# Aircraft General Knowledge

**System design**

**Safe life** = 1 load path = no redundancy = no catastrophic damage during life cycles

**Fail safe** = more than one load component = redundancy [preferred way to use]

**Damage tolerance:** capability to withstand a certain amount of damage to structural parts until the damage is detected during an inspection

Certification specifications lay down requirements for design, material quality and characteristic, …

**CS-23** = normal, utility, aerobatic, commuter airplane

**CS-25** = large airplane

Strain = measure of deformation of a loaded structure = change in size / original size

**Dynamic Load** = occasional / not continuous
**Cyclic Load** = repeated reversible loads

**Limit load should be the Maximum load** is the max load expected during the flight and the aircraft shall be capable of withstanding **150%** of it

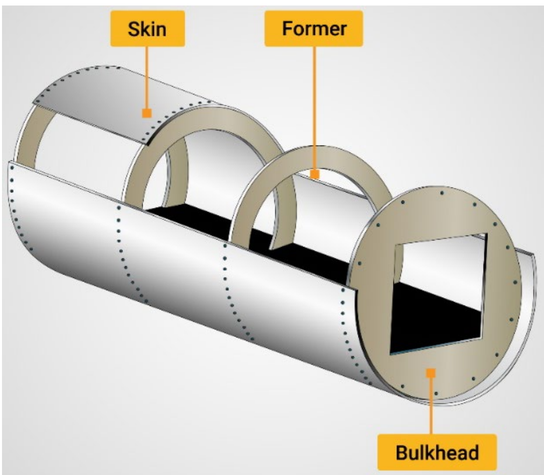
**Area to inspect** during a **walkaround** that are more **prone to stress**:

- Wing root
- Fuselage and skin near bulkhead
- Aircraft skin at the top and bottom of the fuselage
- Fuselage around the windows

**Corrosion colour** by element:

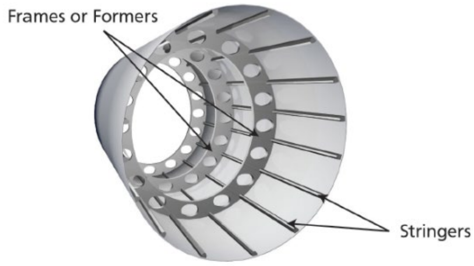
- Copper, bronze = blue/green patina effect
- Aluminum, magnesium = white/grey powder
- Iron = Red/brown streaks
- Metals and other alloys (especially in combination with saltwater) = yellowish colour

**Flutter** is due to torsion and bending and to prevent it, it can be useful to use a stiff structure (to avoid excessive vibrations) and a balance mass in front of the hinge line. CG of the surface must be as forward as possible to avoid flutter. It occurs when an external **force** is applied to the aircraft **with a periodic frequency** that is **equal to the natural frequency** of that aircraft and can be avoided by ensuring the aircraft remains inside the certified flight envelope, particularly for speed limitations and during turbulent conditions
- When in a gust a wing bends upwards, aileron flutter might occur if it deflects downwards, because the location of the aileron center of gravity lies behind the hinge line
- Flutter prevention = high stiffness + balance mass in front of the control surface hinge line




Torsion box is made of wing spar, ribs, skin reinforced by stingers

Spars (longheroni) = carry the wings bending moments
Skin = carries the pressurization loads and give the shape to the wing
Ribs (centine) = maintain the shape of the wings
Stringers = help the skin to absorb the (longitudinal compressing) loads




Components giving fuselage its form are bulkhead and frames

Plug type doors can move inside and outside of aircraft

Floor venting is used to avoid floor buckling during a rapid depressurization

**Cockpit windows** have lower speed limit (in relation to bird strike) when window heater is inactive

Cockpit side windows are defogged only

Primary task of the cockpit windshield heating (only vinyl is heated) is to improve window's impact strength, while the secondary task is defogging and deicing

**Cockpit eye reference indicator** consists of 2 white and 1 red ball and the aim is to have the correct horizontal and vertical field of view only moving eyes, reducing head movement

Engine compartment decking and firewall are usually made of titanium or stainless steel

**Hard-time maintenance**: planned for a component which is overhauled or replaced upon a set number of hours or cycles

**On-condition maintenance**: predictive involving replacement or overhaul of components before a failure happens (like after a regular inspection). It is based on monitoring of critical parameters of component or piece of equipment.

During preflight indication of stress damage may be [according to EASA]:

- Wrinkled or stretched skin
- Restriction in a flight control

**Corrosion identifiers**:

- Powdering: Due to corrosion, ferrous materials start to turn into a red powder.
- Paint Discoloration: Red/brown/green/etc colour from the corrosion may seep through the paint.
- Rust: On steel, it is a reddish corrosion by-product.
- Etching: describes eroded metal by corrosion.
- Pitting: Creation of localized pits/small holes in the material surface due to surface corrosion
- Cracking: Combination of high tensile stresses together with a corrosive environment.
- Flaking: A layer may fall off when it loses its structural connection with the underlying layer due to corrosion.

## Hydraulic system

**Desired properties** of hydraulic fluid are:

- high flash point
- low flammability
- incompressibility
- anti-corrosive
- thermal stability

Most **common pressure** on most large aircraft: **3000 psi** [pressure can be measured by a pressor transducer and is measured against atmospheric pressure]

A system where there is low pressure when the hydraulic system is at idle is called an **open center hydraulic system.**

**Open center systems** are usually used for systems which do not require a constant pressure to be maintained all the time.

Most used type of oil: Mineral or synthetic

If a mineral based hydraulic oil is used in a system designed for synthetic oil, **seal damage** may occur

Hydraulic systems are normally **pressurized by engine driven hydraulic pumps**

Filters are used in both the pressure and return lines

**Parameters to monitor** the systems on display are: pressure, fluid temperature and quantity

If in an aircraft with 2+ hydraulic systems, if 1 of them fails a master caution and amber light appears (as there is still one system working)

**Pop-up indicator**: when the pressure reaches a specific value, it comes out to signify an impending filter bypass that means the filter needs to be cleaned or replaced. The filter is still able to work but soon will be clogged.

**Axial piston pump**: constant pressure pump (variable volume) managed with the swash plate

**Drive Gear Pump**: constant displacement = constant volume, variable pressure. Requires ACOV (Automatic Cut-Out Valve)

The **ACOV similar to a pressure relief valve**, but more complex, and allows the system to reach an equilibrium (against a set spring pressure) which creates a constant pressure, no matter the system requirements by **regulating the pressure**. It is not good in the case of a hydraulic leak. Constant pressure pumps don't need an ACOV

Pressure relief valve is used in case of excessive pressure to avoid an overload of the system and not to regulate pressure

An accumulator extends the time between a ''cut out' and a ''cut in'' in an ACOV

In general, an accumulator is used to provide temporary hydraulic power in the event of a system failure or emergency and/or dampen fluctuations in hydraulic pressure. Is also used for absorbing the pressure of thermal expansion on closed systems

It is also normally at the same pressure as the system because the gas/air is used to equalize the pressure inside the accumulator itself.

If hydraulic fluid is coming out from a gas charging valve, it means there is an internal leak in the accumulator itself.

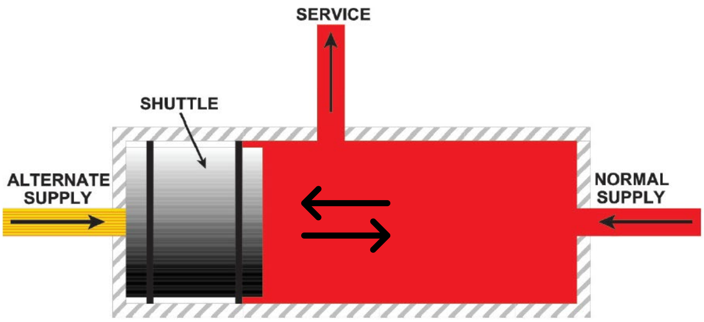
**Hydraulic reservoir is pressurized** to provide positive fluid pressure at the pump inlet and **to prevent cavitation** (air bubbles). They are **pressurized by air from the pneumatic system** or in an emergency from engine bleed air

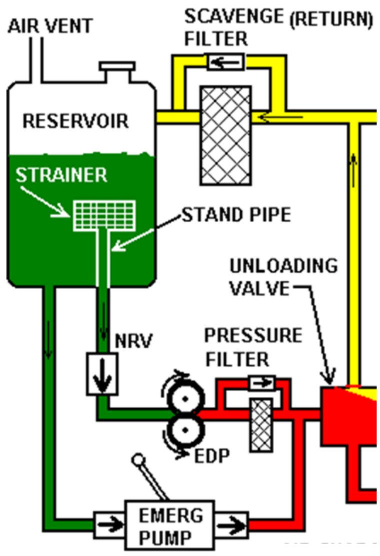
**Single acting actuators** move in only 1 direction and there is a spring to push the piston back

Hydraulic fuses prevent total system loss in the event of an hydraulic leak

**Non return valve** is also called a **check valve** (similar to a diode where current flows only in one direction)

**Shuttle valves** help to switch from one feed line (normal supply) to another (alternate supply) when one of them fails. The shuttle shifts towards the low-pressure feed line (the failed one) so that the line can be fed by the alternate line



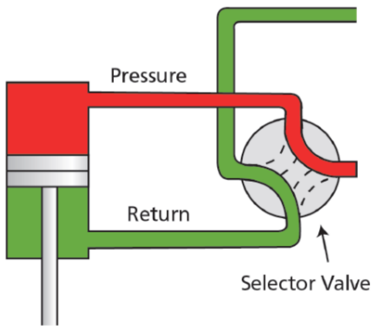




**Low pressure** alert= pressure problem = output pump pressure insufficient

Temperature problem = leak

**Stand (stack) pipe** = is connected to the main feed line and allows to measure the level of fluid in the reservoir. If the level goes below the stand pipe level, the residual fluid is used only for the emergency systems. [It contains an amount of fluid that cannot leak even if there is a leak in the reservoir itself and is used in case of emergency]

The **selector valve** directs pressure to either side of the piston of an actuator



## Landing gear

A tire can be retreaded 7+ times if the grooves (scanalature) are worn out.

When **emergency extension** is needed:

- The **uplock** mechanism has to be **mechanically activated**. It is really efficient when the gear is fully up.
- If the backup system for a landing gear extension is of the free-fall type, the **hydraulic cut-off valve** has to be moved with mechanical power to release the hydraulic pressure

An **over-center lock** is the mechanical structure locking in the down position the landing gear.

A **blowdown emergency gear extension** system uses a bottle of gas (nitrogen or compressed air) to move a shuttle valve that allows for the movement of the actuator.

**Anti-retract latch** block the landing gear lever in the down position and is used to avoid the retraction when on the ground. The system can be overridden under specific conditions.

**Overcenter mechanism** locks the landing gear in the down position

An aural warning shall be used when a landing is attempted and any gear is not locked down.

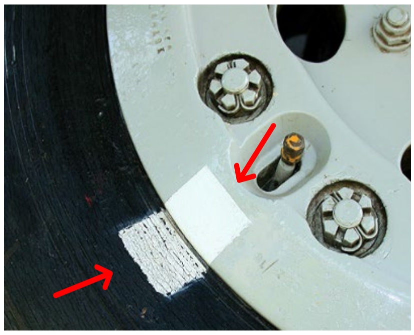
Rudder pedal nose wheel steering provides a smaller deflection (7°) of the nose wheel in compare to hand wheel steering/tiller (78°).

Rudder pedal nose wheel steering is functional only when the aircraft is on the ground. It is deactivated during take-off and while the aircraft is in the air for safety reasons.

Larger aircraft have a limited steering capability also in the main gear to allow for reduction of sideways stress during turns.

**Torsion links** are used **to prevent rotation** of the landing gear piston in the oleo strut and it **connects the inner and outer cylinder**. **Most stress** is carried by the torsion link **between the inner and outer cylinder** of the main oleo leg during **small radius turns**.

**Ply rating**: measure the strength or load rating of a tire

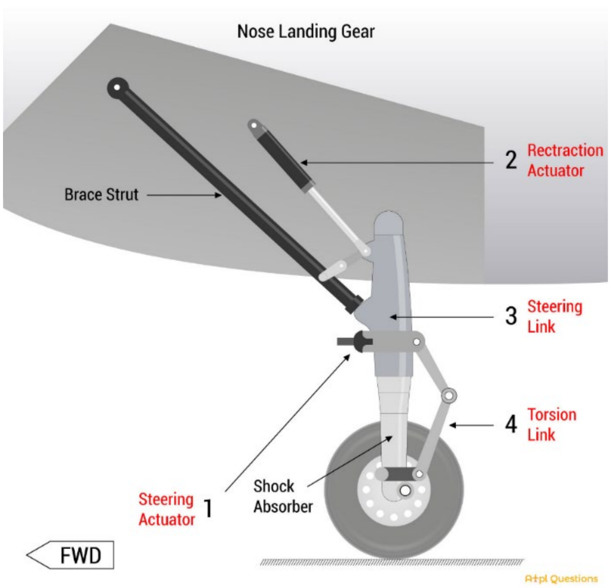


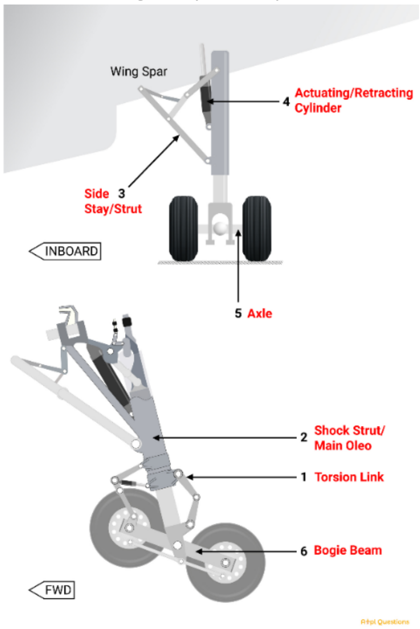
**Fusible thermal plug** protects tire against explosion due to excessive temperature and are installed in the wheel hub

**Tire treads** (battistrada) separation is **not always easily visible** and it can cause burst of the tire itself during takeoff if not detected during preflight inspection by the pilot.

**Tire creep** is the circumferential movement of the tire in relation to the wheel rim

Main wheel steering is used with nose wheel during low-speed taxiing and maneuvering only to improve maneuverability and reduce excessive abrasion of the main wheel tires



## Brakes

To check the **wear of the brakes** a pilot needs to check for the **PIN extension**.

When on a slippery runway, the autobrakes apply the pressure as indicated and the antiskid system manage the single wheel brake pressure to avoid skidding (slip ratio).

**Autobrakes cannot be used if antiskid is inoperative** (autobrakes cannot operate without an operating anti-skid system)

The **autobrakes** will bring the aircraft to a **complete stop** if there isn't any pilot interference and **will not disengage** until a pilot action.

The achievable deceleration levels of full manual braking and the autobrake RTO mode are the same (but with manual breaking a greater distance to stop is required as there is a higher reaction time).

In certain conditions **autobrakes will not engage until a certain speed of the wheel is reached**.

**Antiskid** unit can **prevent brake application before touchdown** on landing (even if pressing the brake pedal).

**RTO** configuration gives **maximum CONTINUOUS deceleration** but **NOT CONSTANT**.

Autobrakes will **not activate** for **RTO** if speed **< 90 kts**

The autobrake system **can be disconnected** (even during an RTO) by any of the following actions:

- The pilot operating the pedal brakes
- Using the selector switch on the autobrake panel
- Retracting the speedbrake lever
- Moving the throttles forward

If the autobrake system is not armed, the aircraft will not generate a takeoff warning [this is not true in the real world].

**ABS setting is independent of weight**, because it has to be seen as a **deceleration rate** (if we have an aircraft weighting 100 or 50 tons with mode 1 autobrake, the ABS will decelerate the aircraft always at the same rate [e.g. 4 $m/s^2$])

**Input data for antiskid system**:

- wheel speed
- groundspeed (also called reference speed)
- wheel speed at all the wheels on the boogie

The failure of anti-skid system at least doubles the minimum braking distance on a dry runway

In emergency when a hydraulic failure occurs, high pressure air can be fired (one shot) in the braking system. This makes the brakes feel soft or spongy underfoot and not reactive or sensitive as in normal operations.

## Flight controls

**Fully hydraulic** = Irreversible = Fully powered by hydraulic means

**Partially powered controls** = Connected by mechanical links via hydraulic.

**Fully manual** = Connected by means of mechanical links only

Reversible flight control systems give the pilot tactile feedback and do not require an additional artificial feel to be installed since the aerodynamic force feedback is provided to the pilot.

Partially powered controls give the pilot tactile feedback, but not as much as a fully manual control as the hydraulic system is compensating for some of it.

**Pitch trim**: zero force position of the control column doesn't change (joke doesn't move as trim is moved)

**Aileron trim**: zero force position of the control column change (joke moves as trim is moved)

**Rudder trim**: zero force position of the pedals change (EASA way of saying it: altering the neutral position of the artificial feel unit)

**Rudder ratio limiter** is used to avoid excessive rudder input when at high speed and altitude (tail can be destroyed). For this reason, if it gets stuck in cruise, there is a limitation in the maximum crosswind component on landing. **Pedals are not physically reduced in excursion**, but at a certain movement corresponds a reduction in rudder excursion as IAS increases.

**Variable stop system (rudder)**: the movement of the **rudder and pedal** travel are proportional. However, as IAS increases the **movement** of both of them **are physically reduced** (when the rudder is limited in movement at high speed, the pedal is also restricted)

**Blow back** is the 3rd method used to limit rudder deflection

Pressure relief valve is used to prevent excessive forces on flight controls, allowing the surface to retract.

Hydraulic valves act on the actuator of the control surface.

**Primary flight controls** we have REAR (Rudder, Elevators, Ailerons, Roll spoilers)
**Secondary flight controls** we have FSSST (Flaps, Slats, Speedbrakes, Stabilizer, Trim tabs)

**Secondary flight controls**

**Auto slat function**: slats automatically extend when the wing is about to stall. When such condition ceases to exist, they will retract automatically. This allows for improved stall characteristic at high AOA during TO, APP and LDG

Automatic ground spoilers occur on landing when weight on wheels is registered

**Flap load relief system** retracts flap when current airspeed is excessive for the current flap configuration and when speed decreases it will extend them at the previous one.

Trimmable horizontal stabilizer is moved by a hydraulically actuated jack in large aircraft

**Double pole switch** is used to avoid trim runaway as a pilot need to push both the switches to trim as one releases the trim brake and the other actuate the motor

If flaps extend on 1 wing only, the aircraft will roll in the direction of the clean wing and will yaw in the direction of the wing with extended flaps. Clean wing may stall.

Trailing edge flaps are extended with an hydraulic system with electrical backup

**Fly-by-wire** [DAMN]

- **Normal law**: is the system mode which is active throughout the flight and is terminated when system failures occur that prevent its use.
- **Alternate law**: is the highest reduced mode of operation which provides most features of normal law. Some features such as automatic stall protection (automatic pitch protection) are lost and replaced by conventional warnings for the pilots to manually correct the condition. Degraded flight envelope protection.
- **Direct law**: its used should failure conditions prevent operation in Alternate law. Autopilot functions are lost, along with flight envelope protection. Oral and visual alert are still present.
- **Mechanical backup**: is the last emergency means of operation and is provided to maintatin level flight only for the limited period of flight control computer reset following a complete loss of power.

A system degradation results in a loss of protection features, so the required alertness of the crew increases and leads to a higher workload.

**Alpha protection mo**de reduces pilots workload because **prevents stall automatically**

When one pilot takes priority of flight controls in a FWB aircraft, an aural warning 'priority left/right' and a red arrow on the sidestick priority light appears.

In case an RA is required, pull/push the stick without hesitation, because the system will automatically take the greatest input possible without going out of the flight envelope limits .

In FWB systems autotrim acts when within speed limit and there is consequently a reduction of pilot workload.

When **2 inputs are detected they are mixed together** (summed algebraically) and if the combined inputs are a full deflection, the result will be not more than a single stick deflection.

**Bank angle protection** allows the pilot to bank up to a certain angle without constant pressure. Over such value constant pressure is required on the sidestick to keep it. There is also a **bank angle limit** that cannot be overtaken, no matter the sidestick input.

FBW systems are lighter, reduces workload and have fligt envelope protection.

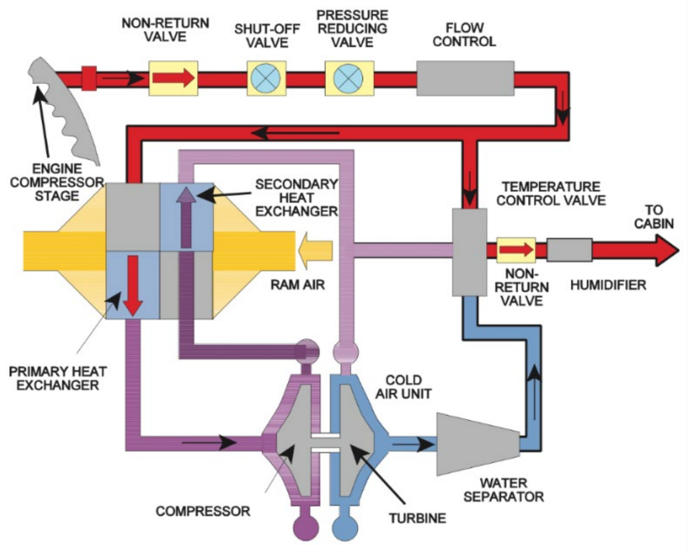
If an electric wiring controlling one a control surface fails, the system can use a different actuator with a different computer

Logic of controls from pilot to surface movement:

- Pilot operates controls: sidestick, yoke or rudders
- (PFC) Primary Flight Computer: mechanical movements converted into electrical output
- (ACE) Actuator Control Electronics: converts electrical signals into analogue signals sent to (PCU) Power Control Unit
- Control valve controls the movement of the Hydraulic actuators moving the flight control surface.

**Pneumatic/bleed air supply**

Bleed air is compressed air taken from the High-pressure compressor stage of a gas turbine upstream of its fuel-burning sections.




Bleed air pressure is measured against atmospheric pressure.

Source of air for a pneumatic system in a piston engine aircraft:

- Supercharger
- Turbocharger
- Engine driven compressor (choose this if turbocharger is also available as choice, because it is not always on)

In a piston engine, pneumatic system can be used to supply:

- Gyroscopic instruments
- Cabin heating
- De-icing system (inflatable boots)

Using an electric-pneumatic system instead of a bleed air system, means a reduction in fuel consumption and longer range

To **pressurize** the **reservoir of the hydraulic system**, the pneumatic system or bleed air tapped from the compressor is used.

**Cabin pressure is controlled by the outflow valve**

**Pressurization and air conditioning system**

**Air cycle machine/bootstrap** (air conditioning packs) **flow**:

- Bleed air from compressor
- Primary Heat Exchanger
- Compressor
- Secondary Heat Exchanger
- Expansion Turbine

Before the turbine there is a water extractor, while after the turbine there is a water separator.

Main function of a bootstrap system is to cool the bleed air

Major cooling occurs at the heat exchangers

**Cabin pressure inside the cabin is regulated by the inlet and outflow valves**. They maintain a constant and sufficient air mass flow to ventilate the cabin.

Cabin rate of descent = increasing pressure in cabin

If the automatic air conditioning system fails, a manual control by the pilot is possible

**Pack cooling (ground) fan** supply the heat exchangers with cooling air during slow flights and ground operation

**Maximum differential pressure** in pressurized aircraft: **5-7 psi** (turbo prop) and **8-9 psi** (jet)

Inward relief valve is also called a **negative pressure relief valve**. It opens when cabin pressure is below ambient pressure.

Manual control mode of the pressurization system uses a separate circuit to control the operation of the outflow valves

**Anti-ice & De-ice**

**De-ice rubber boots** use high pressure air within a schedule

**Anti-ice system** in modern turbine aircraft uses bleed air from the HP compressor to prevent ice formation

**Thermal anti-ice** protection is considered to be **bleed air** from the engine

Wing aerodynamics is not affected, but performance (max thrust) is affected

Windshield of the aircraft is de-iced via the 3 phases AC aircraft system at 400 Hz at cycles (ON-OFF to maintain a certain temperature)

**Electrical heating** is generally used for **pitot tubes** and **TAT probes**. It is mandatory for pitot tube to be heated, but not for static ports.

Some aircraft do not require tail or horizontal stabilizer anti-ice

A **primary ice detection system** can be defined as a system that can be relied upon as the **sole means of detecting ice accretion or icing conditions**.

**Types of ice detectors**:

- In a **pressure-differential ice detector** (Smith ice detector), small holes are typically heated first to detect ice formation. When they are blocked by ice accretion, there is a drop in dynamic pressure and an indicator illuminates in the cockpit.
- A **vibrating detector** (or vibrating rod or Rosemount ice detector) is an ice detection system where the instrument vibrates at a certain frequency when there is not ice accumulated on it. When ice starts building up, the frequency vibration decreases, lighting a light in the cockpit.
- A **hot rod ice detector** is a system that allow the pilot to make direct visual observation of the presence of ice. De-icing system is activated by a switch in the cockpit

**Piston engine fuel system**

**3 aircraft fuel tank type**:

- Integral (wet wings) [used by most modern aircraft]
- Rigid
- Flexible

**Colour of different AVGAS used** [density = 0,72]:

- 80 = Red
- 100 = Green
- 100LL = Blue
- 115 = Green

MOGAS is more susceptible to carburetors icing than AVGAS

In regards to CS-25 for airplanes and CS-29 for helicopters unusable fuel is the one always remaining in the fuel system irrespective of aircraft attitude due to design limitations.

Fuel gauges should be calibrated to indicate empty when all the USABLE fuel is extracted from the tank

**Drain valve** is used to measure quality and take sample of fuel [also for fuel tank maintenance, but choose it if is the only option]

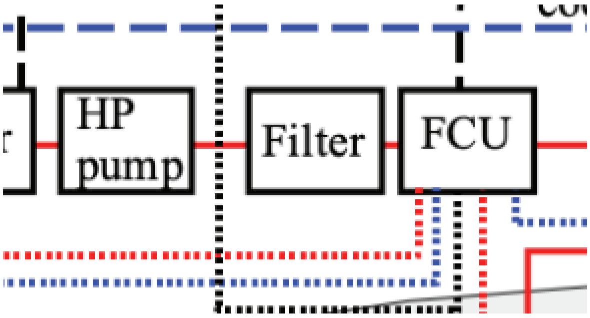
Pressure-fed fuel system is used to feed fuel from any fuel tank to any engine

**Jet engine fuel system**

Fuel pumps submerged in the fuel tanks of a large airplane are centrifugal low-pressure type. They are submerged so that they can cool using the fuel around them.

Low Pressure Boost Pumps - In the tanks (pressurize fuel).
High Pressure Pumps - Engine Driven, in the engines

The engine Fuel Control Unit (FCU) is protected from damage by debris by the fine filter located between the HP fuel pump and the governor unit (FCU itself). The reason why a fine filter is located between them is in case of pump debris during pump failure. Impellers can fall apart.




FCU regulates fuel flow, so FF measurement must be made after the FCU

Low pressure pumps are supplied with **115 V AC**

On large airplane, the fuel tanks can be vented through (ram) air intakes on the underside of the wing.

**Fuel tank venting** protects against excess positive or negative pressure damaging the tank and components.

**Fuel tanks are pressurized** to prevent vapor locks and reduce vaporization of the fuel.

To recover from a **fuel imbalance**, use the **cross-feed valves** and shut down the wing tank fuel pump of the wing with lower fuel.

**Baffles** are fitted in fuel tanks to damp spanwise fuel motion.

Check valve = non-return valve

**Capacitance type fuel gauge** system measures the fuel quantity by **measuring the dielectric change between fuel and air**. It has a fail-safe mechanism so that **in case of failure**, the indicator slowly goes towards the **empty position**, to avoid indicating a fuel level higher than the real quantity.

**Magnetic measuring type dip stick** are a visual method to read fuel in the tank. Measurements are made from the dip stick and data tables in the aircraft documentation

**Fuel additive** is used to **reduce the freezing point** and reduce risk of formation of ice crystals forming at low temperatures

Feed box increases the fuel level at the boost pump location by ''trapping'' fuel so that such pumps are fed independently from the aircraft attitude

| Type of fuel | Flash point (°C) | Freezing point (°C) | Specific gravity (kg/L) |
|---|---|---|---|
| Jet A | +38 | -40 | - |
| Jet A1 | +38 | -47 | 0,8 |
| Jet B | -20 | -60 | 0,78 |

To measure the **fuel pressure**, sensors are installed at specific points in the fuel system. The most common locations for measuring fuel pressure are:

- In the line **between the booster pump and the engine**: This is typically where the fuel pressure is measured in low-pressure fuel systems, where a booster pump is used to supply the fuel to the high-pressure pump.

- At the **outlet of the high-pressure filter**: In high-pressure fuel systems, where the fuel is supplied directly to the high-pressure pump, the fuel pressure may be measured at the outlet of the high-pressure filter.

**Cross-feed** is used to allows fuel from one tank to supply the engine. Fuel is not going from one tank to another.

**Smoke detector systems**

Types of detectors:

- **Optical**: smoke particles reflect and scatter lights
- **Ionic**: variation of current flow through a detector (current reduces if there is smoke, triggering the alarm)
- **Solid state**: operate using the change of resistance

They may give false alarms due to dust or dirt or condensation

**Fire protection system**

Cockpit indications in the event of an engine fire: bell, red alert message, red light in the engine fire switch (master warning).
In a big aircraft 2 bottles of extinguisher/fire extinguishing discharges are required per engine nacelle.
The squib fired for the engine fire extinguisher bottle is detonated electrically
2 independent engine fire extinguishers | every engine needs to be provided with 2 distinguished engine shots [CS-25]

- **Pressure sensor (gaseous)**: a closed tube, when heated, causes the gas to expand triggering an alarm via a pressure switch. Testing of the system is done by heating up the gas at the appropriate temperature to trigger the alarm activated. A fault warning (loop fault indication) is shown if low pressure is present in the sensor tube

- **Continuous loop** type system has a long tube (fire wire) running around the engine compartment and when fire is present, the fire wire will increase the current flow (decreased resistance of the material) and an aural and visual warning will be shown in the cockpit. In a **dual loop**, both fire wires have to signal the fire to trigger the warning. This is inherently more reliable than other systems. An aircraft can be allowed to depart if one of the fire detection loops (of the dual loop) is not working. If the tube is broken, during a test no signal or fault alert appears. **Low resistance + Low capacitance = faulty**. When the sensor is crushed, if the wiring touches the casing there will be a flow of current and this will set off the fire alarm.

- **Bimetallic detector** uses the principle of expansion for solid materials due to applied heat. Signal delay circuits are usually incorporated to trigger the warning after a given time after the contact, in order to avoid false indications caused by vibrations.

When pulling the fire handle, the fire bottles squibs are armed and automatic actions take place:

- Closure of the fuel shut-off valve
- Closure of hydraulic shut-off valve
- Closure of engine bleed air valve
- Deactivation of the electric generators
- Disabling of engine thrust reverser

Fire extinguisher are operated by an electrically fired cartridge rupturing a seal in the head of the bottle.

**Rain protection**

Windshields have **hydrophobic seal coating**. The coating causes rain droplets to bead up (forms large water droplets) and roll off the windshield enhancing the vision of the flight crew. It is applied externally by the manufacturer and deeply penetrate the windshield surface.

**Oxygen system**


Purpose of the regulator:

- Supply 100% $O_2$
- Supply diluted $O_2$ [mixed with cabin air]
- Supply $O_2$ on demand
- Supply $O_2$ at positive pressure

It is dangerous to use $O_2$ in the vicinity of oil and grease because the interaction with oil-based products creates a fire hazard

Chemical $O_2$ generators can be found in the cabin, toilets and smoke hood (used by cabin crew when there is smoke in cabin). It cannot be interrupted after it started. They start to flow when the mask is pulled. They have a heat shield as during oxygen generation it can reach up to 250 °C

Passenger mask provides a continuous flow of a mix of oxygen and cabin air for about 12-20 minutes. Shall not be used if there's smoke in the cabin. They also contain a flow indicator.

They have to be automatically deployed if cabin altitude > 15000 ft or can be manually deployed by the pilot

Portable oxygen bottles are primarily intended for first aid use

Pilot oxygen bottle has different position:

- Diluted [mixed with cabin air]
- 100% [no overpressure]
- Emergency [continuous 100% with overpressure to avoid any contaminant like smoke to enter]

A pressure relief valve in a high-pressure gaseous oxygen system is to relieve overpressure if the pressure reducing valve malfunctions

## Electrics

### General

Bi-metallic circuit breakers (thermal) have a slow response time
Magnetic circuit breakers have a quick response time

Circuit breakers are used for both AC and DC and must be able to withstand the transient overcurrent that occurs when switching on electric motors (inductive loads)

Relay is an electromagnetic operates switch

If in an **electrical circuit** an **overload** occurs but is not detected, the electrical line could **overheat** and cause a **fire**

A 10°C increase in temperature operation in a computer cut to half the life expectancy

A **thermal circuit breaker** protects the system in the event of a **prolonged overcurrent**

**Static dischargers**:

- Are placed on wing and tail tips to facilitate electrical discharge
- Are located on wing and tail tips to reduce interference with the on-board radio communication system to a minimum
- Limit the risks of transfer of electrical charges between the aircraft and the electrified clouds

When using a fuse with a higher rating than prescribed in a healthy system nothing problematic will happen

Electrical bonding is used to equalize the electrical potential of the different aircraft parts. It consists in connecting all components with flexible wire strips creating an easy path for electrons to pass between parts. An example of inadequate bonding may be static noise on the radio

**Braided wire** is used to protect the cable from electromagnetic induction from other electrical systems

To assess the state of charge of a lead-acid battery compare the on-load and off-load battery voltage

The **metal box/casing around a lithium battery** is designed to contain **thermal runaway**. It should be **vented**.

Should however one cell set on fire, it will spread to the other cells within the battery

**Fully charged battery voltage under no electrical load**

- Ni-Cd → 1.2 V
- Lead-Acid → 2.2 V
- Lithium → 3.6 V

When carrying out a battery condition check using the aircraft voltmeter a load should be applied to give a better indication of condition.

**Generator and Alternator**

**Constant Speed Drive** (CSD) is a hydro-mechanical device which is positioned **between the engine and the brushless AC generator**. It is designed to keep the **generator running at a constant speed (and frequency**).

**Excessive CSD oil temperature, low pressure and oil level** indicate an **impending failure** of the CSD. If any of these occur an indication will pop up and the pilot is required to **disconnect the CSD from the gearbox** in flight throught the proper switch. It can **only be connected again on ground** after engine shut down. **CSD are lubricated by internal oil**.

An **AC generator** driven via a CSD requires a **voltage regulator** to maintain **constant voltage under varying generator loads and speeds**. The voltage depends on the intensity of the magnetic field and not on the RPM of the conductor.

If load increases, the voltage regulator increases the excitation current.

**Integrated drive generator (IDG) = Generator + CSD** | it is lubricated by its own internal oil system

**(Static) Inverter is used from DC to AC**.

**Starter generator** = AC electric motor + Generator. It performs as an electric motor during engine start and after engine start as a generator.

During start of an engine fitted with brushless AC generator, the initial excitation is provided by a set of permanent magnets

A **Frequency wild AC Generation** system means that the output **frequency** of the generator **varies with engine speed**

If a **Generator has a failure**, its **bus is transferred** to another source and the **generator is disconnected from its bus**

On a modern brushless 3 phase AC Generator, the current that provides the field excitation to the rotor comes from the permanent magnet generator installed on the same shaft as the main generator.

A **Transformer Rectifier Unit (TRU)** consists of a transformer and a rectifier all in one and is **used where AC distribution** system needs to **supply a DC system (AC → DC)**.

**Generator circuit breakers** (GCB) must be configured to protect the remaining generators whistl delivering power to essential loads. The Generator control unit (GCU) and Bus Power Control Unit (BPCU) ensures proper generator operation and power distribution.

The function of the GCB is to close when the voltage of the generator is greater than the battery voltage and to open when the opposite is true.

GCU of an AC generator are provided with a permanent indication to record the failure and all the command originating from the control panel are applied via the GCU, except dog clutch release (= CSD disconnect)

On **large aircraft generators supply a 115/200 V AC** and **TRU supply the bus bar with a 28 V DC**

In the event of a generator failure, an **inverter convert a 28V DC from the batteries to a 115 V AC**

The **APU has its own AC generator** that supplies the aircraft with 3 phase 115 V, 400 Hz AC

In a 4 engines aircraft, each generator is connected to a dedicated busbar.

**Generators in parallel** are required to have the **same voltage, frequency and phase**

**Generator** - rotating armature (induced windings) and a stationary field.
**Alternator** - stationary armature (induced windings)and a rotating field.

Number of pole pairs = Frequency X 60 / RPM | numbers of poles = 2*poles pairs

**Hot bus or direct bus** are bus **directly connected to the battery**. For this reason, they are also called **battery bus bar**.

In a DC motor, increasing the load decreases the spin speed, which increases the current and the torque.

**Torque = Power / RPM** | Torque is directly proportional to the strenght of the magnetic field

Armature Runaway = Everything decreases (current in armature and stator decreases and torque decreases)
Rotor Seizure = Everything increases (current in armature and stator increases and torque increases)

**Piston engine**

**Vapour lock** results from fuel boiling. As ambient pressure drops at higher altitudes, fuel changes more easily from liquid to vapour.

**Fuel booster pumps** are fitted in the tanks which will pressurize the fuel in the pipelines from the tank to the engine, pushing fuel towards the engine rather than engine driven pumps sucking fuel from the tanks.

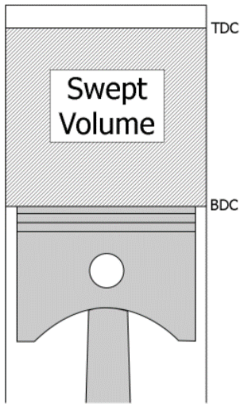
In case of complete **boost pump failure**, large aircraft will be **limited** by **maximum operating altitude**

**Detonation** occurs when parts of the mixture reach such a high temperature that they ignite spontaneously at an earlier stage than they should do during power stroke.

The conditions in which detonation is most likely are a **high manifold pressure, CHT** and **low RPM**.

For this reason, **if detonation occurs**:

- Decrease manifold pressure
- Enrich the mixture




**Swept volume** is the displacement of the cylinder per single stoke

The safest method to prime an engine is to inject additional fuel in the cylinder intake ports. If the aicraft doesn't have such system, pumping the throttle is the used method

The purpose of the **diffuser** (compensating jet) is to **maintain** the **constant mixture ratio** across a wide range of engine speeds

**Accelerator pump** in the carburettor enable **proper functioning** of the engine **during throttle advance**

Manifold pressure (static pressure) decreases if ice builds up in the carburetor. After carburetor heat is turned on, ice melts and manifold pressure rises.

If a manifold presure gauge consistently registers atmospheric pressure, the cause is probably a leak in the pressure gauge line. In fact this gauge measures the difference of pressure between the engine and the outside, so if there's a leakage in the gauge the pressure will equalize and read a fixed value.

**Carburetor heat** reduce air density and so the mixture is richer.

The operating principle of a float-type carburetor is based on the venturi throat and the air inlet

**Specific fuel consumption** (SFC) = mass of fuel required to produce unit power for unit time

**Specific range**: is the distance flown per unit of fuel [NM/kg]

Fuel injection systems are less prone to air intake icing than the traditional carburetor fuel system because there is no need for a venturi in the air intake

**Piston engine fuel** need to have **good anti-knock** (anti detonation) properties (high octane rating)

The **crank assembly** of a piston engine comprises:

- crankshaft
- connecting rods
- piston

**Pre-ignition** may arise when the mixture is ignited by abnormal conditions within the cylinder before the spark occurs at the plug

**Impulse magneto coupling retards the spark** during engine starting

The magneto in a ignition system is switched off by grounding both the primary and secondary circuits (grounding the primary automatically ground the secondary)

If the **ground wire between** one of the **magneto and the ignition switch** become **disconnected**, the engine cannot be shut down by turning the switch to the OFF position

The **operating principle of magnetos** in a ignition system consists of opening the primary circuit in order to induce a low amperage, high voltage current, which is distributed to spark plugs

In a **dry sump system** the **scavange pump** (pompa di recupero) has a **greater volume** compared to the **pressure pump** to make sure that the engine sump remains dry

The reading on the engine oil pressure gauge is the pressure of the downstream of the pressure pump

Viscosity is the tendency of a liquid or gas to resist flow

**Lubrication system indication:**

- High oil pressure due to low OAT or stuck oil pressure relief valve
- High temperature and low-pressure fluctuation due to a leak

In **comparison** to the **wet sump** system, **dry sump** oil systems have:

- Better control of cooling, as the oil does not have to stay sat in the bottom of the hot engine;
- The ability to perform aerobatics and keep the engine correctly oiled;
- Less oil oxidation and contamination;
- Higher capacity for oil, as it is limited by the external reservoir, which can be made larger than the engine sump.

A **turbocharger main task** is to **maintain power with increasing altitude** as air density decreases, therefore making power available less affected by altitude. Using exhaust gases, a turbine rotation put a compressor into rotation via a common shaft. The **pressure** of the compressed air (boost) can only be **monitored via the MAP gauge**.

An **intercooler** is used to **minimize the risk of detonation**. It is placed between the supercharger and the inlet valve (manifold) because of the high temperature at which the supercharger brings the compressed air. The higher the temperature inside the engine, the bigger the risk of detonation.

**Critical Engine**: the critical engine is the engine, the failure of which would give the biggest yawing moment.

When the **critical engine fails** and the propeller moves to the feathered position, the **aircraft will yaw towards the failed engine** due to the asymmetric thrust. This is known as "Critical engine yaw". If the center of gravity (**CG) is AFT**, this yawing motion will create **more stress on the rudder** as the rudder will have to work harder to counter the yawing motion. This is because the aft CG increases the leverage of the failed engine on the aircraft, making it more difficult to control.

The **propeller going downward** creates **more thrust** than the propeller going upward, so the critical engine also depends on the direction of rotation (clockwise or anti-clockwise):

- Clockwise rotation: critical engine LEFT, worst crosswind LEFT
- Anti-clockwise rotation: critical engine RIGHT, worst crosswind RIGHT

When excessively leaning the mixture but still on the rich side of the peak EGT, CHT and EGT can be exceeded (after the peak is reach, we enrich the mixture and CHT decreases).

EGT is used to set the correct mixture.

Excessive presure in the cylinders of a constant speed propeller can be caused by a combination of HIGH MAP and LOW RPM

Upon reaching cruise altitude in a constant speed propeller, when less power is required engine power is reduced by lowering the manifold pressure and increasing blade angle, to decrease RPM

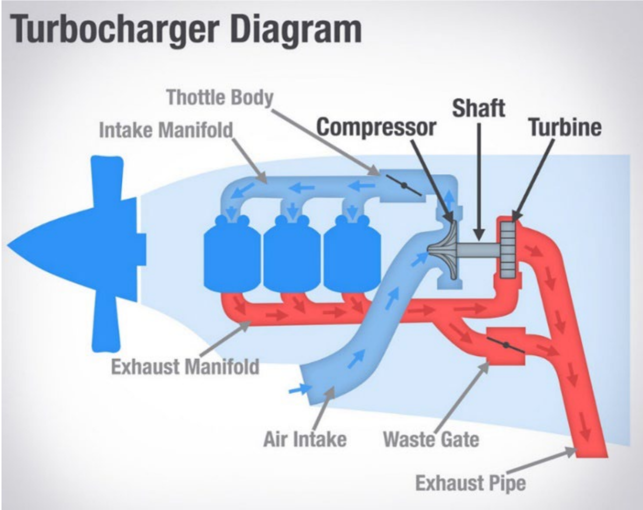
In a turbocharged engine, the **wastegate valve regulates the amount of exhaust gas that bypass the turbine** (not used to spin the turbine). So **max RPM is reached when wastegate valve is closed** (all the gases are used by the turbine)

**FADEC controls ignition timing** and has 2 power supplies and 2 separate but identical channels to achieve redundancy

In a prop engine with FADEC, there is only the throttle lever (no mixture or prop lever)

To unfeather an engine we need to move the blade angle to ''fine'', pushing it full forward, which will initially provide negative thrust, but as soon as the engine turns on, it will produce thrust.

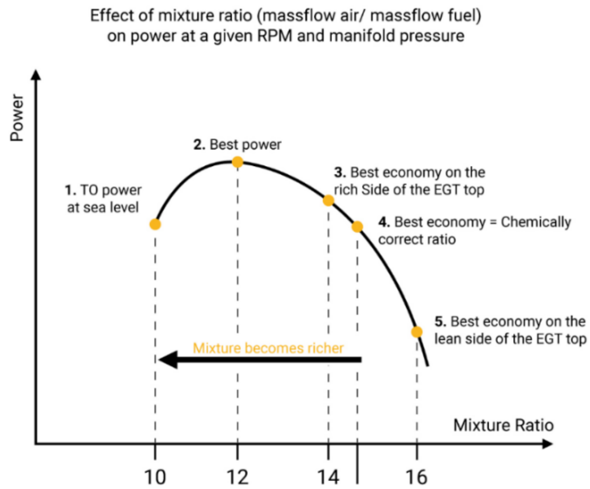
To select reverse thrust in a variable speed propeller from high RPM/low pitch condition, the power lever is moved to the reverse position and the blade moves from low pitch directly to the reverse position




In a **variable pitch propeller**:

- Throttle moves MAP
- Blue lever moves RPM

**Slipstream effect** is most prominent at high airspeed and low power




Mixed definitions for piston engine:

accelerator pump —> for advance throttle , example (go around moment)

primer pump —> provide additional fuel for engine start

mixture control —> correct the variation in the fuel/air ratio

impulse magneto coupling —> retard the spark during engine start + provide a stronger spark on tdc

intercooler —> minimize the risk of detonation

venturi in a carburetor —> create suction to cause fuel to flow

diffuser —> maintain constant mixture at low and high power settings

contact breaker in ignition system —> control the primary circuit of the magneto

distributor in ignition system —> distribute secondary current to sparking plugs

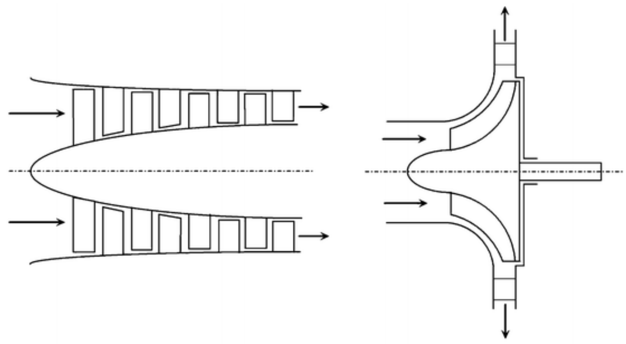
propeller reduction gearing —> limit the propeller rotation speed

turbocharger —> maintain power with increasing altitude

carburetor --> supply correct fuel/air mixture at all speed

**Turbine engine**

$$\text{Thrust} = M \times (V_{jet} - V_{flight}) + A\,(p - Po)$$




Combustion occurs theoreticallly at constant pressure

Once the air passes throught the stages of the compressor, it passes next via a diffusor that slows down the air as it would be to fast to combust optimally in the combustion chamber

**Bypass ratio**: air bypassing the engine core in relatoin to the air entering the core

The **bypass air** has the effect of lowering SFC by causing an overall decrease in average exhaust gas flow velocity and a higher mass flow

**Specific Fuel Consumption** = SFC = kg/h divided by thrust (turbofan) or kg/h divided by unit of shaft power (turboprop)

**Specific range** = NAM/kg

Total temperature = $T_0 = T + 1/2\ V^2 / c_p$ | Static temperature = $T = T_0 - 1/2\ V^2 / c_p$

Total pressure = $P_0 = P + 1/2\rho V^2$ | Static pressure = $P = P_0 - 1/2\rho V^2$

**Starting system**:

- Start valve admits bleed air supplied by the pneumaic system to operate the starter.
- Igniters are selected ON and are ready to light the mixture
- High pressure shut off valve deliver fuel that is sprayed into the combustion chamber. The flame becomes self-sustainable.
- Spools reach the self-sustained speed that doesn't require air starter assistance. Air started circuit is canceled.

One advantage of the **multiple spool jet engine design** is that a **smaller air starter** driving only a single spool can be used

Regarding a **divergent duct** we know that:

- Speed decreases
- Dynamic pressure decreases
- Static pressure increases
- Static temperature increases
- Total pressure remains constant
- Total temperature remains constant

A free power turbine is one not connected to a compressor, but to a propeller. It is usually placed after a HP turbine connected to a compressor. RPM are kept constant by a constant speed unit (CSU)

When Power change Free power turbine remain constant (the rest change)
When RPM change Free power turbine speed change (the rest constant)

This is the long complete rule that works with all type of this question

When the Power is decreased | increased

- Free power turbine RPM remains constant by a constant speed unit (CSU) and blade angle decrease|increases
- Gas generator speed decreases | increase.
- Propeller blade angle decrease | increase.
- EGT decreases | increase.
- HP spool speed decreases | increase.

When RPM is decreased | increased

- The free power turbine speed decreases | increase (free turbine and prop are linked by shaft)
- Gas generator speed remain constant.
- Propeller blade angle remain constant.
- EGT remain constant.
- HP spool speed remain constant.

**<u>Components</u>**

Ram recovery process involves a divergent inlet (pitot intake) where the ram air enters and flow velocity decreases to an optimum speed for the compressor

Compressor: rotor followed by stator [A shaped] | Turbine: stator followed by rotor [U shaped]

In a turbine there is a stator first because air coming from the combustor needs to be aligned to maximize efficiency.

In a compressor there is a rotor first as the IGV are used to align the flow before entering the compressor

In a compressor stators increase the pressure while rotors increase pressure and velocity

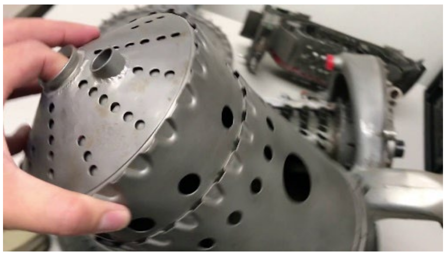
The exhaust section is formed by:

- Jet pipe
- Exhaust cone
- Propelling nozzle

**Inlet Guide Vanes (IGV)** or **Variable Inlet Guide Vanes (VIGV)** sit in front of the first LP compressor stage and have their angle set to make sure the air hits the compressor blades correctly (VIGV also control compressor airflow). This is done to prevent a surge, a complete breakdown of the airflow through the engine that usually can occur during low RPM and RPM changes, so acceleration and deceleration *(according to EASA VIGV are located at the front of the HP compressor and control compressor airflow together with VSV)*

**Nozzle guide vanes** (NGV) are the equivalent of the IGV but between the combustion chamber and the turbine. Pressure remains constant across it

**Swirl vanes** provide better fuel burn by slowing down the incoming air and creating a swirl motion (movimento vorticoso). They reduce the average axial flow speed in order to stabilize the flame front and generate a swirl of incoming air to enhance mixing of fuel with air.



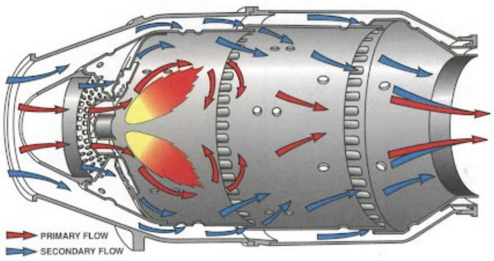
**Axial compressor**: compression ratio per stage 4:1 (total from 10:1 to 30:1)

In a compressor stage, if the axial air velocity increases more than the rotor blade velocity, stall margin increases

In a compressor, stator velocity decreases and the static pressure will increase

A **compressor stall** is most likely to occur in a compressor designed for a **high EPR operating at low RPM** and when the airflow stagnates in the later stages of the compressor, **stall occurs in the front stages**.

Axial compressor have a lower pressure ratio by stage but can compress a larger mass of airflow than the centrifugal compressor.




Centrifugal compressor compression ratio: 4:1

Axial compressor compression ratio: 10:1 (single spool) | 30:1 (multi spool)

The combustion chamber inner casing is cooled by a secondary cold air flow.

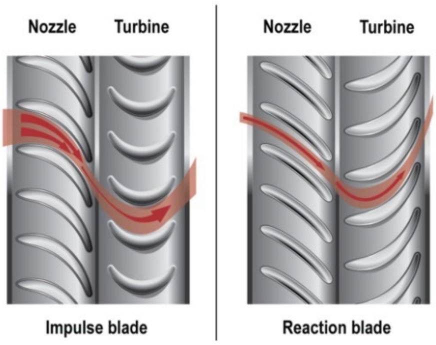
**Combustion** is assumed to take place at **constant pressure**

There are **2 types of combustion chamber**: multiple chamber (also called can type) and annular.

The **annular type** results in a shorter size and more uniform combustion with more even distribution of the thermal loads on the HP turbine (**reduced thermal stress on the turbine**)

In a **can type combustion chamber**, a total of only 2 igniters are usually fitted since the chambers are inter-connected

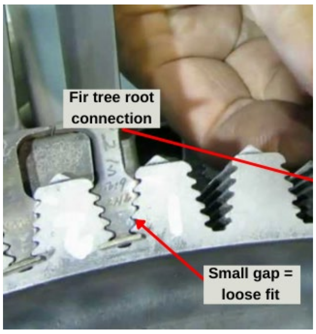
**Drain valves** or vent valves are used to remove unburned fuel from the combustion chamber




**Diffuser** is used to slow down the air flow before entering the combustion chamber and to prevent the flame from extinguishing

The pressure drops across the rotor blades between the nozzle guide vane and the turbine

In a **turbine stator** pressure decrease and velocity increase | In a **compressor stator** pressure decrease and velocity increase




In the compressor, the rotor increases pressure and velocity, the stator only increases the pressure

**Impulse Turbine**: Pressure DROPS across Nozzle, Pressure CONSTANT across Rotor [IDC]
**Reaction Turbine**: Pressure CONSTANT across Nozzle, Pressure DROPS across Rotor [RCD]

Turbine rotor blades are mounted on a disk or drum using a ''**loose fit''** to limit damage to the blades due to vibration

**Tip shrouds** are used to prevent airflow to spill around the blade tips, reducing the radial flow of gas that would be lost (blade tips are usually shrouded to prevent tip losses) => contributing to an **increase of efficiency of the turbine**


**Active clearance control** is used in turbine to provide enhanced **clearance between the blade tips and the casing**. It is achieved by **controlling the turbine case temperature** with the use of cool air.

Bleed valves in axial flow compressor are fitted to reduce the tendency to compressor stall

APU are started using electrical starter.

**Ignition system** is equipped with **2 exciters units** and **2 igniters plugs**

Engine start sequence:

- Start selected (bleed air coming in the engine and compressor start rotating)
- Ignition ON (igniters ready to light up when necessary)
- High pressure fuel ON (fuel start mixing with bleed air)
- Light-up (combustion starts)
- Self-sustaining speed (the engine spool is able to self-sustain after a certain rotational speed is reached)
- Starter circuit cancelled

High bypass engines are equipped with **cold exhaust reverser** only (fan reverser) in order to save costs and mass at the expense of a reduction in available reverse thrust

**Shaft power** is generated converting kinetic energy into mechanical work

**Propelling jet** (accelerated air after the turbine) is generated converting potential energy (pressure) into kinetic energy (velocity) [converging duct]

**Engine operation and monitoring**

The **primary input signals** for a hydro-mechanical **gas turbine engine** fuel control system include:

- $N_2$
- Compressor discharge pressure
- Compressor inlet temperature
- Fuel shut-off
- Thrust lever angle

**Small engines** can be **started using battery**

**Large engines** can be **started using 2 external sources or APU**, they cannot only be started with batteries

Fuel flow information is measured in the line between the fuel control unit and the engine burners

Fuel pressure information is measured between the booster pump and the engine

FADEC checks all input and output data and has its own power source to feed power to its sensors. It has dual input, so even if one failure occurs, it has a redundant input. If FADEC fails, the engine fails and shut down

FADEC consists of an electronic engine control unit and its peripherals (fuel metering, acutators, wiring, sensors,…)

FADEC has its own power source and has 2 channels for data redundancy in case 1 fails

FADEC functions:

- Automatic thrust rating control
- Engine operation within safe limits
- Fully automatic engine starting
- Thrust reverse control
- Engine overspeed and/or an EGT protection function
- Engine monitoring and elp for maintenance and troubleshooting

Igniters can be used continuously and at low intensity (low energy is required) when there's risk of engine flameout

To ensure ignition in condition of high altitiude and low temperature, the ignition system supplies a heat-intense spark.

Engine start sequence:

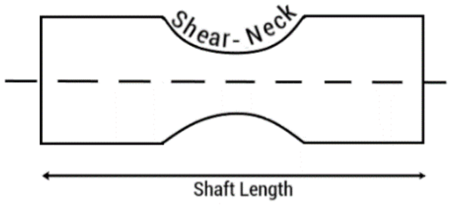
- Ground: Starter – Rotation – Ignition – Fuel
- In flight (windmilling): Rotation – Ignition – Fuel

[question] if a gas turbine engine/oil heat exchanger is located downstream of the HP fuel pump, internal leakage of the heat exchanger will cause oil level to RISE.

Some aircraft are fitted with 2 gearboxes to divide load of the accessories. The **supplemental gearbox** is usually **low speed** and **connected to the LP shaft**

The **Auxiliary gearbox** is:

- Driven by a high-pressure shaft, via internal gear to external gearbox
- Lubricated by oil
- **Drives AC Generator via CSD**
- **Drives the Oil pumps, HP Fuel pumps and Hydraulic pumps**




In the event of leakage to recognize the origin:

- Hydraulic = Red or Purple colour
- Oil = Yellow or Brown colour

**Shear neck** is a shinkage fitted to **prevent engine failure in case of mechanical failure** of the gearbox.

There are **2 idle setting of thrust**: ground idle and flight idle. Flight idle has a higher power setting so that in the event of a go-around thrust is readily available

**High pressure shutoff valves (HPSOV)** deliver fuel to the fuel nozzle. They are located between the Fuel Control Unit (FCU) and the Flow Meter that is located just before the Fuel Spray Nozzles.

For **turboprop** engine:

- the **beta range** goes from just below flight idle to maximum reverse
- the **alpha range** is the range of power lever position between flight idle and maximum power

**Vibrations sensors** are used to indicate imbalance of one or both of the spools

A turbine engine is run at **ground idle** for a period of time prior to shutdown **to prevent seizure of the rotor blades in their seals** (to prevent permanent deformation (creeps) in rotor blade).

Different types of **engine start malfunctions**:

- Dry Start: Fuel fails to flow to the engine
- Hung Start: The engine lights up, but fails to accelerate properly
- Hot Start: Light up is followed by a very rapid rise in EGT and continue to accelerate
- Wet Start: The engine fails to light up, RPM stabilizes at a low value (before attempting a restart, must do a dry run or blow-out)

Most important oil system indication during engine start is oil pressure (as for light aircrafts, check oil pressure after startup)

Spool-up time is necessary because a request for a rapid acceleration may cause a flameout due to overfly rich mixture or a compressor stall or surge

$N_1$ is the % of the fan and first stage of the LP compressor and turbine

**EPR (Engine Pressure Ratio)** is the ratio between LP turbine last stage and LP compressor (fan)

With a constant EPR, the thrust decreases when the altitude increases and at the same environmental conditions a given EPR setting maintains the thrust irrespective of engine wear due to ageing

**Engine trending** means that **expected** performance data, speeds,… are knows and **compared against actual data** to diagnose many problems before they become an issue and plan maintenance accordingly

Indicators used to monitor the engine:

- Oil temperature and pressure
- Chip detector caution light
- Fuel flow

''ENG OIL PRESS'' is an indication that occurs if there is low engine oil pressure and high oil temperature

**Tailpipe fire** can occur at engine start or shutdown and is the result of an **excess of fuel in the combustion chamber**, **in the turbine or in the exhaust nozzle, that ignites**. This produces abnormally **high EGT** and **visible jet of flames** out of the back of the engine.

If the pressure relief valve of oil system gets stuck, there is and excessive oil pressure

If the pressure relief valve of oil system doesn't seat properly (remains slightly opened), there is a lower-than-normal oil pressure indication

An aircraft accelerates (net thrust constant): dynamic pressure increases and specific thrust decreases

**If air is tapped from HP compressor:**

- EPR (outlet pressure/inlet pressure): the bleed air is not compressed so outlet pressure decreases while inlet pressure remains constant → ratio decreases
- EGT (engine gauge temperature): less air available for cooling so temperature increases

With an engine controlled via EPR:

- With constant EPR the thrust decreases when the altitude increases
- At the same environmental conditions, a given EPR setting maintains the thrust irrespective of engine wear due to ageing

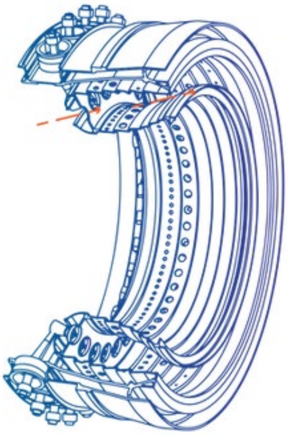
An aircraft accelerates:

- Dynamic pressure increases
- Specific thrust decreases (thrust/mass flow rate) because net thrust is constant and mass flow increases

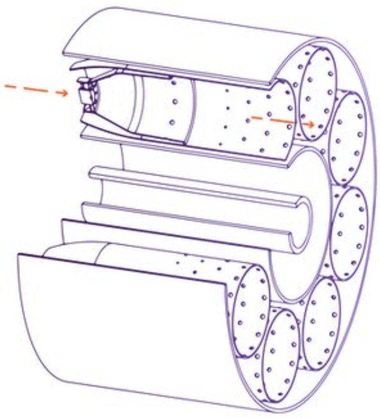
APU panel (it also has a dedicated start switch):


## Other images

| | | |
|---|---|---|
| **IMPULSE TURBINE** | | |
| Nozzle guide vanes<br>(form convergent ducts – accelerate the gas) | Velocity increases | **Pressure decreases** |
| Rotor Blades | Velocity decreases | **No change in pressure** |
| **REACTION TURBINE** | | |
| Nozzle guide vanes | | Pressure remains constant |
| Rotor Blades<br>(form convergent ducts – accelerate the gas, creating reaction force which drives the turbine) | Velocity increases | Both temperature and pressure decrease |



Annular



Multiple Chamber