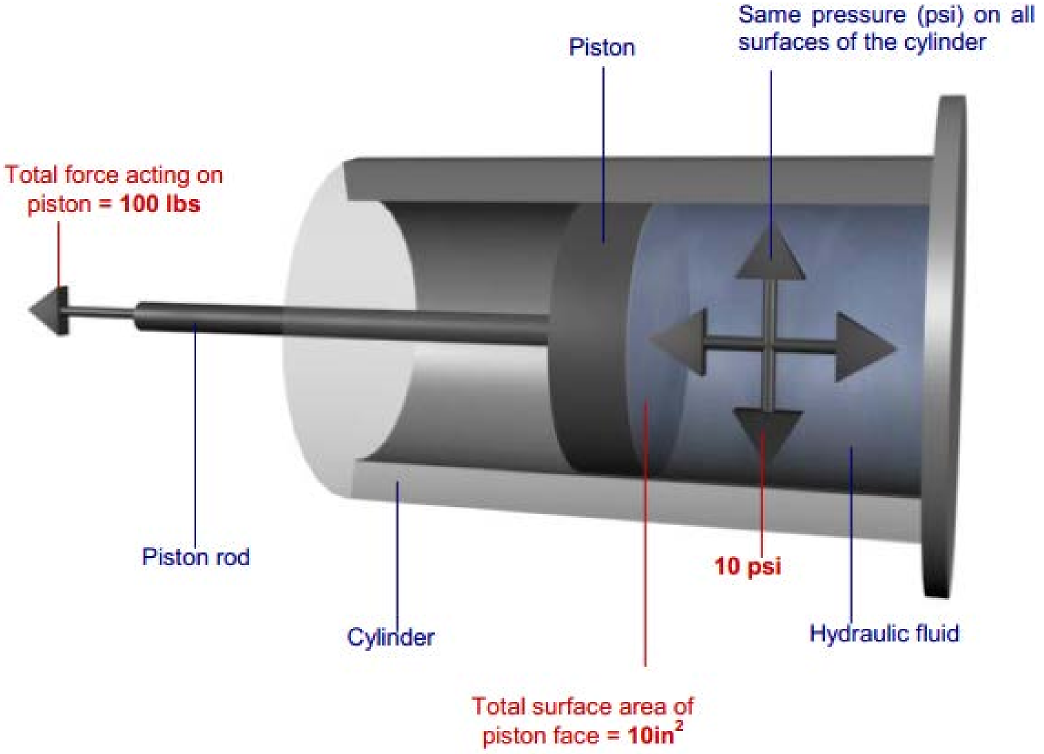
Simple illustration of Pascal's Law

In hydraulic systems, power is transmitted as **fluid pressure** to a mechanism, which converts this power into **mechanical work**.

Mechanical Work
In this context, actions like a retractable undercarriage or the movement of control surfaces, flaps, etc.

Fluid Pressure
Because the hydraulic fluid is not compressible, the force exerted on it is "carried over" to the areas that are in contact with the hydraulic fluid. This "force" or pressure in the fluid is known as fluid pressure.

If a fluid is stationary and confined under pressure in any container, the pressure is the same on all surfaces of the container.



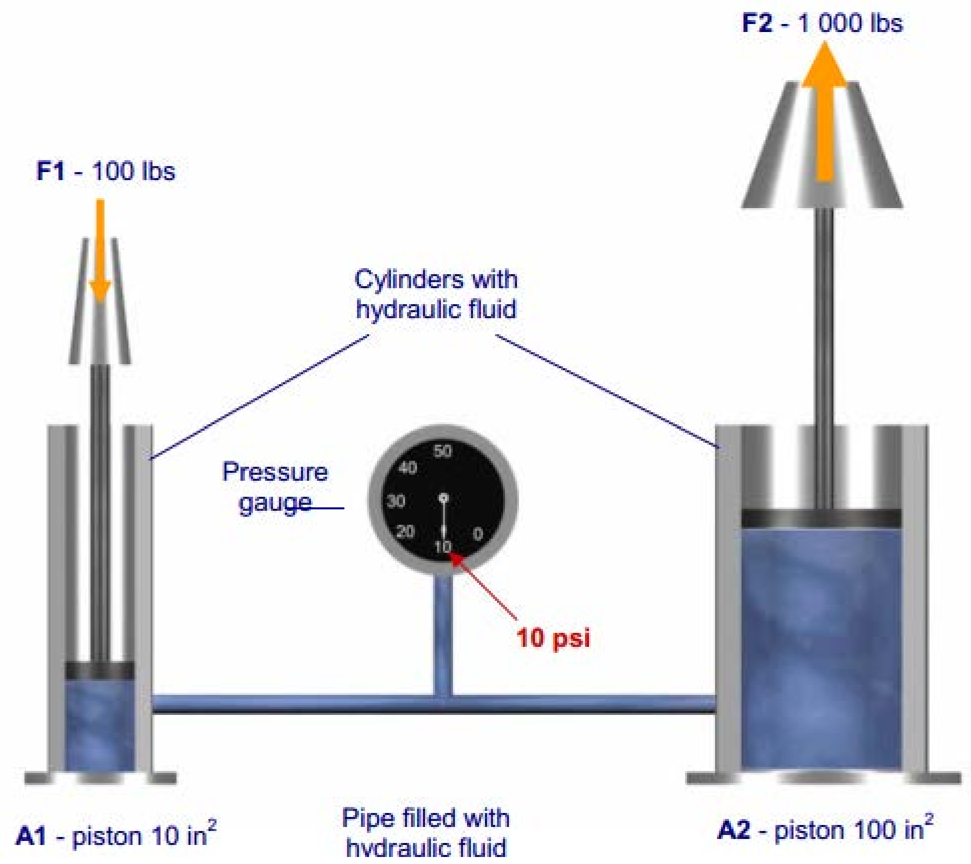
This graphic shows a cylinder with a piston and a piston rod. If the fluid in the cylinder is at a pressure (**P**) of 10 psi and the area of the face of the piston is 10 in2, the total force acting on the piston and transmitted by the rod to any mechanism to which it may be connected is 100 lbs.

Total Effective Pressure

This is the total force exerted on a particular surface of a container. It is calculated using the following formula:

Total effective Pressure	**=**	**Pressure (psi)**	**x**	**Surface Area (in^2).**
100 lb	**=**	**10 psi**	**x**	**10 in^2**

A hydraulic system is a high power, extremely accurate, remote control system. This graphic demonstrates the principle of fluid pressure in a simple hydraulic machine.



Two cylinders are shown connected by a pipe, fitted with a pressure gauge:

- The small cylinder (A1) is fitted with a piston of 10 in2.
- The large cylinder (A2) is fitted with a piston of 100 in2.
- Application of a force (F1) of 100 lbs to the rod of the small piston produces throughout the fluid a pressure (P) of 10 psi as indicated by the pressure gauge.
- This pressure (10 psi) acting on the face of the large piston produces a force of 1000 lbs supporting the force (F2) on the second cylinder.

Total Force

This is the total force exerted on a particular surface of a container. It is calculated using the following formula:

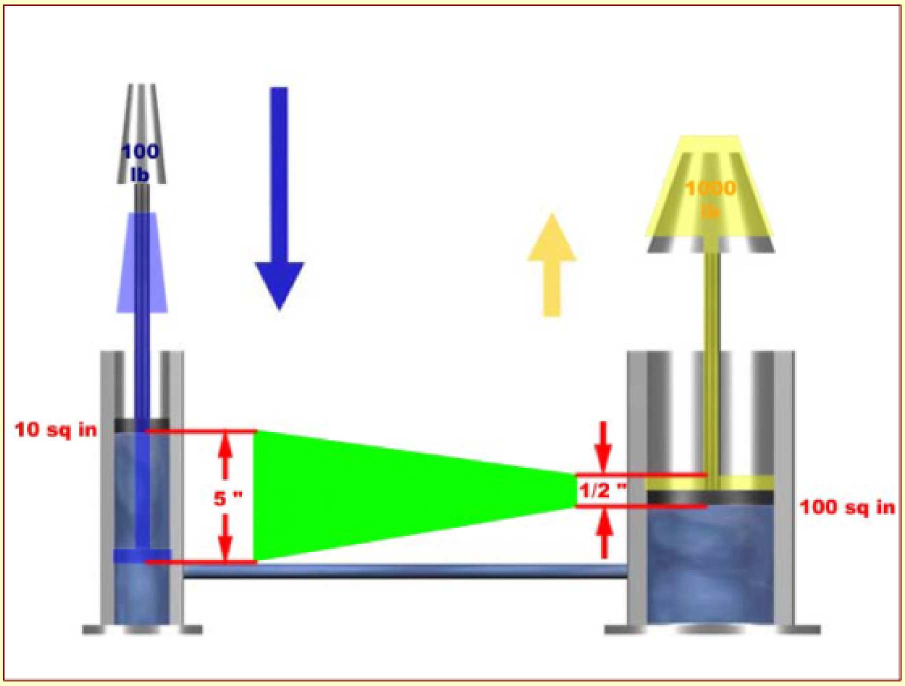
Pressure x Area = Force

10 psi x 100 in^2 = 1 000 lbs.

Example:

The principle of hydraulic power transmission can best be illustrated with a practical example:

1. Refer back to Pascal's Law that states, **"Pressure applied to any part of a confined liquid is transmitted with undiminished intensity to every other part."**



2. It follows that if the small piston is pushed downwards in the cylinder through a distance of **five inches** …

3. The large piston will move upwards in its cylinder through a distance inversely proportional to the areas of the two pistons.

4. The large piston will thus move through **10 ÷ 100 x 5 = ½ inch**.

5. The work done by the small force (i.e. force x distance through which its point of application moves) is transmitted hydraulically and equals the work expended in moving the greater force through a shorter distance.

2.4 Types of Hydraulic Fluid

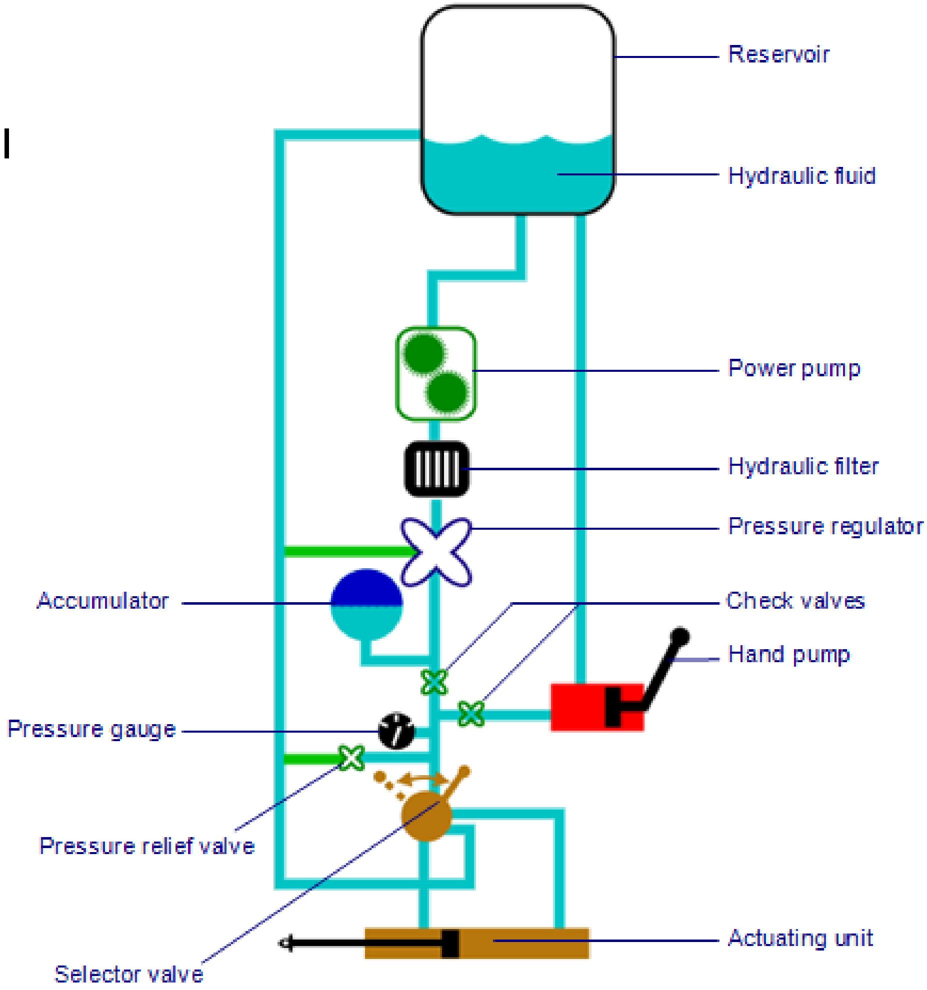
Over the years considerable effort has gone into the development and improvement of hydraulic fluids. As the material used in aircraft construction changed, so did the composition of hydraulic fluids.

There are three main types of hydraulic fluid, i.e. each type uses a different base:

Vegetable based hydraulic fluids	Mineral based hydraulic fluids	Synthetic hydraulic fluids
		
• These hydraulic fluids are composed essentially of castor oil and alcohol.	• These fluids are processed from petroleum.	• Synthetic hydraulic fluids are normally phosphate ester (synthetic) based.
• It is dyed blue for identification purposes.	• It is dyed red for identification purposes.	• It is dyed purple for identification purposes.
• Vegetable based hydraulic fluid is flammable.	• This type of fluid is also flammable.	• It is fire resistant.

2.5 Hydraulic System Components

Hydraulic systems typically have the following components:



Diagrammatic representation of a typical hydraulic system

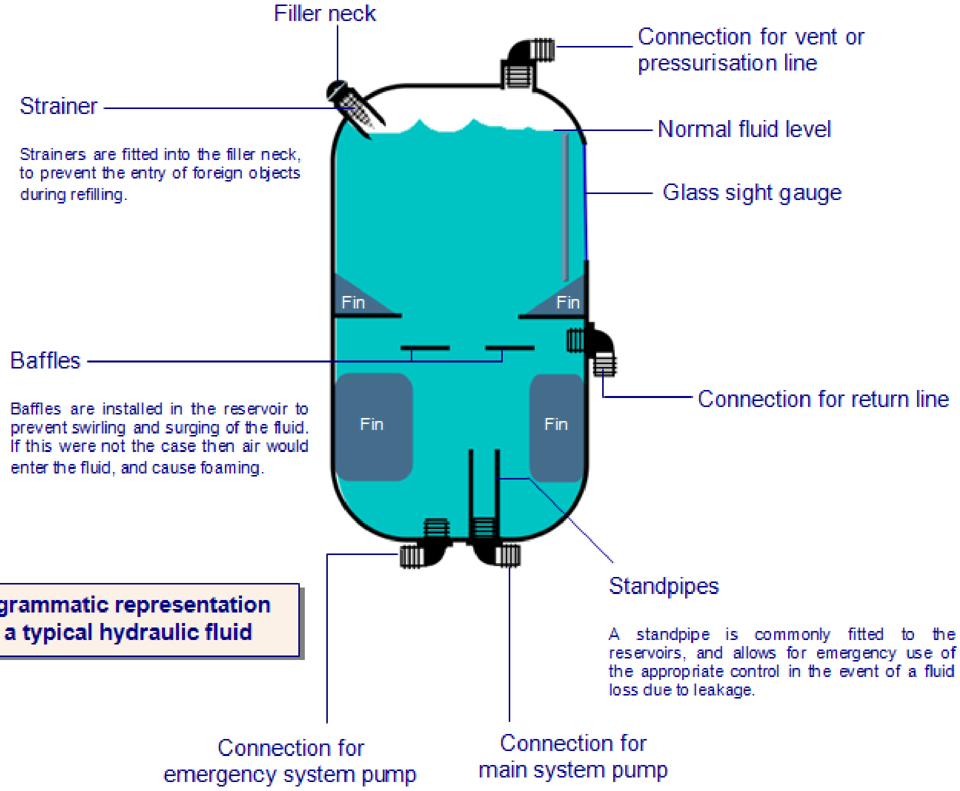
2.5.1 Reservoir

The reservoir serves as a storage unit for hydraulic fluid and compensates for system loss due to leakage. It also provides fluid when charging the system accumulator. An airspace is provided above the normal level of fluid to allow for expansion and for the escape of entrapped air. Whenever a hydraulic actuator moves there is a demand for fluid on one side of the piston whilst fluid on the other side of the piston is forced to return. During operation of actuators, the fluid level in the reservoir will vary due to different volumetric area in the hydraulic cylinder on either side of the actuator piston.

A typical reservoir has a screened filter to prevent foreign matter from entering the tank, a vent to allow air to leave or enter the tanks when the fluid level rises or falls, and baffles to prevent surging of fluid. A sight gauge enables the fluid level to be checked. On some reservoirs a transmitter provides fluid quantity to a remote cockpit gauge.

In the event of a major leak in the hydraulic lines, fluid supplied to the pump would then be wasted through that leak. The use of a standpipe prevents the system pump from receiving fluid once the fluid level falls below the standpipe. The remaining fluid in the reservoir will then be available for emergency pump operation.

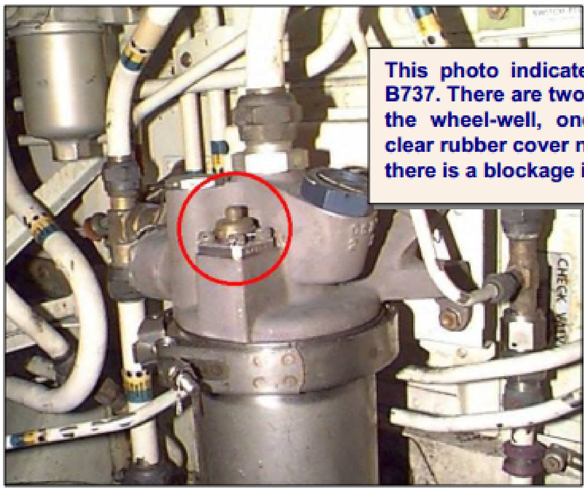
For aircraft that fly at high altitude where the atmospheric pressure is correspondingly low, the reservoir is pressurised to ensure that the pump receives a constant supply of fluid and therefore does not **cavitate.** (Occurs when the supply fluid coming from the reservoir is of insufficient flow to satisfy the requirement of the pump.)



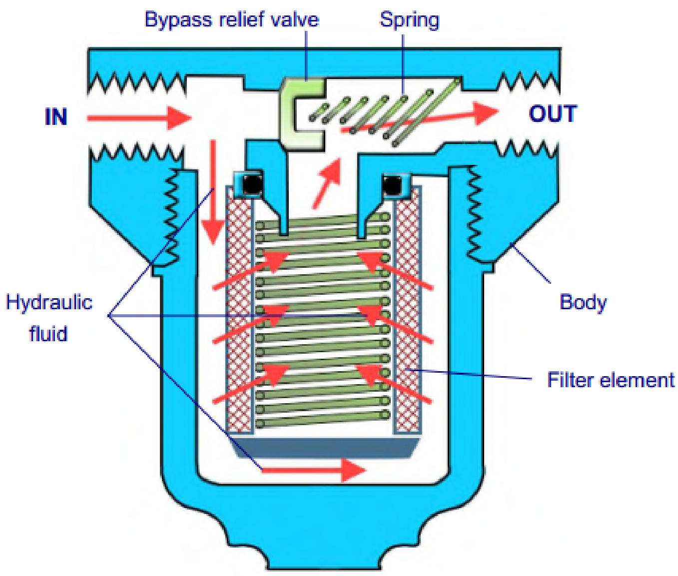
Diagrammatic representation of a typical hydraulic fluid

2.5.2 Hydraulic Filter

A filter is a screening or straining device through which the fluid is circulated. It is used to clean the hydraulic fluid, thus preventing foreign particles and contaminating substances from remaining in the system. If such material is not removed, it may cause the entire hydraulic system to fail.



This photo indicates a hydraulic filter of a B737. There are two hydraulic return filters in the wheel-well, one for each system. The clear rubber cover near the top will turn red if there is a blockage in the filter.



This graphic shows a typical **micronic** type of filter. Take special note of the bypass valve that is incorporated in the system (the valve forces the fluid to go through the filter). If the filter gets blocked, the pressure will build up, and if it exceeds the limit of the bypass valve, it will force the valve to open thereby ensuring that the system can still receive hydraulic fluid (even though it will be unfiltered).

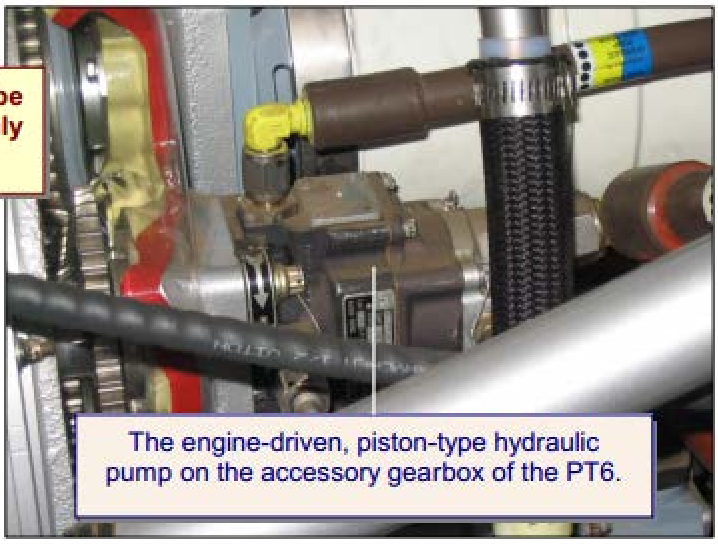
Micronic (1 Micron = 1 Millionth of a Metre)

This indicates the size of the openings in the filter element. If the openings are 2 microns it implies that any particle larger than 2 microns in diameter will remain behind in the filter.

2.5.3 Pumps

The purpose of the pump is to supply a fluid flow to the hydraulic system, and therefore it is the "heart" of the circuit. In order for a pump to provide pressure to operate a system, a resistance to fluid flow must be provided. The continued flow of fluid from the pump against the resistance will then cause the hydraulic pressure to rise until it reaches the required system pressure. Hydraulic pumps can be: Electrically driven, Engine driven (EDP), Bleed Air driven (ADP), Ram Air driven (RAT), Hydraulically driven (PTU) or Hand Pump (emergency).

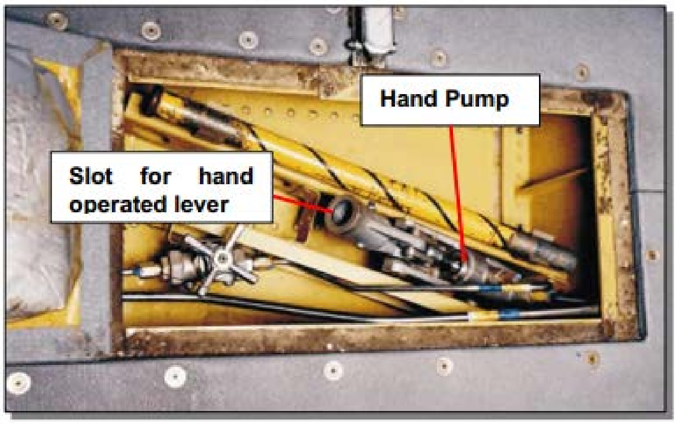
Note: Hand pumps may also be connected but are often used only in emergency situations.



The engine-driven, piston-type hydraulic pump on the accessory gearbox of the PT6.

2.5.4 Hand Pumps

The primary purpose of the hand pump in the system is to provide an emergency means of operating components when the power pump fails. Its secondary purpose is for ground testing when it is impracticable to use the power pump.



Most hand pumps are of the piston type and are usually double action pumps.

2.5.5 Pump Drives

Utilising RAM AIR this impellor driven pump is typically deployed into the external airstream by electric motor or spring:

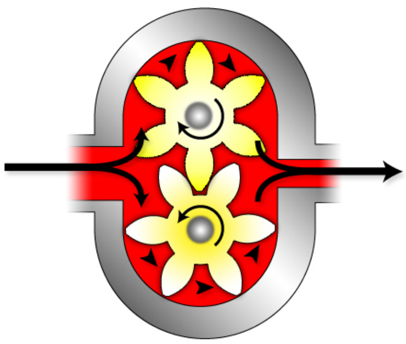
- Normally the last resort emergency pump for the system (aircraft)
- Typically provides hydraulic pressure to the flight controls only to land the aircraft
- Will have a minimum airspeed required for effective operation
- Normally just enough flow to do the flight controls (approx 11 GPM @ 3000PSI)
- Common abbreviation RAT.

Ram Air Turbine (RAM)

2.5.6 Gear-Type Pumps

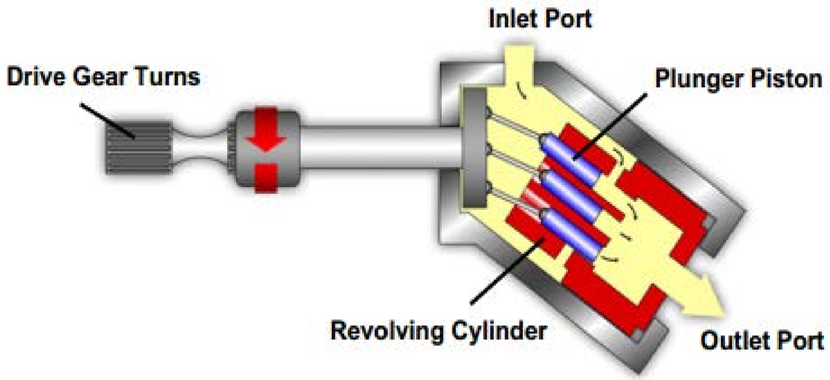
The gear type pump is generally found in the lower pressure systems and provides pressures up to 1500 psi.

The pump consists of 2 steel gears, one of which is turned by the engine accessory gearbox and is called the drive gear. The meshing of the pump gears allows for the other gear to be driven. At a constant RPM, the pump will deliver a **constant volume** of fluid.



2.5.7 Piston Type Pump

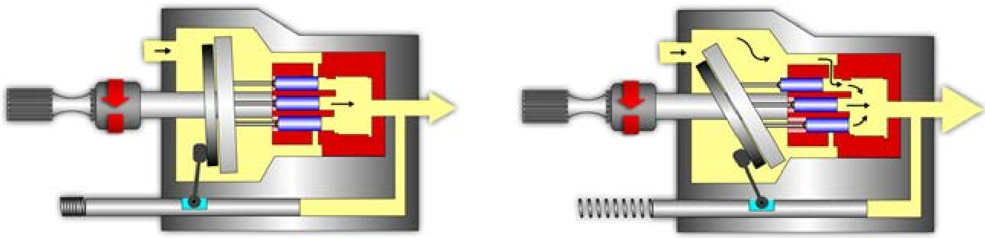
A revolving cylinder carries a set of reciprocating piston plungers, which draw in fluid on an upward stroke, and discharge the fluid under pressure on a downward stroke; this type of pump is very common and has the ability to produce upwards of 3000 psi.



Note: Because of its capability to develop fairly high-pressure (aircraft hydraulic systems operate normally in the region of 3 000 psi), piston-type pumps are most commonly used in aircraft hydraulic systems.

2.5.8 Variable Displacement Pumps

These pumps supply all the demands of the hydraulic system. If actuators are in operation then a mechanism automatically increases the volume of fluid flow from the pump, and conversely reduces the flow when actuators are not in use. A constant system pressure is maintained, and there is no need to include a pressure regulator in the hydraulic system. The piston pump, illustrated below, is a typical variable displacement pump.



Enough flow to maintain pressure

High Flow Rate

2.5.9 Constant Volume Principle

In the constant volume system the pump output is fixed. A pressure regulator is used to unload the pump when the system pressure is reached.

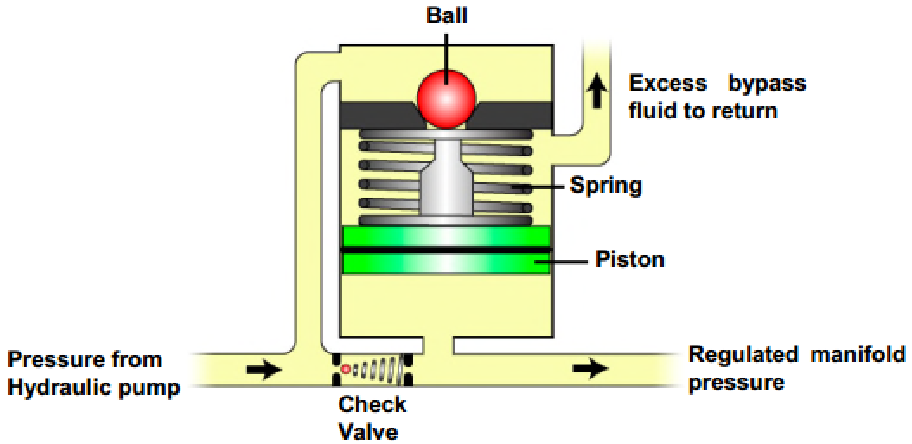
2.5.10 Constant Pressure Principle

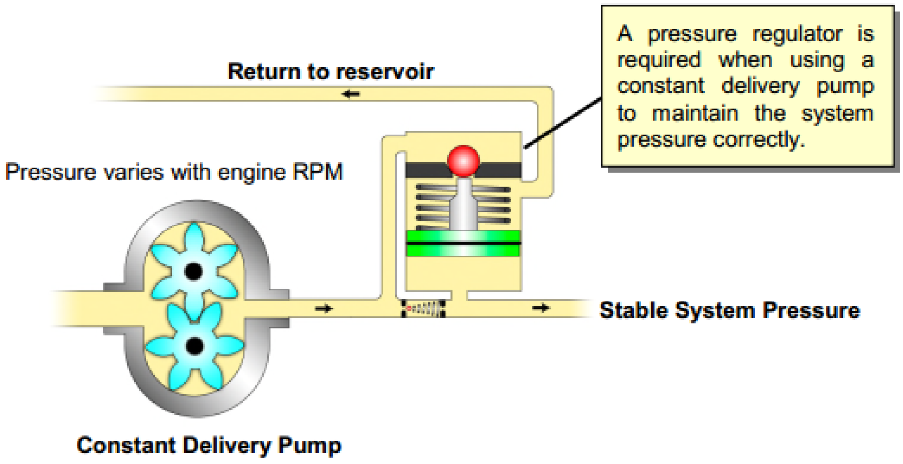
The constant pressure system utilizes a variable output pump, the output being varied according to the system demands. Some small aircraft use electric hydraulic pumps which are controlled by a pressure switch.

2.5.11 Pressure Regulator

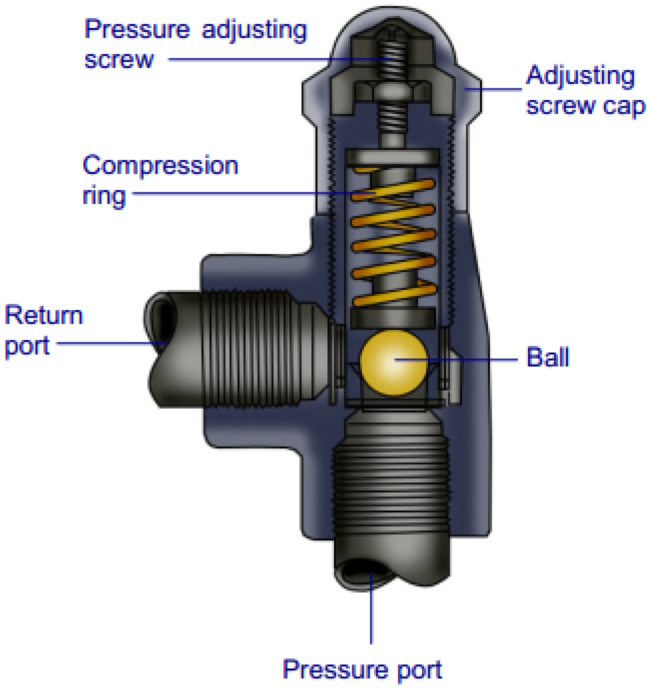
Used with constant volume systems (allows fluid by-pass and return to reservoir), the pressure regulator has two functions:

- To control and maintain the normal pressure in the system at a predetermined value.
- To relieve the pump of its load when the system is not in use.





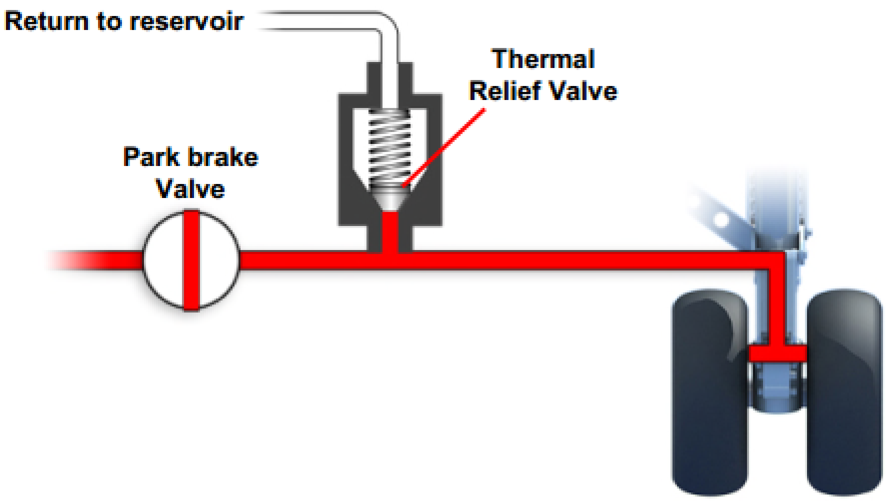
2.5.12 Pressure Relief Valves



Should the pressure regulator in a hydraulic system become inoperative with the pump running, the system pressure would increase to a value beyond the maximum design pressure, which may result in the system failing. To overcome this, a pressure relief valve is incorporated to prevent failure of components or rupture of hydraulic lines.

The relief valve is always set to operate at a pressure higher than the pressure regulator "cut-out". If the relief is set at a value lower than that of the regulator unit, it will open and cause the hydraulic pump to operate continuously.

2.5.13 Thermal Relief Valves



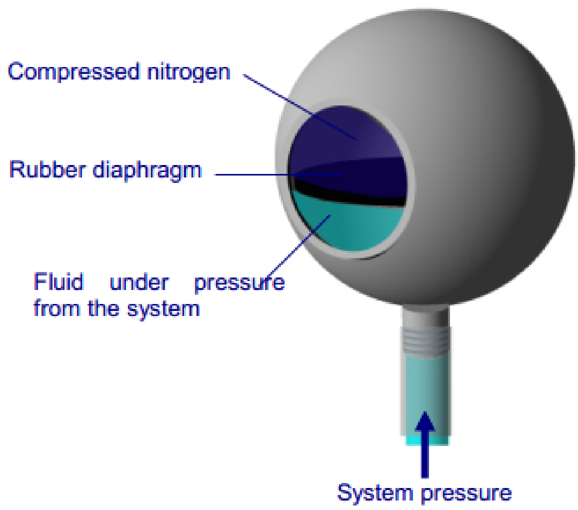
Thermal Relief Valves protect the system from overpressure caused by thermal expansion of trapped fluid. Typically used for park brakes.

2.6 Accumulators

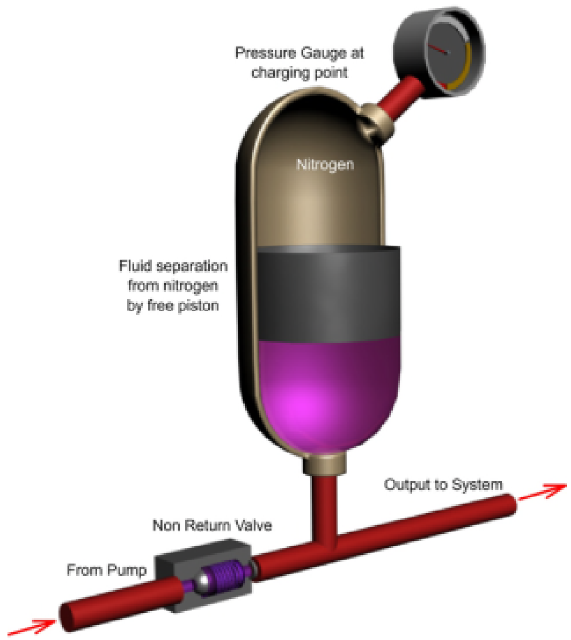
The accumulator provides fluid movement for the following:

- It maintains line pressure for a short time following the failure of the hydraulic powered pump.
- It assists the pump in maintaining line pressure when two or more services are used simultaneously.
- It prevents abrupt changes in line pressure between the higher value where the cut-out valve cuts out, and the lower value where the valve cuts back in and line pressure is once again boosted by the pump.
- It dampens pulsations of the hydraulic pump.
- It allows for thermal expansion.
- Can be used to store emergency braking pressure.

The accumulator may take various forms and examples of these are shown below. Some simple accumulators have no separating device and gas pressure is applied directly to the surface of the fluid, but this type is not common in transport aircraft.



Diaphragm Type Acumulator



Piston Type Acumulator

Normally pre charged with Nitrogen to approximately 50% of the operating hydraulic pressure, a pressure gauge on the unit indicates the stored gas pressure. This pressure must be checked before hydraulic pumps are turned on otherwise the gauge will indicate hydraulic pump pressure.

2.7 Check Valves

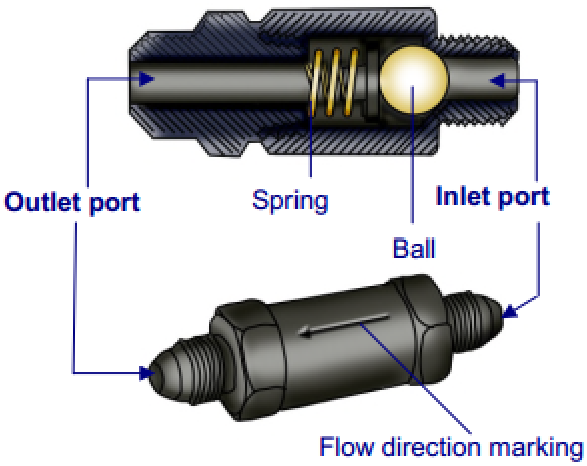
For hydraulic components and systems to operate as intended, the flow of fluid must be rigidly maintained. The check valve allows free flow of fluid in one direction, but no flow (or a restricted flow) in the other direction is allowed.

Two types of "in-line" check valves are commonly found in hydraulic systems:

2.7.1 Simple Type

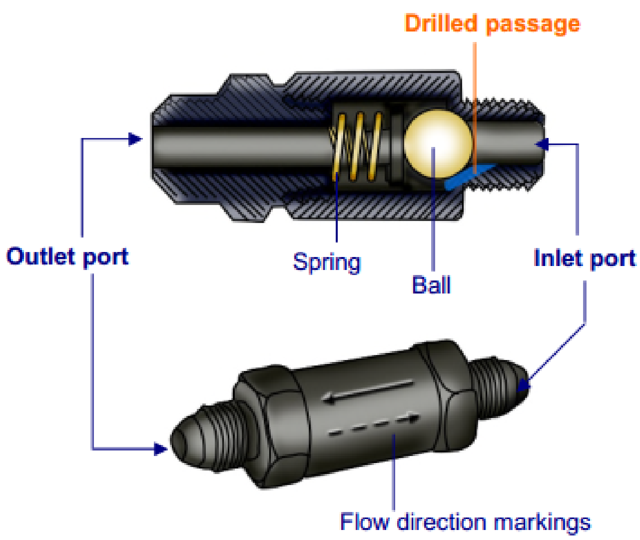
In the "simple-type" in-line check valve the fluid pressure (delivered by either the pump or the accumulator) forces the fluid past a ball that is held against an opening by a spring at a certain pressure.

The moment the pressure drops the ball closes the opening and no fluid can flow back past the ball.



2.7.2 Orifice Check Valve (Restrictor Valve)

An orifice check valve is designed to provide free flow of hydraulic fluid in one direction and restricted flow in the opposite direction. One of the most common applications of this device is in the “UP” line of a landing-gear system. Since the undercarriage is usually quite heavy, it will tend to fall rapidly upon lowering, unless some means of restricting its movement is used.

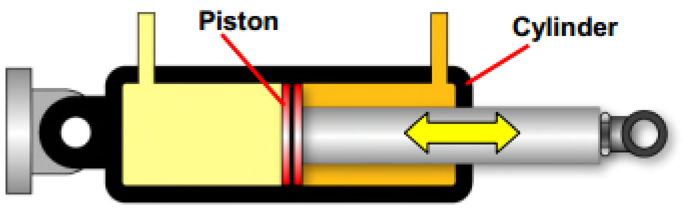


Since the “UP” line is the return line for hydraulic fluid, any restriction in this line will limit the movement of the gear. Thus, the gear movement must await the flow of the return fluid as it moves towards the down position. When used in this application, the valve must be adjustable to allow the extension rate of the landing gear to be controlled.

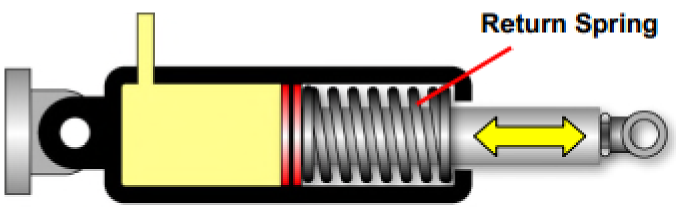
An orifice check valve is also used in some flap systems to control the rate of movement of the flaps. Because of the air pressure on the flaps during flight, there is a continuous force tending to raise the flaps to a streamline position.

2.8 Hydraulic Actuators (Jacks)

The purpose of the jack is to convert the force produced by the fluid pressure into useful work in the form of movement of the piston. The cylinders may be one of a number of different types. Single Acting and Double Acting non-compensated type actuators are normally used on landing gear systems. Double Acting compensated type actuators are normally found on flight control systems where equal force is required to operate control surfaces in both directions.



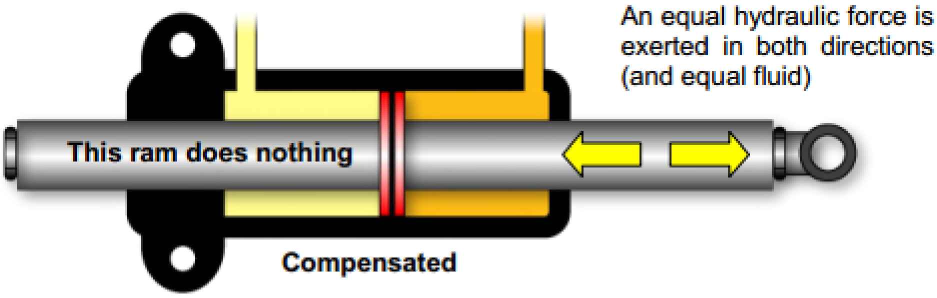
Double Acting non compensated Actuator

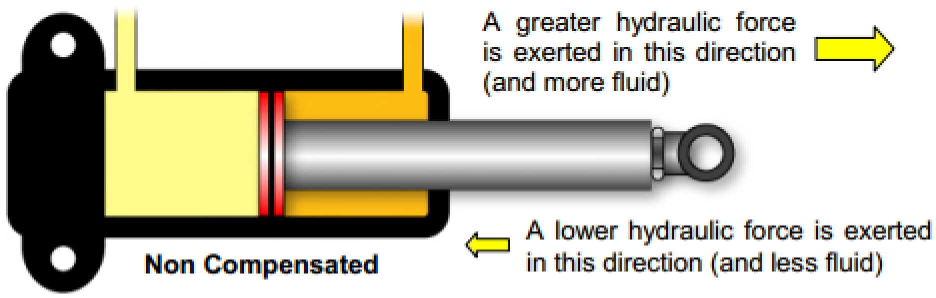


Single Acting non compensated Actuator

A retractable nose wheel may be operated using a single actuating cylinder.

2.8.1 Compensated / Non Compensated Actuators

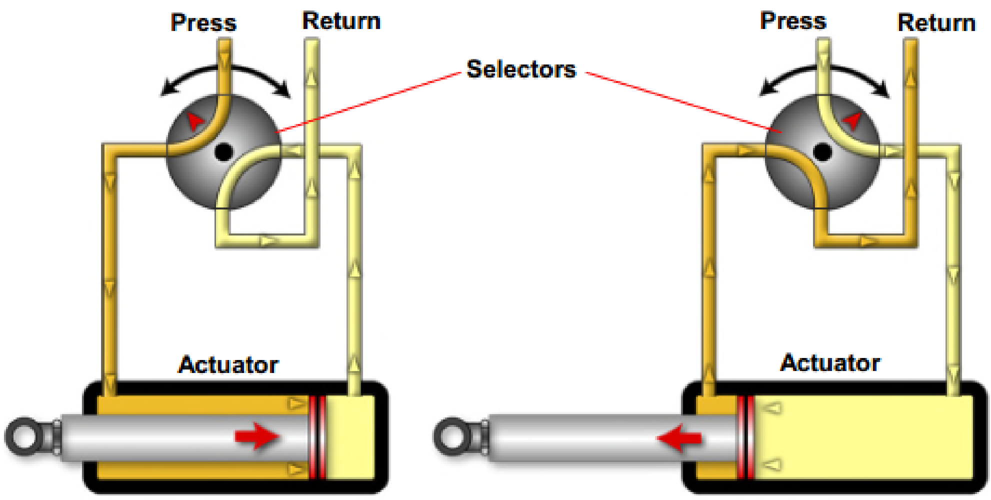




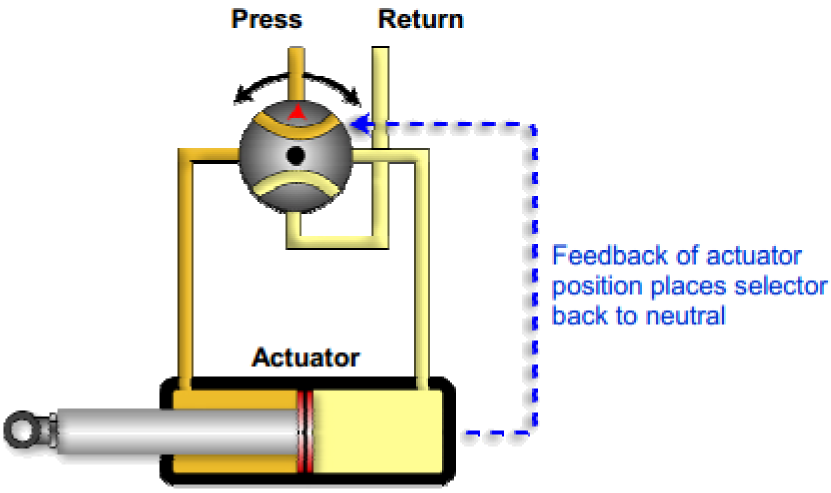
2.9 Selector Valves

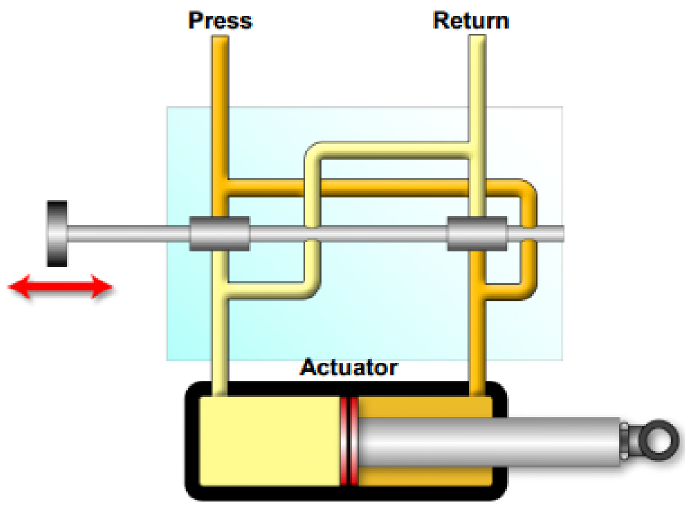
In almost any hydraulic system, one or more directional control valves or selector valves are required to control fluid flow.

The simplest type of valve is merely an on-off valve to open or close a passage. However more usually the actuating cylinder is required to reverse operation. In such cases it is necessary to incorporate a four-way valve which permits fluid flow in either direction. Selector valves may be of rotary, poppet or piston type.



Rotary Type Selector Valve



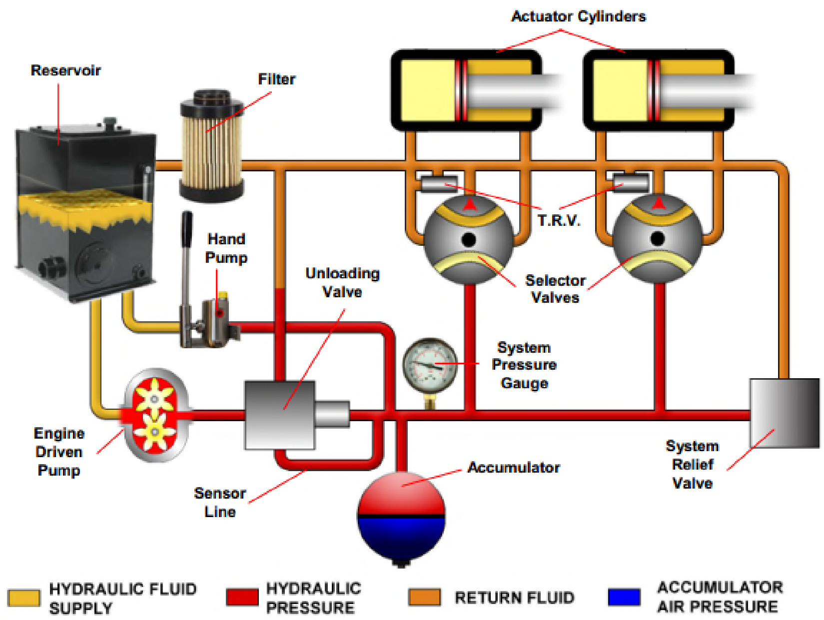


Inline Type Selector Valve

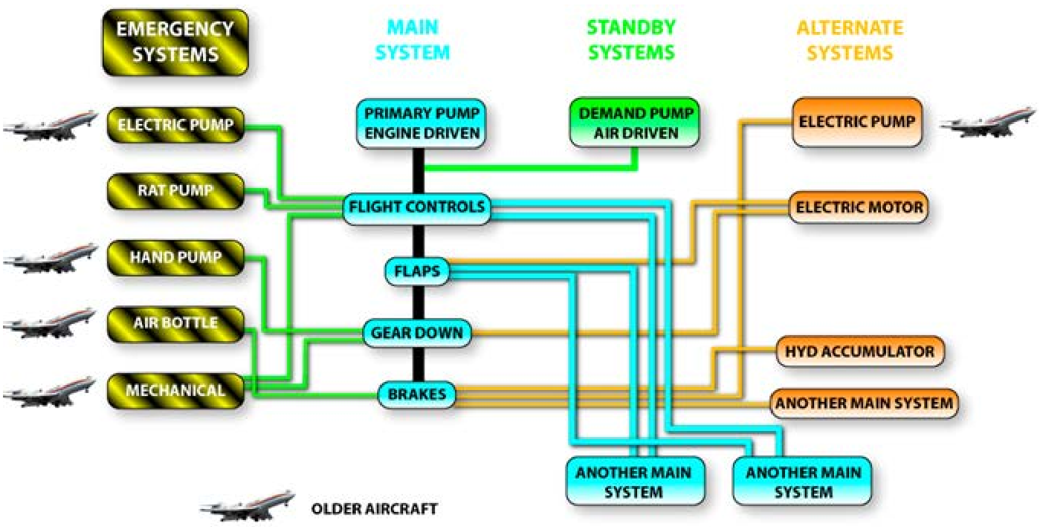
2.10 Aircraft Systems

2.10.1 Circulating System

With this system, operating pressure is maintained between the system pump and the selector valves which are normally placed in parallel and allows the supply pressure to be available instantaneously whenever a service is selected. If this type of system employs a fixed volume pump an un-loading valve (pressure regulator) is provided to regulate system pressure and prevent the pump from being continuously loaded. Other closed-centre systems may employ a variable displacement pump where volume is reduced to idle as system pressure reaches normal operating range. A system incorporating this type of pump does not require an un-loading valve.



2.11 Redundancy - Summary



2.11.1 Aircraft Brake Systems

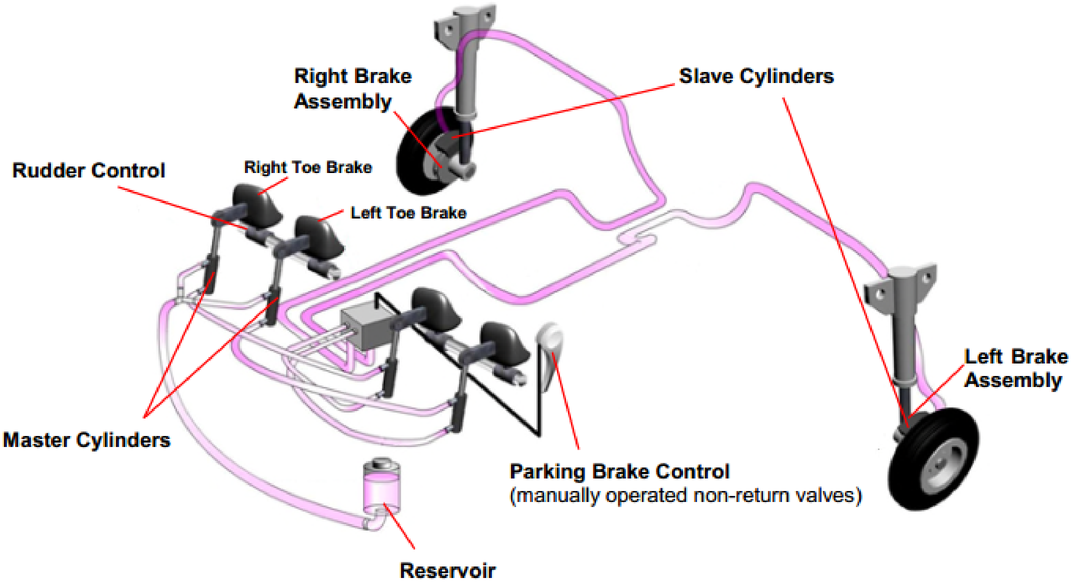
Brakes are fitted to main wheels only. The brakes must supply enough force to provide for holding the aircraft during normal run up, slowing the aircraft after landing and steering the aircraft.

They are hydraulically operated and usually of the self adjusting disc type. In a simple brake system operated by pilot toe pressure, fluid from a master cylinder is supplied under pressure to slave cylinders or brake calipers which apply the brakes.

When the brake pedal is released the master cylinder piston is returned to a position where hydraulic pressure is removed from the brake caliper.

On light aircraft the braking system is usually independent of the aircraft's hydraulic system and contains the following components:

- Hydraulic fluid reservoir
- One or two master cylinders
- Mechanical links from the rudder pedals to the master cylinders
- Fluid lines and flexible hoses
- A brake unit for each main wheel.



2.11.2 Park Brake Mechanism

To apply the park brake, pressure is applied via the rudder pedals, a park brake knob or lever is then moved and positions a valve which traps the applied pressure when the pedal force is removed. To release the park brake the control lever is moved to off.

Parkbrake - ON

Parkbrake - OFF

2.12 Brake System Faults

Common faults which can reduce braking effectiveness include:

- Air in hydraulic lines - a springy/spongy feel.
- Hydraulic fluid leak - brake toe pedal moves slowly away without the pilot being able to apply maximum pressure.
- Water or dirt between brake pad and disc - reduced braking effectiveness, noisy brake operation.

Until a pilot develops a feel for aircraft brakes, the following factors could cause significant and unexpected response when applying the brakes:

- Incorrect tyre pressure/tyre condition
- Aircraft weight
- Runway surface condition
- Aircraft speed
- Aircraft brake condition.

If excessive brake pressure is applied, the brakes can lock a wheel (or wheels). These results in skidding, loss of directional control and possibly tyre blow out. Blow out reduces braking effectiveness and directional control to dangerously low levels which could cause serious damage to the airframe.

Anti skid braking is fitted to most large aircraft. It uses electronic sensing to measure wheel rotation. If wheel rotation speed is below a predetermined level, the brakes are temporarily released of hydraulic pressure by incorporating anti-skid valves. Wheel rotation is now able to increase again, where upon the brakes are quickly reapplied! By keeping the wheel rotation speed just above a skid condition, maximum braking capability is achieved.

2.13 Introduction

The undercarriage is the assembly attached to the underside of the aircraft often referred to as the landing gear. The undercarriage is required to:

- Absorb the compression loads of landing
- Support the weight of the aircraft while parked
- Allow the aircraft to taxi and manoeuvre while on the ground.

Landing gear arrangement is classified as either fixed or retractable, and normally takes the form of the conventional tricycle configuration. This comprises of one landing gear assembly under each wing, and a nose or tail wheel.

Fixed

Retractable

Fixed:

\+ simple construction
simple shock absorbers
low weight

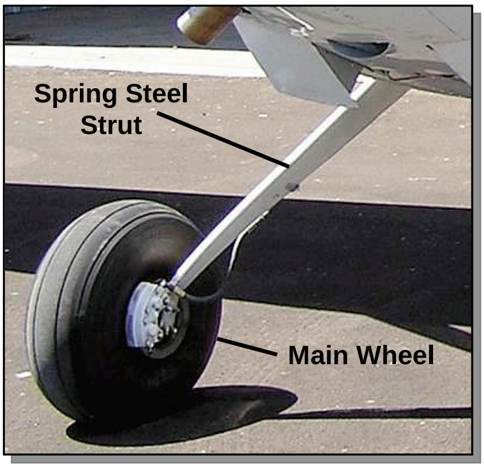
\- High Drag
Some aircraft put streamlining covers over the gears to reduce drag

Retractable:

\+ no drag when retracted

\- high weight, high drag during extension and complicated construction and operational emergency extension system required

2.13.1 Fixed Undercarriage

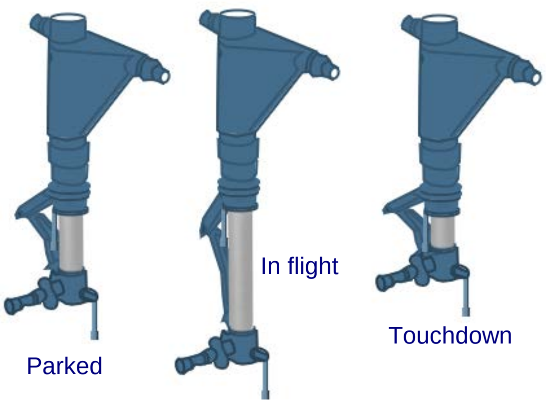


All fixed undercarriage systems use some type of spring device or shock absorber to allow initial compression on landing. On small light aircraft the spring device method is usually adequate for the main landing gear. However, every good spring absorbs energy when compressed and therefore will release energy in the form of recoil (equal and opposite force). During a heavier than normal landing, this recoil force can throw the aircraft back into the air and result in two or three bounces.

Larger aircraft generally use an oleo (oil-air filled) shock strut to absorb the energy of the landing loads. The common types of struts used are the oleo and elbow shock absorber. Nose wheel struts are of the oleo type while tail wheel suspension may be only a simple spring device.

As aircraft become larger, the recoil is a potential source for an accident. Shock absorbing devices are designed to allow compression but reduce the speed of the recoil, keeping the aircraft on the ground. This is achieved by restricting the oil flow in the oleo shock absorber during the recoil phase.

This graphic indicates typical strut compression and extension during various phases of operation:



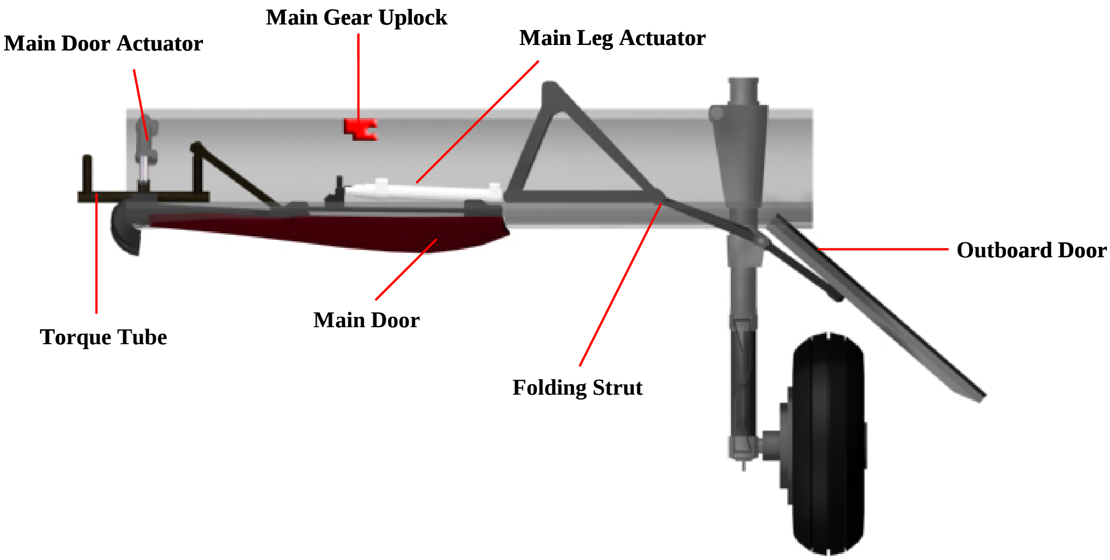
2.13.2 Retractable Undercarriage

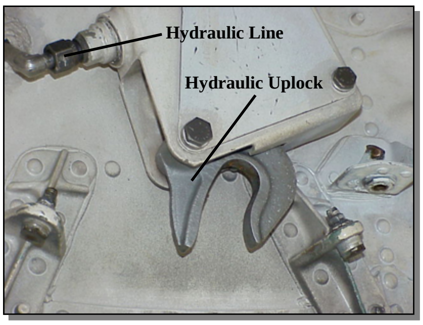
For faster aircraft, a retractable undercarriage reduces 'form drag' and allows for a faster and more fuel efficient flight. Due to design, retractable systems result in additional aircraft weight and are generally fitted to aircraft which are larger and heavier compared to basic training aircraft. These systems incorporate oleo struts which can be retracted inside the airframe.

Many types of aircraft incorporate 'flipper doors' which open to allow the strut assembly to be hydraulically retracted into the undercarriage wheel well. The doors then close streamlining the aircraft fuselage to reduce drag. Although the majority of these systems are hydraulically operated, they can also be electrically and/or pneumatically powered. Retractable undercarriage systems also require:

- Up and down locks.
- Up and down position indicators.
- An emergency extension method.

The undercarriage is usually retracted using hydraulic or electro-hydraulic power. Once retracted the gear is held up by mechanical uplocks.





In the event of a hydraulic or electrical system failure affecting the undercarriage operation the uplocks may be mechanically released allowing the gear to fall down under gravity. On others, large springs pull the gear to the down position at the very last stage of the extension cycle ensuring that the gear engages and remains in the down lock position.

2.14 Undercarriage Position Indicators, Switches and Warnings

Micro switches on the nose wheel and main gear provide the pilot with information on the state of the landing gear, whether their retracted, in transit or extended.

Some landing gear designs provide down and locked visual indicators in case of electrical failure.

Micro switches are small electrical switches which are used to open / close an electrical circuit. Two micro switches are needed for each strut. These switches indicate when that strut is up and locked (respective indicator light extinguished), or down and locked (green light on).

When all three landing assemblies are retracted, no lights are illuminated.

When all gear is extended, the lights indicate "three green".

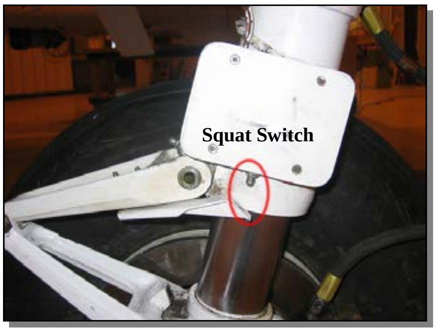
A transit indicator light (red) is also provided to indicate if one or more of the undercarriage struts is not in the position that the landing gear lever is selected to, i.e. undercarriage lever in down position and one or more wheels not locked down.

2.15 Undercarriage Disable

There are two types of switches commonly used to disable the retraction circuit to prevent accidental undercarriage retraction while the aircraft is on the ground:

2.15.1 Squat Switches

Squat Switches are micro switches fitted to each main undercarriage oleo strut causing a solenoid to lock the landing gear handle in the down position when the oleo is compressed (weight on wheels). Consequently, the undercarriage handle cannot be raised if the aircraft is on the ground.



2.15.2 Air Switch

The Air Switch is operated by pitot and static pressures. It is calibrated to cause an open circuit below about 60 kt (disable) and closed circuit (enable) above 60 kts. The actual airspeed setting will depend on the type of aircraft. Consequently, the undercarriage cannot be raised if the aircraft is not moving at greater than its 'enable' airspeed. This protects the aircraft from inadvertent retractions on the ground.

CAUTION: While the aircraft is on the ground, the undercarriage selector must be left in the DOWN position at all times.

Ground air sensing is also used to enable or disable aircraft systems that may change to different modes of operation between ground and air operations, such as air conditioning or pressurisation

Squat or air switch failure may allow inadvertent retraction whilst on the ground. Windy conditions or the temporary lifting of the aircraft could also result in unintentional retraction.

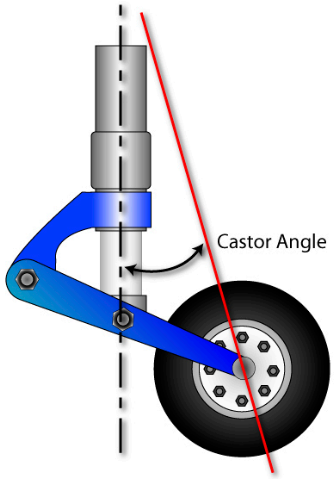
2.16 Undercarriage Warning

During cases of high workload, or an emergency condition exists, even experience pilots may forget to lower the landing gear.

For this reasons a warning sound will notify the crew when the aircraft is in the landing configuration but the landing gear is not extended:

- Throttle is reduced below a certain power setting.
- Flaps are extended in the landing configuration.
- A certain angle of attack is reached (in the case of a flapless landing).
- At or below the approach speed.

2.17 Nose Wheel Steering



Rudder pedals on light aircraft usually provide a mechanical means to turn the nose wheel as well as the rudder. This allows direct nose wheel steering during taxi. Large aircraft often have a small hand operated steering wheel or lever (commonly called a tiller) to provide hydraulically powered nose wheel steering. Differential braking action and asymmetric power can also assist with steering on light aircraft but should be avoided on larger aircraft.

The nose oleo of a tricycle undercarriage aircraft must provide for rotation about its vertical axis. A castoring nose wheel may be steered through differential braking or differential power.

Aircraft that are designed to be steered by this method will have a large castor angle.

Aircraft fitted with nose wheel steering units need the wheel assemblies to be turned when the upper oleo leg steering collar is turned. A torsion link (torque link) is provided to transfer the twisting movement from the steering collar to the nose wheel.

Wheel shimmy is the tendency for the nose landing gear wheel(s) to oscillate from side to side.. It usually manifests itself as a vibration which increases in intensity as speed is increased. Shimmy occurs when a particular wheel tries to deviate from the fore and aft position without steering input. As the tyre is forced back into line with aircraft track on the ground, an oscillation is set up as these 'out of phase' forces interact. Nose wheel shimmy can be reduced significantly by the fitment of a shimmy damper.

One type of shimmy damper is the piston type which restricts oil flow between either side of the shimmy damper cylinder. The cylinder is attached to a fixed part of the strut assembly whereas the piston rod is connected to the chrome portion of the oleo strut that can turn.