AGK

System design, load, stress & maintenance

- **Damage/fault tolerant design**:
  - Capability to withstand a certain amount of **weakening** of a structure without **catastrophic** failure
  - Takes **cracking** of the structure into account
- **Fail safe design:**
  - More than one **load carrying component, parallel** structural parts, load sharing
  - Based on **redundancy** of components
  - **Does not** imply that the system will **never fail** despite having backups
- **Safe life design:**
  - Replacement of part after a given number of **cycles/flight hours** in use
  - **One** load carrying component is **sufficient** provided it is strong enough
  - **Does not** imply that the system will **never fail** in the safe life period

There is <u>no most favourable</u> design method, as each component varies

- **Maintenance:**
  1. **Hard time:** Component **overhauled/removed** after a set number of **hours/cycles** regardless of condition
  2. **On condition: Monitoring** of critical parameters & replacement of parts if a limit value is **exceeded**
- **Stress:** Force/area
  1. **Tension:** Force **resisting** from being **pull**ed apart
  2. **Torsion:** Caused by **twisting**
  3. **Compression: Push force**
  4. **Torque: Axial** rotation force
  5. **Shear:** Force **parallel** to cross section
  6. **Buckling:** Effect of more than one force
- **Strain:**
  - **Deformation** due to **stress**, expressed as a % **change of dimension** of original dimension
- **Elastic deformation**
  - Tendency of material to **return** to its **original** state
  - Temporary & reverses when load is removed
- **Corrosion:** Incorrect metallic bonding
  1. **Stress**: Continuous tensile load + corrosion
  2. **Intergranular**: Grain boundaries inside metal
- **Fatigue:** Material is continually loaded & unloaded & will **eventually break** even though **load is the same**
- Aircraft flies **beyond** certified load factor: Subject to **permanent deformation**

	No effect	**Minor**	**Major**	**Hazardous**	**Catastrophic**
Qualitive	None	Probable	Remote	Extremely remote	Extremely improbable
Quantative	None	10^{-3}	10^{-5}	10^{-7}	10^{-9}
Flight crew	None	Slight workload	Physical discomfort	Physical distress	Fatality/Incapacitation
Airplane margins	None	Slight reduction	Significant reduction	Large reduction	Hull loss
Passengers	Inconvenience	Physical discomfort	Physical distress	Serious/fatal injury	Multiple fatalities

Airframe

- **Engine compartment** decking & firewall: **Stainless steel/titanium sheet**
- **Sandwich** structure:
  - Consists of **two thin sheets** separated with **light core** material
  - Low **mass** high **stiffness**
  - **Stabilizes** covering sheets
  - **Unsuitable** for absorbing **concentrated loads**
  - **Does not** use **resin**
- **Composite structure:**
  - Consists of **matrix & fibres**
  - Component strengths can be **tailored** to the **direction of load**, **not** the same in all directions
  - **Higher strength to weight** ratio compared to other metal
- **Truss type:** Small **light** aircraft/training planes
- **Monocoque:**
  - Takes **all the load** on a stressed skin
  - Normally uses **aluminium/magnesium alloy**
- **Semi-monocoque:**
  - Fuselage of **transport airplanes**

- **Consists** of **skin, frames & stringers**
- Normally uses **aluminium/magnesium alloy**

- **Cantilever:**
  - Attached to the aircraft at the wing root **only** (No struts/braces/wires)
  - Vertical loads/bending moments highest at **wing root**
- **Wings:**
  - **Torsion box:** Consists of **spars, ribs, wing skin** reinforced by **stringers**
  - **Ribs:**
    - **Maintains** aerodynamic **shape**
  - **Stringers:**
    - Assists skin to absorb longitudinal **compressive** loads
  - **Wing skin:**
    - When unable to bear load, it transfers them to the **spar** via ribs & stringers
    - Bears **cylindrical** load during **pressurization (TENSION)**
  - **Spar:**
    - **Bears most of the load**
    - Consists of **web & girders** (I-beam)
  - In the **air**:
    - Lift **loads** carried by **upper/lower skin** surfaces & **spars**
    - **Tension** on **lower** surface & **compression** on **upper** surface
  - On the **ground:**
    - **Tension** in **upper** surface & **compression** on **lower** surface
  - **Wing bending moments:**
    - Reduced by installing "**upfloat" ailerons,** using fuselage fuel first while maintaining fuel in wings **as long as possible**
    - **Torsion:** Effect of **aileron deflection** or **positive sweep** (As the surfaces hit the air at non uniform levels a twisting motion is induced)
    - From **wing root** to the **tip:** First **compression** then **tension**
- **Aerodynamic flutter:**
  - Caused by **torsion** & **bending,** COP ahead of COG
  - **Avoided** by **increasing torsional stiffness** & adding **balancing mass in front** of control surface hinge
  - **Avoided** by ensuring **correct mass distribution** within the control surface during design
  - Wing bends **downwards**: Flutter may occur if the aileron deflects **upwards** as aileron COG is behind hinge line
  - Wing bends **upwards**: Flutter may occur if the aileron deflects **downwards** as aileron COG is behind hinge line
- **T – Tail aircraft:**
  - **Vertical stabiliser** Is not affected by **influence of wing turbulence**
- **Fuselage:**
  - Consists of: **skin, frames & stringers** (No spars/girders)
  - **Pressurization** load = <u>**Tension**</u>
  - **Shell** structures transmit: **Normal bending, tangent bending, tension & torsional stresses (NO SHEAR)**
  - **Torque links**: Most stress when making **tight turns** during **taxiing, turning** at a **small radius**
  - **Floor proximity emergency escape** lights: Gives additional **guidance** during **evacuation** in **reduced visibility**
- **Cockpit window**:
  - **De-icing** provided by **electrical heating**
  - Some aircraft have **speed restrictions** related to **bird impact** when **window heating inoperative**
  - **Window heating** improves **strength** of cockpit windows
  - Cockpit side windows **not** provided with de-icing, only **defoggers**
  - Made of: **Glass** & Inner surface made of soft **polycarbonate laminate**
  - **Green** system **"On"** information light and an **amber failure warning light**
- **Airplanes designed for long haul** cannot be used for **short haul flights** as **lifetime** of **fatigue sensitive parts** have been **determined on a load spectrum**
- **MZFM:** Maximum zero fuel mass – Total **maximum permissible mass** of the aircraft **without** usable fuel

<u>Hydraulics</u>

- Pascal's law: Pressure exerted on hydraulic fluid within an enclosed system the pressure will **increase equally** throughout the fluid, and act at **right angles** to the container walls. Force/area\
- Area(A) x distance(A) = Area(B) x distance(B)
- Most common:
  - **Phosphate ether** based fluids (Skydrol) is **purple**
  - **Synthetic oil** (Maybe **mineral**). Synthetic = Highest resistance against cavitation

- Operated at **3000<u>psi</u>**

- Hydraulic power is a function of **system pressure** & **volume flow**
- Monitoring parameters: **Pressure, fluid temperature & quantity**
- Flight deck indicator for hydraulic pressure: **<u>Transducer</u>** connected to an **indirect indicator**
- **Max power output & low mass**: Achieved by having **high pressure** system & **low volume flow**
- Hydraulic circuits:
  - **Open centre:** Has capabilities for **idle flow**
- Hydraulic braking system:
  - Uses nitrogen
- **Valves:**
  - **Shuttle** valves: (Switches between 2 sources of pressure)
    - Switch hydraulically operated units to the **most appropriate pressure supply**
    - Enables an **alternate** supply to an **actuator**
  - **Selector valve**: **Direct** system pressure to either **side** of the **piston** of an **actuator**
  - **Check/non return valve:** Works the same as an **electronic diode** allowing fluid to flow in one direction only
  - **Pressure relieve valves**: Protects against **excessive system pressure**
  - **Cut-out valve**: Used in a **fixed volume pressure** control hydraulic system
  - **High pressure relief valve**: **Failure** of **normal method of system** pressure limiting control
  - **Relief valve**: Makes sure the **pressure does not exceed** permitted pressure in the system
- **Actuator/jack**:
  - Converts hydraulic pressure into **linear motion**
  - **Hydraulic lock** is when no movement of piston takes place
  - **Single actuator**: Is powered in **one direction only** by hydraulic power, the return movement being another force
- **Pumps**
  - **Variable displacement vs. constant pump:** Variable **adjusts** the fluid pumped to the fluid **required**, moves fluid only when **necessary**
  - **Separate pressure regulator**: Used in hydraulic system in conjunction with **constant delivery** type pump
  - **Hand pumps:** Connected to the **bottom of the reservoir**
  - **Axial piston pumps:** Produces **high pressure when required** but can be **off loaded** to **reduce power** consumption
  - **Over heat detectors**: Installed at the **<u>pumps</u>**
  - **Low pressure alert**: Located at **pump outlet**, indicates **insufficient pump output**
  - **Pump failure**: **Quill drive** will shear **to offload & protect gearbox**
- **Filters**:
  - In **both pressure** & **return lines**
  - **Pop-out indicators:** Warn of **impending clogging/by-pass**
- **Reservoir:**
  - When **powering up**, fluid in reservoir **will decrease slightly**
  - Discounting leaks, it **fluctuates** with **jack displacement** & **accumulator pressure**
  - **Pressurized** to prevent **cavitation** in the pump inlet to the EDP, using **bleed air**
  - **Pressurized** to ensure inlet is provided with **continuous** supply of fluid free from **foaming**
  - Hydraulic fluid **temperature** is measured here
- **Accumulator**:
  - Store **fluid under pressure** (**energy storage**)
  - Provide a **limited alternate** supply of pressure in an **emergency**
  - **Dampen** out fluid pressure **fluctuations/variations**
  - Allow for **thermal expansion**
  - Cater for small internal **leaks**
  - Hydraulic fluid found in gas container = an internal leak in accumulator
- Hydraulic fluid **properties**:
  - Thermal stability
  - Low emulsifying characteristic
  - Anti-corrosive
  - High flash point
  - Irritating to **eyes & skin**
  - Incompressible
  - Ideally **low viscosity** to minimise power consumption and resistance to flow
- Internal **leaks** will cause **fluid temperature increase** (As the pistons/accumulators have to work more, becomes hotter)
- The **security** of the hydraulic system comprises:
  - Filters
  - Pressure Relief Valves
  - By-pass valves
  - Fire Shut-off valves
  - **Hydraulic fuse:** Prevent **total system loss** in the event of hydraulic leak/rupture

- **Quill drive**: Shear to **offload & protect** gearbox
- **Ram air turbine(RAT)**: **Flight controls** in the event of **loss** of engine driven hydraulic power
- **Stack pipe**: In **hydraulic reservoir** to provide **emergency supply**

Landing gear

* You should be acquainted with the parts of a landing gear

- Emergency extension methods:
  - Compressed nitrogen bottle: Used in emergency to lower landing gear & keep doors opened
  - Auxiliary hydraulics
  - Free-fall/gravity
- Damping element: Hydraulic fluid/oil
- Spring element: Nitrogen
- Gravity extension: Method when there is complete hydraulic failure
- V_{LO}: Speed at which landing gear can be operated with full safety
- V_{LE}: Flight speed with landing gear down
- Amber light: At least one wheel is in the travelling/unlocked condition
- Green light: Landing gear is locked down
- Over-centre mechanism principle : Down lock mechanism uses over centre principle, it locks the landing gear in the up/down position
- Torsion links/scissors: Avoids rotation of the piston rod relative to the gear oleo strut
- Retracting on the ground prevented by:
  - Electrical control system being routed through weight on wheels switch
  - Anti – retract latch: Can be overridden under specific conditions
  - Latch located in landing gear lever
  - Locking pins with flags
- Shimmy:
  - Damaging vibration of nose wheel while on the ground
  - Tendency of sinusoidal motion on the ground
  - Overcome by using accumulator associated with the steering cylinder
- Steering is achieved by mechanical rods connected to rudder pedals
- Anti-skid:
  - Speed sensor
  - Control unit/computer: Inputs – Idle & braked wheel speed, desired idle wheel train slipping rate
  - Control valve
  - Is available when using auto-brakes
  - Activates when main wheel spin up has been detected
  - Brake pressure decreased on slower spinning wheels
- Parking brake system: Fitted together with its own accumulator & system components
- Auto brake system:
  - Disconnects by pressing pedals
  - Disconnects by pilot action after landing
  - Low level: Auto-brakes works without delay
  - Works during thrust reversal
  - Works <u>above</u> pre-set minimum speed
- Accumulator: Supplies a limited amount of brake energy in the event of hydraulic system loss
- Brake units for transport category aircraft: Multiple disks
- Brake life: Extended by using steels brakes & use many small brake applications during taxi preventing temperature buildup
- Hydroplaning: When friction coefficient = 0
- RTO (Rejected take off mode):
  - Activates maximum braking with anti-skid above a certain speed, as soon as take-off is rejected & throttles moved to idle position
  - Is armed at low speeds
- Under-inflated tires: More wear at the **shoulders**
- Tubeless tire:
  - Lower risk of bursting
  - Better adjustment to wheels
  - Requires solid/branched wheels
  - Eliminates internal friction between tube & tyre
  - No built-in air tube
  - A radial side casing
- Tire-creep:
  - Circumferential movement of tyre in relation to wheel flange

  - Tire marks align with rim marks
  - A normal problem
- Ply rating: Parameter indicating tire relative strength
- Overheat protection: Due to prolonged braking, a hollow bolt is screwed into the **wheel rim** which melts at a given temperature (Thermal fuse) & deflates the tire to prevent it from **exploding/bursting**
- Worn tires can be repaired several times

Flight controls:

- Primary flight controls: Ailerons, elevators, rudders & roll spoilers
- Yoke rearward & to the left: Right aileron moves down, left aileron moves up & elevator moves up
- Yoke forwards & to the right: Right aileron moves up, left aileron moves down & elevator moves down
- Elevators: Lateral axis
- Ailerons: Longitudinal axis
- Rudder: Normal/yaw/vertical axis
- Manual flight control (cable-reversible): direct controls using cables like Cessna 172
  Powered assisted control (hydraulic-reversible): direct controls but with hydraulic system help
  Powered controls (Irreversible) that use hydraulic pressure and servo motors to move the surfaces
  Power assisted controls = do not require Q-feel system
  Powered controls = require Q-feel system (artificial feel)
- Pitch Trim = moving the tab
  Roll Trim & Yaw Trim = Moving the controls (yoke or pedals) = moving the neutral point/zero force point of the Q - feel
- Manual flight controls:
  - Requires gust lock
  - There is feedback to the pilot's controls of the aerodynamic forces acting on the control surface
  - Are less complex
  - Does not require artificial feel
- Irreversible flight controls
  - Does not require gust lock
  - When one hydraulic system is lost: Remaining systems will take over control
  - Requires artificial feel unit
  - There is **no** feedback to the pilot's controls of the aerodynamic forces acting on the control surface
  - Trimming achieved by adjusting the "zero force point" of the feel system
- **External** gust locks:
  - Prevent movement of the control column if the controls are not fitted with servo tabs
  - Gust lock: When it is ON, there are provisions to prevent take off
- Rudder limiters:
  - Restrict rudder deflection during high IAS
  - Rudder ratio changer: **Reduces** rudder deflection for a given rudder pedal deflection as the IAS **increases** (Not decrease)
  - Variable stop system: **Limits** both rudder & rudder pedal deflection as the IAS **increases**
- Rudder trim
  - Actuation on the ground with engine running: Rudder moves, rudder pedals move in corresponding direction
  - An adjustment of the zero force rudder position
  - In **fully powered**(Irreversible) systems by altering the neutral position of the artificial feel unit
- Artificial/Q feel unit:
  - Connected in parallel with the primary controls
  - Functions in parallel with an irreversible hydraulic actuator
  - Fitted to prevent over-stressing of the aircraft & provides increased forces as the speed increases
- Control surface range of movement restricted/limited by **primary** stops at the surface
- Control jamming protection: Disconnect part of control system that becomes blocked
- Control column/wheel:
  - Zero force position does **not** change when using pitch
  - Zero force position changes when using aileron trim
- Over tensioned cables: Excessive friction in the cables
- Hydraulic valves: Acts on the actuator of the control surface
- V-tail aircraft controls that act together: Stick in one axis & rudder pedals
- Large aircraft without trim tabs: Trimming is possible by adjusting the neutral point of the artificial feel mechanism by means of a trim switch

Secondary flight controls:
Speed-brake, lift augmentation devices & trimmable stabilizer (Moved by hydraulically actuated **jacks**)

- Trim tabs: Reduce hinge moments but reduce control surface efficiency

- Auto slat system extends the slats automatically when a certain value of angle of attack has been reached (Receives signal from stall warning system)
- Elevator trim: Double switch used to reduce possibility of trim runaway(When trim system malfunctions)
- Spoilers:
  - Located symmetrically on the wing surface
  - Ground spoiler extension activated when main wheel spin ups
- Trailing edge:
  - Fowler: Moves aft then turns down
- Leading edge:
  - Krueger: Close to the root

Fly-by wire:
- Most basic mode: Direct
- System based on electrical (analogue) signals from a computer sent to hydraulic actuators
- Modes: Normal, alternate, direct & mechanical
- Advantages:
  - Direct & indirect weight savings through simplification of systems
  - Improvement of piloting quality throughout flight envelope

Pneumatics:
- Differential pressure = **7 – 9psi**
- Bleed air:
  - Used for cabin pressurization
  - Usually taken from **low pressure stage/low pressure bleed air valve** of the **high stage compressor**
  - **High pressure stage** from **high pressure compressor** if it is **necessary**
  - Engines bleed air is **not** considered to be high pressure, it only takes air from high pressure **compressor**
- Piston engine aircraft: Uses ram air **or** inlet air manifold (Discrepancy)
- Pressurization:
  - It is required as at altitudes above 10000ft there is sufficient ambient air pressure to force the oxygen required into our lungs to allow us to breathe normally
  - Flight level/ambient pressure = Cabin altitude pressure – differential pressure
  - Capability to maintain cabin pressure higher than ambient pressure
  - Positive pressure: Cabin pressure higher than ambient
  - Negative pressure: Cabin pressure lower than ambient, negative pressure relief valves open
  - Cabin altitude decreasing = pressure inside cabin increasing, cabin rate of climb decreasing
  - Percentage of oxygen remains constant regardless of cabin air compression or pressurization
  - Limitation of pressurized cabin: Due to maximum positive cabin pressure at maximum cabin altitude
- Cabin pressure controller:
  - Control cabin altitude, rate of change & limit differential pressure
  - Control by delivering a substantially constant flow of air into the cabin & controlling the outflow
  - Maintain cabin altitude via position of outflow valves
  - Cabin pressure is regulated by airflow leaving the cabin
  - Outflow valves remain partially open in level flight
  - Ditching controls: Close outflow valves when landing on water
  - Flight altitude & differential pressure remains constant = mass air flow through cabin is constant
  - Cabin pressure decreases more slowly than atmospheric pressure
  - 2 modes:
    1. Constant pressure differential: Changing differential pressure slowly during climb/descents
    2. Isobaric: Maintains same cabin pressure during climbs/descents
- Excessive cabin altitude warning: Activates at 10000ft
- Cabin altitude rate of change selector: Controls cabin altitude rate of change
- Depressurization in case of emergency:
  - Cabin altitude & cabin vertical speed **increases** until differential is **zero,** then the **cabin VSI** shows a descent **equal** to **aircraft VSI**
  - Differential pressure will rise to its maximum value, thus causing the safety relief valves to open
  - In level flight If the outflow valves are locked, the cabin pressure will rise, indicating a descent on the cabin altitude indicator
  - Pressure relief valve: Acts in case the pressure reducing valve malfunctions
- Air conditioning: Air that has been controlled in respect to temperature & pressure
- Air condition automatic control failure: Pilot can revert to manual control & set the valve to the required setting
- Pack cooling fans: Supplies heat exchanger with cooling air during slow flight & ground operations
- Pack inlet inflow valve: Used to maintain a constant & sufficient air mass flow to ventilate the cabin

- Bootstrap/turbo compressor:
  - (1) Air supply/first heat exchanger (2) Compressor (3) Heat exchanger (second in some cases) (4) Expansion turbine COOLING (water separation comes just after this stage) [ACHE]
  - Refers to cold air unit/air cycle machine arrangement for mainly turboprop, primary function is to cool bleed air
  - Air cycle machine/air conditioning pack: Causes a **pressure & temperature drop** in bleed air
  - Mass air flow is routed to the secondary heat exchanger outlet to the turbine inlet
  - Turbine drives the compressor & creates a temperature drop in the conditioned air
  - Compressor increases temperature of the air and makes heat exchanger more efficient
  - Expansion turbine reduces air temperature & pressure
  - Heat exchangers cools bleed air in front & behind the compressor of the air cycle machine
  - Primary heat exchanger: Precools engine bleed air
  - Secondary heat exchanger: Cools air behind the pack's compressor
- Combustion heater:
  - Is separate, to prevent exhaust gas from contaminating cabin air (CO poisoning in MEPs)
  - Powered by fuel from aircraft fuel system
- Short-haul turbojet aircraft cabin air: Humidity is not controlled

Icing:

- Components to be protected:
  - Engine air intake & pod
  - Front glass shield
  - Pitot tubes always provided with heater & static tubes may also be
  - Waste water masts
  - Leading edges of the wings: Leading edges of the slats partially/completely
  - A part of the whole leading edge
- Bleed air/thermal/hot air anti-icing:
  - The most commonly used by large jets
  - Bleed air from HP compressor
  - An over-temperature indicated by warning lights
  - Reduces max thrust but does not affect aerodynamic performance
- Turbo-prop aircraft:
  - **Anti-icing** protection at engine inlets, pitot & static ports
  - **De-icing** protection: Wings
  - Propeller protected electrically
- Pneumatic system with inflatable boots/pneumatic mechanical:
  - For wings
  - Used for large turboprop
  - Used for only for **de-icing**
  - Operated when there is approximately 1.5cm of ice on leading edges **visibly**
  - Inflates each pneumatic boot for a few seconds
- Propeller de-icing:
  - Uses slinger rings
- Electrically powered ice protection systems:
  - On small surfaces
  - Used for pitot-tubes, static ports & windshield
- Flight deck window:
  - Electric heating
  - Heating facility used on a continual basis as it reduces the thermal gradients which adversely affect the useful life of components
  - Supplied by 3 phase AC
  - Heating systems cycle ON/OFF to maintain a windscreen temperature between 18^{o} - 35^{o}
- Hot rod ice detector:
  - Accumulate ice & is visible from the cockpit
  - A heated probe & built-in floodlight
- Rotor ice detector:
  - Measurement based on torque
- Pressure deferential/Smith's ice accretion detector
  - Small holes freeze first
  - Activated by a decrease in dynamic pressure
- Rosemount vibrating ice detector:
  - Light in cockpit alerts crew of aircraft icing
  - Principle of vibration

- Advisory ice protection system: Flight crew activates ice protection systems based on standard flight manual criteria of a total temperature reading & sighting of moisture. The ice detector signals serve as a back-up indicator
- Automatic ice protection system: Ice detector automatically activates ice protection systems at the optimal moment
- Primary manual ice detection system: Flight crew activates ice protection systems based on ice detector signals

Fuel:

- Flash point:
  - Lowest temperature of vapour at which it ignites in contact with a flame
  - Vapour ignites in contact with a flame & extinguishes immediately
- AVGAS usually used for reciprocating piston engines
  - AVGAS 100: Green
  - AVGAS 100LL: Blue
  - AVGAS 80: Red
- MOGAS: Increased risk of carburettor icing
- Transport aircraft wing tanks:
  - Integral, built internally into the aircraft structure, saves weight & space
- Small aircraft:
  - Fuel stored in wings
  - Incorporates volumetric top off valve float switches
  - Typically measured by **level** of the fuel tank (Not volume)
- Usable fuel: Total amount of fuel that can be supplied to the engine
- Unusable fuel is sometimes minimised by the incorporation of tank sump pads
- Prevent moisture accumulation by keeping tanks full when not in use
- Ice traps: Fitted in the fuel delivery line between fuel tank & engine
- Presence of water indicated by fluid forming at bottom of the strainer as water is heavier than fuel
- Additives added to fuel to prevent ice crystals from forming/waxing

Fuel systems:

- Fuel pressure measured: Line between booster pump & the engine or at the outlet of the high pressure filter
- Solenoid valve: Electrically operated/activated
- Cross feed valve:
  - Ensure all fuel on board is available to any engine
  - Adjust fuel distribution
- Fuel control unit
  - Protected from debris by the fine filter located between the high pressure fuel pump & governor unit
- Fuel heaters
  - Located at the engine
  - Prevent risk of ice formation from water contained in the fuel at low temperatures
- LP booster pumps:
  - Avoid vapour locking & prevent cavitation/bubble accumulation of the HP fuel pump
  - Electrically driven centrifugal pumps
  - 20 – 100 psi
  - Direct feed lines to engine at positive pressure
- HP booster pump:
  - Driven by engine
- DC fuel pump: Can only feed the APU
- Fuel tanks:
  - Ventilation: Prevents low pressure or excessive overpressure in the tank
  - Pressure kept ambient
  - 2% of total tank space in each individual tank vent space
- Baffles: Restrict fuel movement in the tank during manoeuvres/sideslip
- Refuelling:
  - Pressure refuelling
  - Automatic fuelling shut off valve switches off fuel supply system when the fuel has reached a predetermined value or mass
  - Magnetic drip stick: Measurement done with the indicator & using the documentation
  - Automatic fuelling shut off valve stops fuelling as soon as a certain fuel level is reached inside the tank
  - Bonding & connections to earth terminal between ground equipment & the aircraft should be made before filler cap is removed
  - Via a unique point, an underwing refuelling centre
- Fuel dumping:
  - Required on aircraft where MTOW is higher than MLW

- Fuel dumping to a predetermined safe value
- Special fuel consumption schedules: Minimizes wing G-loads & preserve main tanks for landing

	Jet A	Jet A – 1	Jet B
Freezing point	-40°C	-47°C	-60°C
Flash point	38°C	38°C	-20°C
Density (kg/l) at 15°C	0.78 – 0.83	0.78 – 0.83	0.75 – 0.8

Electrics:

- P = V x I, R = V/I
- Power = Watt, Work/energy = Joules
- Most common frequency = **400Hz**
- Resistance increases with increasing temperature
- Open circuit occurs: loss of continuity prevents components from functioning
- Relay: Electromagnetically operated switch
- Lorentz force: Conductor cuts field lines of a magnetic field
- **CIVIL:** In capacitor current leads voltage & voltage leads current in inductance
- Capacitive reactance ↑ Frequency↓ Current↓
  Inductive reactance ↑ Frequency↑ Current↓
- Circuit breakers:
  - Are used in both AC & DC
  - May be reset manually after fault has been rectified
  - Trip free: Doesn't allow contacts to be held until fault is rectified
  - Magnetic: Quick tripping response
  - Thermal: Protects the system in the event of overload/overheating OR a prolonged overcurrent (Discrepancy)
- Electrical bonding:
  - Provides safe distribution of electrical charge/currents (Main)
  - Protect against lightning
  - Reduce radio interference
  - Ensure 0 voltage difference between aircraft components (No such thing as electrostatic potential)
  - Set aircraft to a single potential
  - Provide a single earth for electrical devices
- Static dischargers:
  - Wicks safely dissipate the static charge of the aircraft in flight
  - Placed on wing & tail tips to facilitate electrical discharge
  - Reduce interference with on board radio communications to a minimum
  - Limits the risks of transfer of electrical charges between the aircraft & the electrified clouds
- Diode/semiconductor: Allows electrical flow in one direction only
- Zener diode: Used for **voltage stabilization**
- Fuses:
  - Light duty/Cartridge: Ceramic with thin wire
  - Current limiter: Allow a short term overload before rupturing
  - Heavy duty/HRC: Used in high current circuits

Batteries

- Main function: Be an emergency source of electric power
- Capacity: Ampere hours
- Thermal runaway = Significant increase in battery temperature
- Lead acid battery:
  - 1 cell output approx. 2 - 2.2V
  - Any cell breaks, whole battery unserviceable
  - Tested by comparing "on-load" & "off-load" battery voltages
- NiCad:
  - Reduced charging time & constant output voltage
  - Even voltage before rapid discharge
  - Weighs less than lead-acid batteries
  - Good discharging-discharging capability
  - Wider permissible temperature range
  - Good storage capabilities
  - Sturdy metal casing
  - Potassium hydroxide electrolyte
  - Need to be monitored from excessive temperature caused by a decreasing voltage
  - High **risk** of thermal runaway

- Parallel batteries: Same volt, sum of capacity
  Series batteries: Sum of volts, same capacity
- When a battery is almost fully discharged, there is a tendency for the voltage to decrease under load
- Battery check: Load should be applied in order to give a better indication of condition
- Battery charging at high charge rate is normal at start up. However not normal when it persists
- Battery control unit isolates battery:
  - From bus when charging complete
  - When battery overheats
  - In case of internal short circuit

Alternators
- AC – DC: TRU/Rectifier
- DC – AC: An inverter
- Brushless AC: Activated by a set of permanent magnets
- AC supply charges battery via transformer rectifier units (TRU)
- Output of generator controlled by varying the field strength
- AC alternators have fixed induced windings (Stator), dynamos have fixed inductor (Field) coil & moving rotor
- Alternator rotor coils: DC
- Alternator stator coils: AC
- Frequency of current depends on its rotation speed
- Frequency "wild": Output frequency varies with engine speed
- Feeder fault on a direct current circuit results in a flux unbalance between voltage coil & series winding turn
- **RPM = Frequency x 2 x 60 ÷ no. of poles**
- Constant speed drive (CSD):
  - Drives generator at a constant speed
  - Ensures electric generator maintains a constant frequency
  - Can be disconnected from drive shaft
  - Is hydromechanical
  - Can be disconnected in flight
  - Requires voltage controller/regulator to maintain constant voltage under variable load
  - Can only be reset on the ground after engine shut down
  - During fault, CSD should be disconnected provided the engine is still running
  - Red arc = Should be disconnected and generator is unusable for the rest of the flight
  - Oil temperature & low oil pressure is monitored
- Voltage regulator
  - Controls current
  - Controls output voltage at varying loads & speeds
  - Controls power required for field excitation of main rotor
  - Increases excitation current when load increases
  - Connected in series with shunt field coil
- Series wound: Voltage varies with load, high starting load
  Shunt wound: Voltage decreases slightly with increase in load, needs presence of magnetic field & min rotation speed
  Compound wound: Voltage constant
- **Star**-connected: (Star karat)
  - Line voltage: √3 x phase voltage
  - Line current: Phase **current**

  Delta-connected:
  - Line voltage: Phase **voltage**
  - Line current: √3 x phase current
- Starter warning lights: Illuminates when starter motor clutch is engaged
- Generator control unit: Modern GCUs are provided with a permanent indication to record the failure, all the commands originating from the control panel are applied via the GCU except dog clutch release

Distribution
- DC:
  - Simple connection
  - High starting torque
  - DC generators connected in parallel to provide maximum power
- AC:
  - Flexibility in use
  - Light weight components
  - Easy to convert to DC
  - Easy maintenance

- HOT BUSSES & DCBUSSES: Directly connected to battery
- Bus bar: A distribution means for electrical power
- Bus tie-breaker (BTB):
  - Allows power to be applied to the failed AC generator's bus bar
  - Ties generator to other bus bars & components
  - Opens when there is **phase** imbalance between generator & other main busbars/generators
- GCB & GCR:
  - Generator control breaker (GCB): Connects generator to busbar
  - Generator control relay/exciter breaker (GCR): Switches excitation of generator field on/off, it closes when generator voltage is greater, opens when battery voltage is greater
  - Over-excitation/over-voltage & under-excitation: Exciter breaker & generator breaker opens
  - Underspeed: **Only** generator breaker opens
- Generator relay: Ensures that voltage are almost equal before generators are paralleled
- Reverse current relay: Ensures battery does not supply current to generator, battery voltage exceeds generator voltage
- Loads sharing on aircraft busbar connected in parallel:
  - Current reduces as loads are switched off
  - During isolation, AC busbar current consumption decreases
  - Both real & reactive loads must be matched
  - Real load regulated by torque from CSD/equalising circuit (Drive shaft which controls frequency) **kVA**
  - Shared/reactive load regulated by voltage regulator (**Excitation current** which controls voltage) **kVAR**
- Paralleled generators, generators connected to the same busbar
  - Equal voltage
  - Equal frequency
  - Equal phase rotation
  - Voltage of the same phase
  - Current unimportant
- Unparalleled generators: Phase unimportant
- Load shedding: Temporary/permanent switching off of certain electric users to avoid overload of generators
- Protected from
  - Over-voltage
  - Under-voltage
  - Over-current
  - Over-speed
  - Under-frequency
- Grounding negative pole of the aircraft structure making it a return path to earth
  - **Single pole circuit**
  - Weight saving
  - Easy fault detection
  - Reduction of short circuit risk
- Motors:
  - DC starter motors: Series wound
  - Reverse direction of rotation by reversing polarity of stator or rotor

Piston engines:

- Diesel engines:
  - An injection engine, intake system does not need icing protection
  - No throttle valves
  - No mixture control
  - Power set/determined by fuel flow only
  - Less flammable than petrol
  - Thermal efficiency is higher than petrol engine because compression ratio is higher than petrol engine
  - Produces soot: Fuel droplets coming from atomiser do not burn completely
  - Produces less maximum power output (No turbocharger)
  - Inlet valves shut before the fuel is injected
- Otto cycle
  - Induction: Inlet open exhaust close. Modified Otto: Both valves open (Valve overlap)
  - Compression: Intake open initially then both close, ignition before TDC at every second crankshaft revolution, Vol decrease & temp increase
  - Power/driving stroke: Both closed. Modified Otto: Before BDC exhaust opens & intake closed
  - Exhaust: Inlet close exhaust open. Modified Otto: Both valves open (Valve overlap)
- Piston engines:
  - Theoretical valve & ignition settings readjusted to increase overall efficiency

- Thermal efficiency 30%
- Process is **intermittent**
- Theoretically combustion occurs at constant volume
- Manifold pressure: Increases as throttle is opened
- Crank assembly: Crankshaft, pistons & connecting rods
- Crankshaft: Transforms reciprocating movement into rotary motion, twice speed of camshaft
- Crankcase: Provides a mounting point for most of the engine components and in which are the main rotating assemblies located
- Camshaft: Rotates at half the speed of crankshaft
- Power measured by friction brake: Brake horse power

- Adiabatic: Expansion/compression with no heat added or lost
  Isochoric: Constant volume process in a thing
- Valves:
  - Held shut by valve springs
- Compression ratio = Total volume ÷ clearance volume
- Power = Torque x RPM
- Total volume = Swept volume + clearance volume
- Engine capacity = (Piston area x piston stroke OR swept volume) ÷ no. of cylinders
- Volumetric efficiency: Amount of charge induced into a cylinder compared with that which would fill the swept volume
- Torque: Measured at the gear box which is located between the engine & the propeller
- Specific fuel consumption: Mass of fuel required to produce unit power for unit time

Fuel:

- Octane rating:
  - Fuel anti-knocking rating or resistance to detonation
  - Higher octane rating = higher maximum compression ratio
  - Higher compression ratio = higher required octane required
- Detonation:
  - Use of fuel with low octane rating
  - Engine overheat/high cylinder heat temperature (CHT)
  - Too weak/too lean air fuel mixture ratio
  - Excessive turbocharger boost
  - High charge temp due to improper use of carb heat
  - Incorrect timing
  - High power at low RPM with constant pitch propeller
  - High manifold pressure & low RPM
  - If engine detonates during climb out: Retard the throttle, reduce MAP pressure & increase or fully enrich mixture
- Vapour lock:
  - Heat produces vapour bubbles that can block the fuel line
  - Vaporizing of fuel prior to reaching the engines
  - High fuel temp, low fuel amount, low ambient pressure & high angle of attack
  - Prevented by providing fuel under pressure
- Pre-ignition:
  - Engine run-on
  - Occurs when local hotspots in the cylinder ignites fuel air mixture before spark plugs fire
  - Likely encountered when cylinder excessively hot or contaminated by deposits of carbon
  - More likely with RPM increase
- Fuel check:
  - Sample cloudy & clears slowly from the top: Water in fuel
  - Checked before the first flight of the day
- Auxiliary fuel pump:
  - Take-off
  - Landing
  - Emergency
  - Suspected vapour lock
  - Failure of engine fuel pump

Carburettor:

- Function: Supplies correct air/fuel mixture at all speeds
- Principle of difference in air pressure at the venturi throat (Which creates suction to cause fuel flow through carburettor main jets) & air inlet
- Air flowing though venturi causes a decrease in pressure at the throat
- Icing conditions:
  - Between -5 to +18^{o}C, visible moisture or relative humidity greater than 60%
  - Formed due to vaporization of fuel & expansion of the air in the carburettor
  - MAP increases after carb heat applied indicates ice was forming
  - Affects both carburettor systems & fuel injection systems
  - Most likely at venturi & throttle valve
- Carb heat:
  - When applied mixture becomes richer
  - When applied density of the air reduces, enriching the mixture
  - Fixed pitch: RPM reduces (Then increases)
  - Constant/variable pitch: RPM constant, MAP reduces
  - Not used during take-off or landing because of loss of power & possible detonation
- Primer pump:
  - Provides additional fuel for engine start
  - Injection of fuel in the cylinder intake ports
  - Excessive priming should be avoided because of:
    1. Risk of engine fire
    2. Risk of flooding engine
    3. Fouls the spark plugs
    4. Washes off the lubricant from the cylinder walls (Most correct)
- Diffuser/compensating jet:
  - Maintains constant mixture at low & high power settings
  - Maintains constant mixture ratio over the operating range of the engine
- Altitude mixture control/barometric correction:
  - Mixture ratio controlled/adjusted via fuel flow to obtain the correct fuel/air ratio
  - Correct variations/maintain the weight fuel/air ratio due to decreased air density as altitude increases
  - Varies fuel supply to main discharge nozzle
  - Reduce fuel to match air
- Accelerator pump:
  - Enables proper functions during rapid throttle advance
  - Temporarily enrich the mixture by pumping more fuel into the induction system during rapid throttling
- Fuel strainer: Positioned upstream of the needle valve

Cooling:

- CHT: Measures temperature of hottest cylinder using thermocouple
- Cowl flaps: Cools CHT
- Air cooled engines: Uses RAM air, fines increase cylinder & head surface area
- Liquid cooled engines: Coolants of composition: 30% ethylene glycol & 70% water

Lubrication:

- Lubrication system:
  - Piston/reciprocating engines use circulation of lubricating oil for internal cooling, mainly mineral oil
  - Reduce internal friction & provide cooling
  - Lubricates, seals, cools, cleans & prevents corrosion
  - Engine protection & hydraulic operation
- Wet sump: Carries oil supply in engine & sump itself
- Dry sump:
  - Oil supply is external
  - Stack pipes, both at the bottom of the tank
  - Oil cooler fitted: In the return line after the oil has passed through the scavenge pump
- Ventilation:
  - Prevent excessive pressure from building in a tank
  - Air space in the top of the tank is for expansion & foaming
- Temperature sensor: Detects temperature after the oil has passed the oil cooler
- Oil viscosity:
  - Tendency of a liquid to resist flow
  - Depends on oil temperature
- Oil pressure gauge:

- Measures pressure of the oil on the outlet side of the pressure pump
- Higher than normal pressure during start-up: Normal/acceptable provided it returns to normal after

<u>Ignition:</u>

- Small aircraft piston engines generally use **high tension** system
- Once engine has started ignition system is independent of the electrical system of the aircraft
- Dual ignition: Improves reliability, combustion efficiency, redundancy & reduce detonation
- Magneto:
  - Principle: Breaking primary circuit in order to induce a low amp, high voltage current which is distributed to the spark plugs
  - Drives primary current from a self-contained electro-magnetic induction system
  - If one fails it will cause a slight drop in RPM
  - Electrical energy from permanent rotating magnets connect to engine
- Impulse coupling:
  - Provides a stronger spark on TDC on engine start
  - Provides retarded(slower timing) spark
  - Inhibited at higher than normal rotational speeds via centrifugal spring
- Spark timing:
  - The faster engine functions, the more the spark is advanced
  - Advanced at high RPM because flame rate & time for complete combustion remains constant
- Contact breaker:
  - Controls primary circuit of magneto
  - Causes very rapid magnetic/flux changes in the primary coil of a magneto
  - Produces the spark via spark plugs when it **opens**
- Capacitor/condenser:
  - Parallel to contact breaker
  - Induces a very high voltage across the secondary windings
  - Prevents arcing(surging) between breaker points
  - Intensify current in secondary winding (Stores energy)
- Distributer: Distributes secondary current to the sparking plugs
- Magneto selector OFF:
  - Grounds <u>primary</u>(More important)& secondary circuit
  - If engine continues to run, grounding wire of one of the magnetos is broken, to shut off engine cut off fuel supply

<u>Mixture:</u>

- Chemically correct ratio 1:15, MAX EGT
- Richness ratio = Real mixture ratio: Theoretical ratio
- Air/fuel ratio or Mixture = Mass of fuel: Mass of air
- Best power mixture = Most power that can be obtained for any given throttle setting
- Altitude increases:
  - Air density decreases
  - Mixture becomes richer
  - Fuel flow too high compared to oxygen getting sucked in
  - Fuel flow reduced to maintain constant RPM
  - Constant mixture = Fuel flow constant
- Altitude reduced:
  - T0 maintain same mixture fuel flow should be increased
- Enriching:
  - Lower CHT
  - Too much causes fouling of spark plugs
  - Makes starting possible & to cool the engine sufficiently while idling
- Leaning/weak:
  - Higher CHT
  - Weak mixture causes overheating
- EGT: Assists pilot in selecting correct mixture
- Choke: Cuts off air supply so that more fuel is burnt, assist start-up

Propellers:

- Constant speed propeller:
  - Compared to fixed pitch propeller with the same design speed: Has a better efficiency above & below the **design point**
  - Compared to fixed pitch: **Maintains** its maximum prop efficiency over a wider range of airspeeds
  - Uses RPM & MAP indicator
- Fixed pitch propeller:
  - Usually designed for max efficiency at cruising speed, at take-off blade AOA relatively high
  - Uses RPM indicator ONLY
- Propeller blades are twisted to maintain constant angle of attack along the blade
- Mechanism to change propeller blade angle: Hydraulically by engine oil
- Control lever: Control propeller regulator
- Double acting: Uses oil pressure for both fine & coarse adjustments
- Single acting: Uses oil to decrease (fine) & spring to increase (coarse) pitch
- Feathering system
  - Used during take-off & landing
  - Actuated by pulling the control lever rearwards
  - Un-feathered by using an electric unfeathering pump
  - Feathering pump: Electrically driven supplies propeller with oil under pressure when the engine is shut down
  - Feathering stop: Prevent the propeller blades from moving beyond the feather position
- Propeller reduction gear:
  - Enable engine RPM to increase with an increase in power & allow the propeller to remain at a lower, efficient RPM
  - Cause the prop to rotate less than engine RPM
- Blade angle of attack (AOA):
  - Angle between chord/face & relative **airstream**
  - Take-off: Decreases
  - MAP/RPM increases: AOA increases
  - TAS increases: RPM constant & AOA decrease
  - During cruise: Relatively high
- Blade angle:
  - Angle between chord & **plane of rotation**
  - TAS increases: Blade angle increases
  - MAP increases: Blade angle increases
  - Power increased: RPM constant & blade angle increase
  - During take-off: Low prop pitch (Fine) = propeller lever position full forward
- Centrifugal twisting moment (CTM): Tends to decrease blade angle (Fine)
- Aerodynamic twisting moment (ATM): Tends to increase blade angle (Coarse)
- Asymmetric loading (P – factor): Happens when airplane has large AOA (Up going blade has higher AOA than down going)
- Torque: Tendency of propeller torque reaction opposite of engine torque
- Slipstream: Airflow spiralling/cock-screw behind prop along aircraft towards vertical stabilizer. Low TAS & high power
- Gyroscopic effect: Precession

Power augmentation

- MAP increase = Air density increase
- Normally aspirated engine:
  - MAP constant, power increase with increasing altitude; This is due to: Increase of air density behind the throttle valve * lower back pressure
  - RPM constant, MAP decrease with increasing altitude, lowering density
  - Engine not turbocharged or supercharged
  - Slightly higher power than super/turbocharged engines due to super/turbochargers requiring power to drive impeller
  - MAP is always lower than ambient pressure when engine is running
- Superchargers:
  - Radial compressors
  - Increase the mass of the fuel/air mixture entering the cylinder
- Turbocharger:
  - Compressor & turbine mounted on a common shaft
  - Driven by exhaust system, diversion of exhaust gas
  - Air enters eye of the impeller & leaves at a tangent to periphery
  - Advantage: Power available is less affected by altitude, maintain power at altitude
  - Advantage over supercharger: Uses exhaust gas energy which would normally be lost
  - Waste gate installed parallel with the turbine
  - Monitored by MAP ONLY
- Waste gate:
  - Prevents overpower

- Completely closed: All the exhaust gases are directed through the turbine
- Seized: May cause MAP to over exceed during descent & MAP decrease during ascent
- Controls speed of turbocharger

• Rated power: Max continuous power for which engine is certified
  Take-off power: Max power engine can deliver for take-off
• Conditions for best power: Cold & dry air at high pressure
• Inter-cooler: Fitted between supercharger & inlet manifold, minimizes risk of detonation
• MAP increases until engine's critical altitude is reached
• Engine fails to stop with magneto OFF: There is excessive carbon formation in the cylinder
• Prolonged running of engine at low RPM/idling: Efficiency of spark plugs reduced, spark plug fouling
• Engine overload:
  - Avoided by increasing RPM before increasing MAP (**M**ixture – **R**PM – **T**hrottle/manifold) **MRT**
  - Avoided by decreasing MAP before decreasing RPM (**T**hrottle/manifold – **R**PM – **M**ixture) **TRM**
  - Excessive pressure: High MAP & low RPM

Turbine engines:

• Gas turbine engines:
  - Combustion takes place **continuously** at constant **pressure**
  - Accelerating air/gas in order to obtain a reaction force, highest axial velocity of air on exit from propelling nozzle
  - Maximum gas temperatures: Within combustion chamber
  - **Propelling jet** generated by expansion of hot gases resulting in a conversion of potential energy (Pressure) into kinetic energy (Velocity)
  - Static thrust: Product of exhaust gas mass flow & exhaust gas velocity [M x ($V_{JE} – V_1$)].
    It is zero when airplane is not moving (Since V_1 = 0)
  - Jet engine thrust T = Air mass flow(m) x [Jet velocity (V_J)– Airspeed(V_V)] + Exhaust cross sectional area(A) x [Jet efflux exhaust static pressure(p_J) – static ambient pressure(p_0)] = $m(V_J – V_V) + A(p_J – p_0)$ [Hecto = hundred]
  - Noisiest part: Jet efflux
  - Ram air increases efficiency of the engine

• Bypass ratio = Bypass **mass** flow ÷ HP compressor **mass** flow
  Bypass mass flow = Inlet **mass** flow – HP compressor **mass** flow
  HP compressor mass flow = Inlet **mass** flow – bypass **mass** flow
• Efficiencies:
  - Jet engine efficiency: Chemical power in the fuel transforms to propulsive power (T x V)
  - Thermal efficiency: Increases with decrease in ambient air temperature
  - Propulsive efficiency: Propelling nozzle thrust to energy supplied to the nozzle
• Divergent duct:
  - Speed & dynamic pressure decrease
  - Static pressure & static temperature increases
  - Total temperature & total pressure remains constant
• Convergent duct:
  - Speed & dynamic pressure increase
  - Static pressure & static temperature decreases
  - Total temperature & total pressure remains constant
• Bypass turbine engine:
  - Portion of air routed through engines & the rest goes through bypass duct
  - Lower specific fuel consumption due to **decrease in exhaust gas flow velocity & higher mass flow**
  - At high subsonic speeds they have better propulsive efficiency than prop or straight jet engines
  - Multi-spool turbofan engines:
    • Fan driven by rear most turbine, more flexible in operation, less prone to surge & with higher compression ratios & has better overall performance
    • Smaller air starter driving only a single spool can be used
  - Single spool axial turbine: Velocity greatest on exit from propelling nozzle, Compressor RPM = turbine RPM
  - Fan is driven by low pressure turbine, creates **most of the thrust**
  - When combustion gases pass through turbine, pressure drops
  - Maximum temperature limited by the temperature at the turbine
  - Starter & igniter: Ignites air-fuel mixture in the combustion system
• Constant speed propeller & free power turbine:
  - Free turbine = Turbine that does not drive compressor.
    No mechanical connection between compressor & power output shaft
    There is mechanical connection between free turbine & power output shaft
    Dependent on rotational speed of gas generator but **not** mechanically connected to it
  - Gas generator = Intake, compressor & combustion chamber
  - Energy delivered by free turbine stages is dependent on the rotational speed of the gas generator

Factors

- **RPM increase:**
  Gas generator speed constant & free power turbine increases
- **Power setting increase:**
  Gas generator speed increase & free power turbine constant,
  Blade angle/pitch increases, thrust & EGT increase, HP spool increase

- Turboprop: Specific fuel consumption expressed in **kg/hour/unit of shaft power**

<u>Main engine components:</u>

- Ram effect:
  - Ram air at intake compressed before entering the compressor, flow velocity decreases
- Intake:
  - Function: Reduce airflow velocity
  - Divergent to reduce airflow velocity & increase static pressure in front of the fan
  - Fan bypass engine spinner: Rain/hail can be deflected into the bypass duct
  - Unfavourable inlet airflow conditions: Max take-off thrust, zero forward speed & strong crosswind conditions
  - Blow-in-doors: Provides the engine with additional air at high power settings & low airspeeds
- Variable inlet guide vanes:
  - Reduce surge
  - Reduce stall at low RPM
  - VIGVs located in front of HP compressor & together with variable stator vanes (VSV) control compressor airflow
  - Fewer VIGVs & VSVs required when using 3 spool instead of 2
  - Imparts an angular change to the airflow
- Axial flow compressor:
  - Ratio typically 35:1, single axial stage 1.2:1
  - Pressure ratio depends on the number of stages
  - Tapered design to maintain constant axial speed in **cruising** flight
  - More expensive & greater vulnerability to foreign object damage
  - Low pressure ratio by stage, but possible to compress a large air mass flow
- Centrifugal compressor:
  - Ratio typically 12:1, single centrifugal stage 5:1
  - High pressure ratio by stage
  - Large diameter
  - Air enters eye of impeller axially & leaves the periphery tangentially
  - Robust & less complicated
- Compressors:
  - Compressor stall: Indicated by increase in TGT/EGT & vibration, it is likely to occur in high pressure ratio compressors operating at low RPMs. Also when the air flow stagnates in the rear stages of the compressor
  - Rotor – stator
  - LP spool runs at a lower RPM than HP spool, same speed as LP turbine & turbofan
  - As air leaves compressor, temperature will be higher than inlet temperature
  - Exit velocity higher than entry velocity of the rotor as: Part of the compressor work delivered to the air is converted to kinetic energy
  - More stages than the driving turbine because power output of turbine is higher than power consumption of a compressor stage
  - Multiple stages required because one stage does not generate sufficient shaft power
- Compressor/rotor blades:
  - Loose fit: To limit damage caused by vibration
  - Rigidly fixed when engine is running due to aerodynamic & centrifugal forces
  - Decrease in size from low to high pressure stages in an attempt to sustain axial velocity
  - Held in place by mountings & resultant aerodynamic & centrifugal forces
- Variable bypass valve/bleed valve:
  - Prevents stall in the LP compressor
  - Counters compressor surge
  - Increase airflow across the rear stages & decrease airflow at the early stages
- Compressor surge:
  - Compressor choke, usually at low powers & flow reversal and/or with unusual aircraft attitude
  - Reduced by controlling the fuel flow (By the FCU – Fuel control unit)
  - Occurs below design speed(**low RPM**) of an axial compressor, at the **front** stages
- Compressor stall:
  - An excessively high angle of attack of rotor blades
  - High compressor RPM & low inlet velocity
  - Caused by axial flow velocity that is low relative to rotor speed

- Occurs below design speed(**low RPM**) of an axial compressor, at the **front** stages
- Occurs at **high RPM** when airflow **stagnates at rear** stages
- Stall margin: Increases when **axial air velocity increases more than** rotor blade velocity

- Diffuser:
  - Decrease flow velocity before entering combustion chamber
  - Increase temperature of air before entering combustion chamber
  - Pressure rises & velocity falls
- Combustion chamber:
  - Primary air to the fuel nozzle area for combustion
  - Secondary air required for cooling of the inner casing
  - Secondary air holes built to increase cooling
  - Swirl vanes:
    - Reduce average axial flow speed in order to stabilize flame front
    - Generate swirl of incoming air to enhance mixing of the fuel with air
    - Does **not** increase air pressure at fuel nozzles
  - Drain valve: Remove unburned fuel from the combustion chamber
  - High temperature material required
  - Can type combustion chambers: Need only two igniters as chambers are interconnected
  - Annular type combustion chamber: Thermal load distribution on the HP turbine is more favourable. It has a **reduced thermal stress** on the turbine
- Turbine:
  - Drives the compressor by using energy from the exhaust gas
  - Stator – rotor
  - Temperature limitations imposed on **turbine blades/sections**
  - High temperature material required at front part of HP turbine
  - **Shaft power**: Generated by expansion of hot gas followed by conversion of kinetic energy (Velocity) into (Mechanical) work
- Turbine blade:
  - Most common: Impulse/reaction type
  - Tip **shrouds**: Increase turbine **efficiency**
  - Clearance control: Provides enhanced clearances between blade tip & the casing
  - Life of turbine blade reduced when increasing frequency of thrust variations during normal operation due to severe **low cycle fatigue**
  - Turbine rotors most affected by creep
- Creep:
  - High blade temperature whilst under centrifugal loading (**Turbine rotors**)
  - Permanent increase in length of metal parts due to a combination of tensile stress & high temperatures over a prolonged period
- Impulse turbine:
  - Nozzle: V increases P decreases T decreases (INVPT IDD)
  - Rotor: V decreases P constant T constant (IRVPT DCC)
- Reaction turbine:
  - Nozzle: V increases P decreases T decreases (RNVPT IDD)
  - Rotor: V increases P decreases T decreases (RRVPT IDD)
- Exhaust:
  - Main function: **NOT** acceleration of exhaust gas, but to extract energy from exhaust gas
  - Propelling nozzle: Designed to obtain correct balance of pressure & velocity to prevent flow separation
  - Exhaust nozzle convergent thus static gas temp decrease when flowing through
  - Cold flow exhausted separately
  - Noise reduced by reducing jet exhaust velocity
- Ice formation:
  - Prevented by using **compressor** bleed air

Parameter	**Inlet**	**Compressor**	**Combustion**	**Turbine**	**Exhaust**
Pressure	Increase	Increase	Constant	Decrease	Decrease
Speed	**Decrease**	**Decrease**	**Increase**	**Increase**	**Increase**
Temperature	Increase	Increase	Increase	Decrease	Decrease

	Velocity	**Pressure**	Temperature
Impulse nozzle	Increases	**Decreases**	Decreases
Impulse rotor	Decreases	**Constant**	Constant

Reaction nozzle	Increases	**Decreases**	Decreases
Reaction rotor	Increases	**Decreases**	Decreases

Additional components & systems:

- Engine pressure ratio = Exhaust pressure(pt8) ÷ inlet pressure(pt2)
  Engine pressure ratio = Jet pipe total pressure to compressor inlet pressure
- Self-sustaining speed: Min engine RPM engine will continue to run without further assistance
- Reverse thrust:
  - Fan flow is deflected
  - Clamshell doors change direction of exhaust stream
  - Reverser thrust door warning light: Reverser doors are unlocked (Not in stowed or locked position)
- Reverse thrust alert:
  - Reverse doors are unlocked with the reverse lever in the stowed position
  - Reverse doors remain stowed with the reverse lever in the deployed position
- Cold exhaust reverser/fan engine bypass reverser:
  - Achieved by reversing the direction of the fan airflow **only**
  - Saves cost/cheaper & less mass at the cost of reduction of available reverse thrust
- Ignition system:
  - Igniter activation should commence prior to fuel entering the combustion chamber
  - Used for ground start, in-flight relight, during turbulence & under heavy precipitation/icing conditions
  - Selected igniters are activated before fuel is delivered to the fuel nozzles
  - Precautionary use during continuous heavy rain & high ambient temperatures
  - Continuous ignition mode: Low power ignition for flameout risk situations
  - Vibrator: Provides AC voltage in order to facilitate transformation to a higher voltage
  - Redundancy: Two exciter units & two igniter plugs
  - After successful engine start, air starter disengaged by coupling between engine N_2 spool & starter by the use of centrifugal force
- Accessory gearbox accessory units:
  - Tacho-generator N_2
  - AC generator and its CSD
  - Oil pumps
  - Hydraulic pumps
  - High pressure fuel pumps
  - Auxiliary gearbox run by high pressure shaft
  - Lubricated by oil
  - Provides drive for variety of services & may even provide for the support of the engine in the airframe
  - Not pneumatic thrust reverser, it is operated electrically/hydraulically or by bleed air
- Full authority digital engine control (FADEC):
  - Basically all functions, checks all input & output data
  - DOES NOT: Modify aircraft speed, counter yaw movement during engine failure, automatically shut-off engine
  - Includes engine over-speed & EGT protection functions
  - Includes engine control unit & its peripherals (Fuel metering/actuators/electrical wiring/sensors etc.)
  - FADEC sensors power comes from power sources on the engine
  - Throttle lever angle (TLA): Provided to electronic engine unit
  - Single fault tolerant
  - Electronic engine control unit (ECU/EEC): Uses data from aircraft systems & its own engine sensors
- Hydromechanical system:
  - N_2,compressor discharge pressure, compressor inlet temperature, fuel shut off, thrust lever angle
- Engine oil system:
  - Magnetic plug collects ferrous particles
  - Chip detectors indicates metal particles in oil, warn of impending failure
  - Magnetic plugs & chip detectors warn of impending failure without having to remove the filters for inspection
  - Scavenge pump volume higher than pressure pump ensures the engine sump remains dry in dry sump system
  - Oil filter clogged: Differential pressure opens bypass valve of main oil filter
  - Oil reservoirs usually located at the front to heat air intake
- Oil to fuel heat exchangers:
  - Jet engine oil cooling through thermal exchange with fuel flowing from tanks, cools oil & heats fuel
  - Internal leakage: Fuel leaks into oil, causing oil level to rise
  - Uses engine oil(High pressure area) & is connected to low pressure area(Fuel)
  - Installed before fuel filter preventing water in fuel to freeze & block the filter
  - Venting: Prevent excessive pressure in the tank
  - High oil temperature indicates heat exchanger failure

- Engine fuel system:
  - Pressurising & dump valves: Admit fuel to the nozzle only if fuel pressure is high enough for atomisation
  - Fuel flow information: Measured in the line between the fuel control unit & engine burners
  - Fuel heated to prevent icing of the LP filter, using fuel heater (Ram air)
  - High pressure shut-off valves (HPSOV) opens to deliver fuel to fuel nozzles after ignition is activated
- Seals:
  - Labyrinth seals: Seals not completely tight, allowing some movement between rotating & static parts

Engine operation & monitoring:
- EGT:
  - Sensed between gas generator turbine & free power turbine
  - HP turbine outlet
- Turboprop:
  - Alpha & beta controls: Propeller & engine RPM
    Alpha: Fine to coarse pitch (Flight range) flight idle to maximum power
    Beta: Fine pitch (Taxi range) negative thrust
    Negative/reverse/braking: Propeller supplies negative thrust & absorbs engine power
  - Output indication: Torque, measured at the reduction gearbox
  - Torque meter situated between engine & propeller
  - Control:
    PROPELLER control lever: Propeller RPM
    FUEL control lever: Torque & turbine temperature
- Abortive/hung start:
  - Too low pneumatic starter pressure
  - Engine lights up but fails to accelerate sufficiently
  - An attempt to ignite fuel before the starter has sufficiently accelerated the engine
  - If it occurs, engine should be shut down
  - N_2 speed stabilizes lower than normal RPM & increased EGT
  - No N_1 rotation although N_2 may accelerate normally
- Starting sequence:
  - Ground: Starter – rotation – ignition – fuel
  - Air (When wind milling): Rotation – ignition – fuel
  - Most important indication during engine start: Oil pressure
- Rupture of LP shaft: Causes turbine over-speed, as turbine feeds LP compressor an there will be excess power
- Pressure relief valve not seating correctly: Results in low oil pressure
- Gas turbine engine trending: Enhance maintenance planning & detect anomalies
- Vibration indicates spool imbalance
- Prior to shutdown:
  - Ground idle allows core temperature to stabilize
  - Prevent seizure of the rotor blades in their seals
- Engine ratings:
  - Max take-off thrust (TOGA)
  - Max continuous thrust
  - Max climb thrust

Other stuff:
- Pressure altitude:
  - Increase: Max thrust & specific fuel consumption decrease
- EPR:
  - EPR constant: Thrust decreases when altitude increases
  - At same environmental conditions, a given EPR setting maintains the thrust irrespective of engine wear due to ageing
- Air is bled
  - Turbine temperature increase
  - Turboprop pneumatic anti icing activated: Propeller RPM remains unchanged, turbine temperature rises & torque reduces
  - EPR reduces, EGT rises
  - Decreases aircraft performance & power
  - Fuel flow increases
- Reduced thrust take-off:
  - Reduces low cycle fatigue damage
  - Reduce maintenance cost
  - Reduced when there is low take off mass, low OAT & high pressure (By selecting higher temp on FMS, less thrust generated, reduced power setting)

- Flat rated engines:
  - Provides constant max take-off thrust up to a certain level of ambient temperature/OAT
  - OAT cannot be higher than flat rated temperature
  - Using max take-off thrust at an OAT below flat rated temperature: Thrust lever is not positioned at the maximum stop

APU:

- Generator
  - Can only be used when no other source is feeding the bus bar
  - Supplies aircraft with 3 phase 115V 400Hz AC
- Automatic protection: High TGT/EGT, overspeed, loss of oil pressure, high oil temperature, low oil pressure & APU fire
- On the ground provides: Electricity, air for main engine starting & air for conditioning (No hydraulics)
- Only monitoring indication system: Fault status
- Can be substituted on the ground with: GPU, starting system & air conditioning cart

Smoke & fire detection:

- Smoke detectors:
  - Installed in upper cargo compartments
  - Optical type: Light attenuation optical detector, light refracts towards photoelectric cell. Detects diffusion of light beam when beam is interrupted by smoke, scattering increases conductance of the cell & output amplified to warning circuit
  - Ionization type
- Fire extinguishers:
  - Power plant/turbine engine: Operated by electrically fired cartridge (squib) rupturing a seal in the bottle head
  - Extinguishant directed to the low pressure end of the outside of the engine compressor
  - 2 required per engine
  - Halon extinguishers (Most common): Interrupts combustion(Not a cooling agent), is not corrosive, supresses chemical reaction of fire & is most effective **flame inhibitor** compared to other extinguishers
  - Extinguisher discharge indicated by light **only**
- Fire detection systems:
  - Installed in high risk compartments: Landing gear wheel wells, APU, & around the engines
- Engine fire detection systems:
  - Incorporates a visual warning light for each engine & a common aural alarm for all engines
  - Includes a test circuit for continuity checks
- Fire detection types:
  1. Continuous loop firewire(resistance & capacitance type):
  - Overheat detection system: Detects heat caused by fire
  - Testing: Wiring & warning tested
  - Low resistance & low capacity = Loop is faulty
  - Fault protection circuit: Inhibits detector when detection line is connected to ground
  - Resistance decrease, capacitance increase, current increase
  - Initiates alarm when temperature increase detected at any isolated point or generally all the loops
  - If inner core contacts outer casing (short circuit) an alarm is triggered
  2. Bimetal strip detectors:
  - Arranged in parallel & are closed during a fire
  - Includes delay in the event of false alarm due to vibrations closing the contacts
  3. Gaseous fire detection system
  - A closed tube, when heated causes the gas inside to expand and trigger an alarm via a pressure switch
  - Decrease in loop pressure can cause a fault
  - Tested by: Heating up sensor (Discrepancy) OR Test circuit carrying out a continuity check (More correct)
- Toilet fire extinguishers
  - **Automatically** activated by heat detection
- Fire handle:
  - Arms extinguishing system
  - Deactivates electrical generators
  - Closes LP valve of fuel system, fuel supple isolated via **pilot action**
  - Closing of isolation & de-icing valves

Rain protection:

- Rain repellent:
  - Shouldn't be sprayed unless rainfall is really heavy
  - Uses hydrophobic chemicals preventing droplets from adhering to window surface
- Bleed air is not used here

Oxygen:

- Supplementary oxygen:
  - Used to protect passengers & crew against the effect of accidental depressurization
  - Automatically presented to cabin crew & passenger following rapid decompression or before cabin altitude exceeds **15000ft**
  - Max operating pressure exceeds: Oxygen is discharged overboard via a safety plug
  - Automatic passenger mask fails, obtain individual mask by opening mask storage compartment with a sharp pointed object
  - Grease should never be in the vicinity as it catches fire easily/spontaneously
  - Smoking ban is imperative & no trace of grease should be found in assembly
  - Possible to indicate oxygen flow with an indicator of pressure
- Chemical oxygen generators for cabin:
  - Pneumatic door opening, continuous flow type
  - Used for cabin, toilets & smoke hood
  - Incorporates a heat shield
  - For 15 minutes
  - Flow cannot be modulated
  - Less capacity
  - Less risk of fire/explosion
  - Easier maintenance
  - Poor autonomy
  - Once activated cannot be switched off
  - Use in severe cabin smoke is useless as toxic smoke is mixed with breathing oxygen
  - To enable oxygen flow, mask must be firmly pulled downwards to the face
  - Installed in toilets
- Gaseous oxygen source for cabin:
  - Electrical door opening
  - Flow can be modulated
  - More capacity
  - More risk of fire/explosion
  - Greater autonomy
  - Reversible functioning
- Cockpit/flight deck oxygen system = diluter demand type oxygen regulator:
  - Is gaseous
  - Regulator in normal/dilute: Oxygen/air mixture ratio increases when the altitude increase
  - Regulator in normal/dilute: Mixture of cabin air & oxygen. Shouldn't be used when there is smoke in cockpit
  - Operates when user breathes in, delivers oxygen when inhaling
  - In case of smoke oxygen should be set to 100%
  - Emergency selector: Continuous flow 100% oxygen supply under positive pressure
- Portable bottle:
  - Amount of oxygen determined by pressure
- Protective breathing equipment:
  - Protects members of the crew against fumes & noxious gases
  - 100% oxygen supplied above 32000ft or manually
- Smoke mask: Mask with flow on request & covers the whole face
  Smoke hood: Covers whole head with continuous flow
- First aid oxygen
  - Gives medical assistance to passengers with pathological respiratory disorders