Airframe, Systems, Electrics, Powerplant

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01 System Design, Loads, Stresses, Maintenance 2 - 2.5%

System design

- **Damage/fault tolerant design:**
  - Capability to withstand a certain amount of weakening of a structure without a 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
  - No catastrophic damage will occur

No most favorable design, as each component varies

- **Redundancy**
  - ↳ duplication, triplication of critical components

CS-23: normal, utility, aerobatic and commuter aeroplane

CS-25: large aeroplane

Maintenance:

- hard time: Component overhaul/removed after a set number of hours/cycles regardless of condition
- On condition: Monitoring of critical parameters & replacement of parts if a limit value is exceeded

Stress: Force/Area
- Tension: Force resisting from being pulled apart
- Torsion: Caused by twisting
- Compression: Push force
- Torque: Axial rotation force
- Shear: Force parallel to cross section
- Buckling: Effect of more to 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 and reverses when load is removed

Corrosion Incorrect metal bonding → for example Potassium hydroxide or hydraulic fluid
- Stress: continuous tensile load + corrosion
- Intergranular: Grain boundaries inside metal

Fatigue: Material is continually loaded and unloaded and will eventually break even tough load is the same

Aircraft flies beyond certified load factor: Subject to permanent deformation

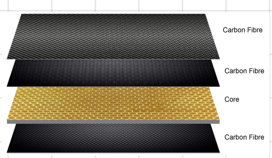
	No effect	Minor	Major	Hazardous	Catastrophic
Qualitative	/	Probable	Remote	Extremely remote	Extremely improbable
Quantitave	/	10^{-3}	10^{-5}	10^{-7}	10^{-9}
Flight crew	/	Slight workload	Physical discomfort	physical distress	Fatality / Incapacitation
Airplane margin	/	slight reduction	Significant reduction	large reduction	Hull loss
PAX	Inconvenience	Physical discomfort	Physica distress	Serious/fatal injury	Multiple fatalities

Load:
- Static loads
- Dynamic loads
- Cyclic loads: dynamic irreversible loads

02 Airframe 2 - 2.5%

Engine compartment decking and firewall: Stainless steel/titanium sheet

Sandwich structure:
- Two thin sheets separated with light core material
- Low mass, high stiffness
- Stabilizes covering sheets
- Unsuitable for absorbing concentrated loads
- Does not use resin



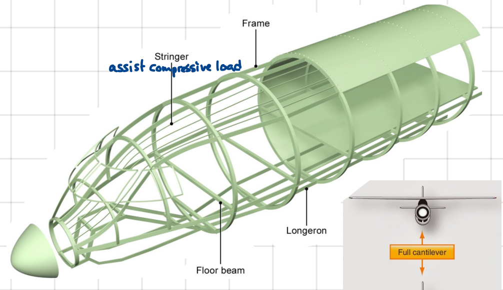
Composite structure:
- Consists of matrix and fibers
- Components strength can be tailored to the direction of load, not the same in all directions
- Higher strength to weight ratio compared to other metal

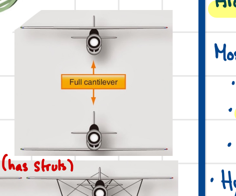
Truss type: Small light aircraft/training plane

Monocoque:
- Takes all the load on a stressed skin

Semi-monocoque:
- Fuselage of transport airplanes
- Consists of skin, frames and stringers

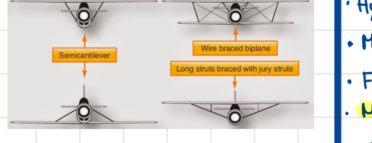
Normally uses aluminium/magnesium alloy



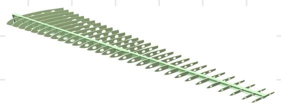


Cantilever:
- Attached to the aircraft at the wing root only (no struts/braces/wires)
- Vertical loads/bending moments highest at wing root

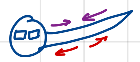
Non - cantilever (has struts)



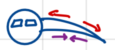
Wings:
- Torsion box: Consists of spars, ribs, wing skin reinforced by stringers
- Ribs
  - Maintain aerodynamic shape
- Stringers:
  - Assists skin to absorb longitudinal compressive loads
- Wing skin:
  - When unable to bear load, it transfers them to the spar via ribs and stringers
  - Bear cylindrical load during pressurization (Tension)
- Spar:
  - Bear most of the load
  - Consists of web and girders (I-beam)
  - Take up the vertical bending moment



In the air:
- Lift loads carried upper/lower skin surfaces and spars
- Tension in lower surface and compression on upper surface

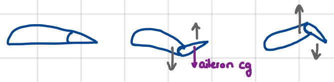


On the ground:
- Tension in upper surface and compression on lower surface



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 surface 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 and bending, COP ahead of CG
- Avoided by ensuring correct mass distribution within the control surface during design
- Wing bends downwards: Flutter may occur if the aileron is deflected upwards as aileron CG is behind hinge line
- Wing bends upwards: Flutter may occur if the aileron is deflected downwards as aileron CG is behind hinge line



T-tail aircraft:
- Vertical stabilizer is not affected by influence of wing turbulence

Fuselage
- Consists of skin, frames and stringer (No spar, girder)
- Pressurization load = tension
- Shell structures transmit: Normal bending, tangent bending, tension and 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 not provided with de-icing, only defoggers
- Made of: glass and 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 as lifetime of fatigue sensitive parts have been determined on a load spectrum
- MZFM: Maximum zero fuel mass – Total maximum permissible mass of aircraft without usable fuel

03 Hydraulics 5 - 6.25%

Yellow oil and black leak hydraulic

Pascal's law:
- incompressible fluid
- Pressure on fluid in enclosed space ⇒ pressure equal everywhere
- Act at right angle to wall Force/area

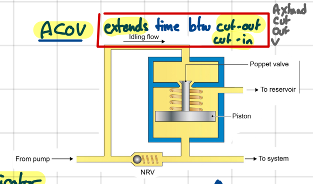
$\text{Area}_A \cdot \text{distance}_A = \text{Area}_B \cdot \text{distance}_B$

Most common:
- Phosphate ether based (Skydrol) is purple
- Synthetic oil (Maybe mineral). Synthetic = Highest resistance against cavitation
- Operated at 3000 psi

Hydraulic fluid properties:
- Thermal stability
- Low emulsifying characteristics
- Corrosive
- High flash point
- Irritating to eyes and skin
- Incompressible
- Ideally low viscosity to minimize power consumption and resistance to flow

ACOV extends time btw cut-out cut-in

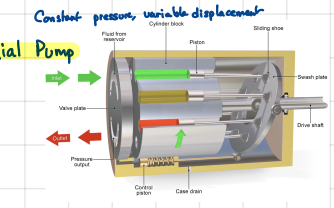
Axload Cut out



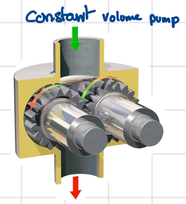
- Hydraulic power is a function of system pressure and volume flow
- Monitoring parameters: Pressure, fluid temperature and quantity
- Flight deck indicator for hydraulic pressure: Transducer connected to an indirect indicator
- Max power output and low mass: achieved by having high pressure system and low volume flow
- Hydraulic circuits
  - Open center: has capability for idle flow
    - Constant low pressure
  - Closed system: pressure maintained ⇒ selector valve
- Hydraulic braking system:
  - uses nitrogen

Constant pressure, variable displacement

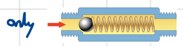
Axial Pump



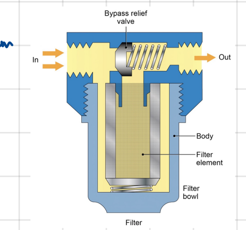
Constant volume pump

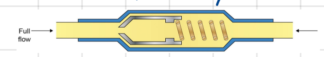


- **Valves:**
  - Shuttle valve: (Switches between 2 sources of pressure)
    - Switch hydraulically operated to the most appropriate pressure supply
    - Enables an alternate supply to an actuator
  - Selector valve: Direct system pressure to either side of the piston of an actuator
  - Check/non-return valve: Works the same as electronic diode allowing fluid in one-direction only



  - Pressure relieve valves: protect against excessive system pressure
  - High pressure relief valve: Failure of normal method of pressure limiting control system
  - Relief valve: Make sure the pressure does not exceed permitted pressure in the system
  - Cut-out valve: Used in a fixed volume pressure control hydraulic system





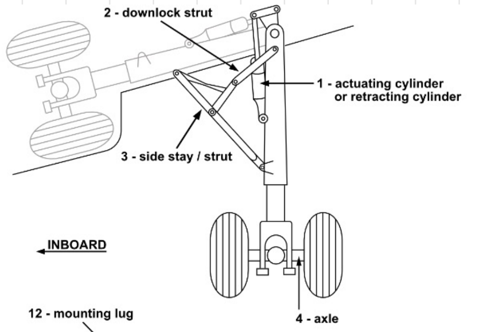
- **Actuator/jack:**
  - Converts hydraulic pressure into linear motion
  - hydraulic lock is when no movement of piston take place
  - Single actuator: is powered in one direction only by hydraulic power, the return movement is another force (Spring)
  - Internal leaks will cause fluid temperature increase (As piston/accomulator have to work more ⇒ become hotter)
    - ↳ Risk of fire
- **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 detector: installed at the pumps
  - Low pressure alert: located at pump outlet, indicates insufficient pump output
  - pump failure: Quill drive will shear to offload and protect gearbox
- **Filters**
  - In both pressure and 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 and accumolator pressure
  - Pressurized to prevent cavitation in the pump inlet to EDP, using bleed air
  - Pressurized to ensure inlet is provided with continuous supply of fluid free from foaming
  - Hydraulic fluid temperature 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

Diffuser is divergent <
↳ V↓ P↑

Scavenge pump → engine sump

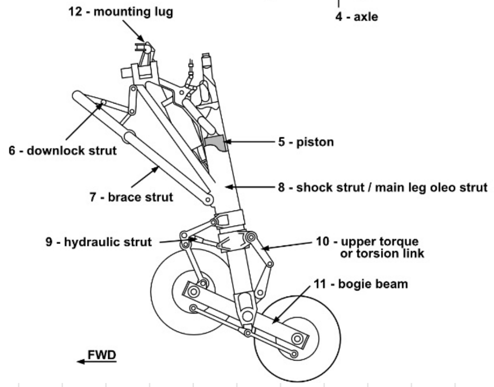
Security of hydraulic system:
- Filters
- Pressure relief valve
- By-pass valve
- Fire shut-off valves
- Hydraulic fuses prevent total system loss in the event of hydraulic leak
- Quill drive
- RAT → for flight controls
- Stack (stand) pipe: in hydraulic reservoir provides emergency supply, supplies main line

04 Landing Gear, Wheels, Tyres, Brakes 5 - 6.25%

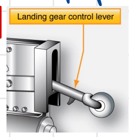


Landing gear

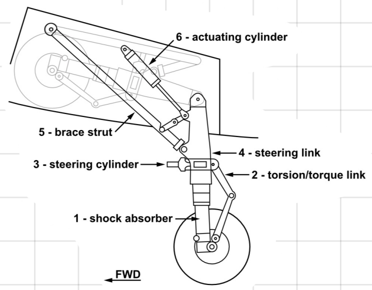
- Emergency extension methods:
  - Compressed nitrogen bottle: used in emergency to lower landing gear and keep door opened
  - Auxiliary hydraulics
  - Gravity extension



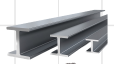
- Damping element: Hydraulic fluid/oil
- Spring element: Nitrogen
- V_{LO}: Speed at which landing gear can be operated
- V_{LE}: Speed with landing gear extended
- Amber light: at least one wheel is in the travelling/unlocked condition
- Green light: landing gear is locked
- Over-center mechanism principle: locks landing gear in the up/down position
- Torsion links/scissor: Avoids rotation of the piston rod relative to the gear oleo strut
- Retraction on the ground prevented by:
  - Electrical control system being routed through weight on wheels switch
  - Anti-retract latch: can be overriden under specific condition
  - Latch located in landing gear lever



  - Locking pins with flags



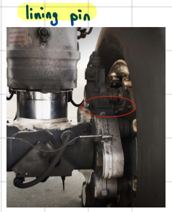
- Shimmy
  - Damaging vibration of nose wheel while on the ground
  - Tendency of sinusoidal motion on the ground
  - Overcome by using accumulator associated with the steering cylinder
- Steering is achieved by mechanical rods connected to rudder pedal (for light aircraft)
- Anti-skid
  - Speed sensor
  - Control unit/computer: Inputs – Idle (1) and braked (2) wheel speed
    – desired idle (3) wheel train slipping rate
  - Control valve
  - Is available when using autobrake
  - 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 and system component
- Autobrake system:
  - Disconnects by pressing pedals / pilot action after landing
  - Low level: Auto-brakes works with delay
  - Works during thrust reversal
  - Works above pre-set minimum speed
  - Can not be used if antiskid is inoperative
  - RTO is not constant deceleration
- Accumulator: supplies a limited amount of brake energy in case of hydraulic loss
- Brake units for transport category aircraft: multiple disks
- Brake life:
  - Steel breaks = many small application



  - Carbon breaks = few long application

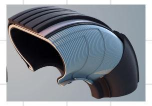
multiple disk brake

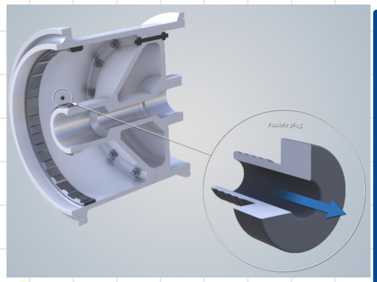
lining pin



- Hydro planing when friction coefficient = 0
- RTO (Rejected Take-Off mode)
  - Actuates maximum braking with anti-skid above a certain speed, as soon as take-off rejected and throttles moved to idle position
  - Armed at low speeds / taxi
  - Maximum CONTINUOUS deceleration

- Under-inflated tires: more wear at the shoulder
  - prone to creep
- Tubeless tire:
  - Lower risk of bursting
  - Better adjustment to wheels
  - Requires solid/branched wheels
  - Eliminates internal friction between tube and tire
  - No built-in air tube
  - A radial side casing



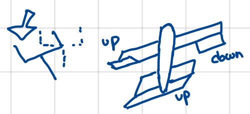


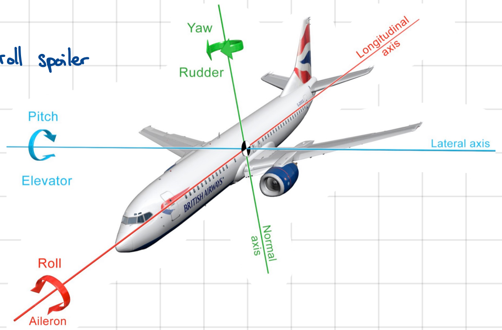
Thermal plugs in wheel rim

- Tire-creep:
  - Circumferential movement of tire in relation to wheel flange
  - Tire marks align with rim marks
  - A normal problem
- Type of breaks:
  - Carbon breaks: fewer long application
  - Steel breaks: many small application
- 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) and deflates the tire to prevent explosion/bursting
- Worn tires can be repaired several time
- Back-up system of extending the landing gear via free-fall
  - Up-lock mechanisms has to be unlocked by opening a cut-out valve to depressurize system (wheels locked by hydraulic pressure)

05 Flight controls 8 - 10%

- Primary flight controls: Ailerons, elevators, rudder and roll spoiler





- Manual flight control (cable-reversible) – Cesna 172
  - Require gust lock
  - There is feedback to the pilot's controls of the aerodynamic forces acting on the control surfaces
  - Are less complex
  - Does not require artificial feel
- Powered assisted control (hydraulic reversible)
  → doesn't require Q-feel
- Powered control (irreversible)
  → uses hydraulic pressure and servo-motors
  → require Q-feel (artificial feel)
  - Does not require gust lock
  - If one hydraulic system is lost → remaining will take over
  - No feedback to the pilot's control of the aerodynamic forces
  - Trimming achieved by adjusting the "zero point force"
  - Aircraft powered down: rudder deflected but pedals centered
- Pitch trim = moving the tab
- Roll trim and yaw trim = moving the controls (yoke or pedals)
  = moving the neutral point/zero force point of the Q-feel
- External gust lock
  - Prevent movement of the control column if controls not fitted with servo tab
  - When ON, provisions to prevent take-off
- Rudder limiters:
  - Restricts rudder deflection during high IAS
  - Rudder Ratio changer: Reduces rudder deflection for a given rudder pedal deflection as IAS increases
  - Variable Stop system: Limits both rudder and rudder pedal deflection as IAS increases
- Rudder trim
  - Actuation on the ground with engine running → Rudder move
    → Rudder pedal move in corresponding direction
  - An adjustement of the zero force rudder position
  - In fully powered (irreversible) systems by altering the neutral position / zero force point of the artificial feel unit

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- 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 and 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 become blocked
- Control column/wheel: (irreversible)
  - Zero force position does not change when using pitch
  - Zero force position changes when using aileron trim
- Over tensioned cables: Excessive friction in cables
- Hydraulic valves: Acts on the actuator of the control surface
- V-tail aircraft controls that act together: Stick in one-axis and rudder pedals
- Large aircraft without trim tabs: Trimming is possible by adjusting the neutral point of the artificial feel mechanism with trim switch

Secondary flight controls

- Speed-brakes, flaps, slats, trimmable stabilizer (Moved by hydraulically actuated jacks)
- Trim tabs: reduces hinge moments but reduce control surface efficiency
- Auto slat system extends the slats automatically when AoA value reached (signal from stall warning system)
- Flap load relief system, protect flaps at various positions from excessive loads
- Elevator trim: double switch used to reduce possibility of trim runaway
- Spoilers
  - Located symmetrically on the wing surface
  - Ground spoiler extension activated when main wheel spin up
- Trailing edge
  - Fowler: Moves aft then turns down
  - hydraulic with electric back up
- Leading edge:
  - Krueger: close to the root

- Fly-by wire FBW
  - Most basic mode: Direct
  - System based on electrical (analogue) signals to control valves from a computer sent to hydraulic actuators for the flight control surfaces
  - Modes
    - Normal
    - Alternate: Looses Automatic pitch protection
    - Direct and mechanical
  - Advantages
    - Direct and indirect weight saving through simplification of systems
    - Improvement of piloting quality throughout flight envelope
- Pitch trim move all horizontal tail without trim control input but computer calculation to relief continuous pilot pitch

06 Pneumatics 5 - 6.25%

Pneumatics / bleed-air supply

- Differential pressure = 7-9 PSI
- Bleed air
  - Used for cabin pressure
  - Usually taken from the HP compressor only
  - Usually taken from low pressure stage / bleed air valve of the high stage compressor
  - Low pressure stage from high pressure compressor if necessary
  - Engine bleed air is not considered to be high pressure, it only takes air from high pressure compressor
  - bleed air gauge measure air pressure relative to atmospheric pressure
- Piston engine aircraft
  - Air source = Ram air
  - Pneumatic source = supercharger

Aeroplane: pressurisation and air-conditioning system

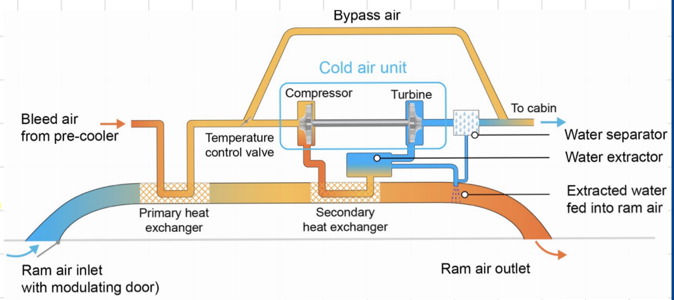
Pressurization

- Required > 10'000 ft
- 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 max positive cabin pressure at max cabin altitude
- manual mode: uses separate circuit to open outflow valve

Cabin pressure controller

Inlet: constant flow
Outlet: variable flow

- Control cabin altitude, rate of change and limit differential pressure
- Control by delivering a substantially constant flow of air into the cabin and controlling the outflow
- Maintain cabin altitude via position of outflow valve (Cabin pressure is regulated by airflow leaving the cabin)
- Outflow valves remain partially open in level flight
- Ditching controls: Close outflow valves when landing in water
- Flight altitude and differential pressure remains constant = mass air flow through cabin is constant
- Cabin pressure decreases more slowly than atmospheric pressure
- 2 modes:
  1) Constant differential pressure: Changing differential pressure slowly during climb/descent
  2) Isobaric: Maintain same cabin pressure during climb/descents
- Excessive cabin altitude warning: Activates at 10'000 ft
- Cabin pressure altitude not allowed to exceed 8'000 ft
- Cabin altitude rate of change selector: Controls cabin altitude rate of change
- Depressurization in case of emergency:
  - Cabin altitude and cabin vertical speed increase until differential is zero, then cabin VSI shows descent equal to aircraft VSI
  - Differential pressure will rise to its maximum value, thus causing 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 and pressure
- Air conditioning automatic control failure: Pilot can revert to manual control and set the value to the required setting
- Pack cooling fans: Supplies heat exchanger with cooling air during slow flight and ground operations
- Pack inlet inflow valves: Used to maintain a constant and sufficient air mass flow to ventilate the cabin
- Bootstrap / turbo compressor:
  1) Air supply / first heat exchanger — A
  2) Compressor — C
  3) Heat exchanger (secondary) — H
  4) Expansion turbine - Cooling (water separation after this stage) — E
- Refers to cold air unit / air cycle machine arrangement for mainly turboprop, primary function is to cool bleed air
- Air machine / air conditioning pack: Causes a pressure and temperature drop in bleed air



- Turbine drives the compressor (and 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 and pressure
- Heat exchangers cools bleed air in front and behind the compressor of the air cycle machine
- Primary heat exchanger: pre-cools 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 MEP)
  - Powered by fuel from aircraft fuel system
- Short-haul turbojet aircraft cabin air humidity not controlled
- Electrically driven air-conditioning system is better than bleed-air system because it reduces take-off distance and increases climb performance due to more thrust available
- Source of air to pressurize the hydraulic reservoir is pneumatic system (bleed air)

07 Anti-icing and De-icing Systems   2 - 2.5%

Types, operation, indications

- Components to be protected:
  - Engine air intake and pod
  - Front glass shield
  - Pitot tube always heated, Static may be
  - Waste water mast
  - Leading edge of the wings: Leading edges of slats partially / completely
  - A part of the whole leading edge
- Bleed air / thermal / hot air-icing:
  - Most commonly used by large jet
  - Bleed air from HP compressor
  - An over temperature indicated by warning lights
  - Reduces max thrust but does not affect aerodynamic performance
- Turbo-props
  - Anti-icing: at engine inlets, pitot and static ports
  - De-icing: wings
  - Propeller: electrically

- Pneumatic inflatable boots:
  - for wings
  - for large turboprops
  - only for de-icing
  - Operated when 1.5cm of visible ice on leading edges
  - Inflates each pneumatic boots for a few seconds
- Prop de-icing with slinger rings
- Electrical ice protection:
  - pitots, static ports, windshield } Small surfaces
- Flight deck window:
  - Electrical heating
  - uses continual bias that reduces thermal gradients
  - Supplied by 3 phases AC
  - Heating cycles ON/OFF to maintain 18-35 °C

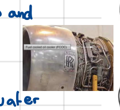
Ice detectors

- Hot rod ice detector:
  - Accumulates ice and is visible from cockpit
  - A heated probe and built-in floodlight
- Rotor ice detector:
  - Measures torque
- Pressure differential / Smith's ice accretion detector
  - Small holes freeze first, they are heated first
  - Activates by a decrease in dynamic pressure
- Rosemount vibrating ice detector
  - Light in cockpit alerts crew of aircraft icing
  - Principle of vibration
  - Can be heated
- Advisory ice protection system: Flight crew activates (manually) ice protection systems based on AFM criteria of total temperature and sighting of moisture. Ice signal detectors are back-up
- Automatic ice protection
- Primary manual ice detection system: Crew activates ice protections based on ice detector signals
- Thin wing freeze more easily than thick wing

08 Fuel System   5 - 6.25%

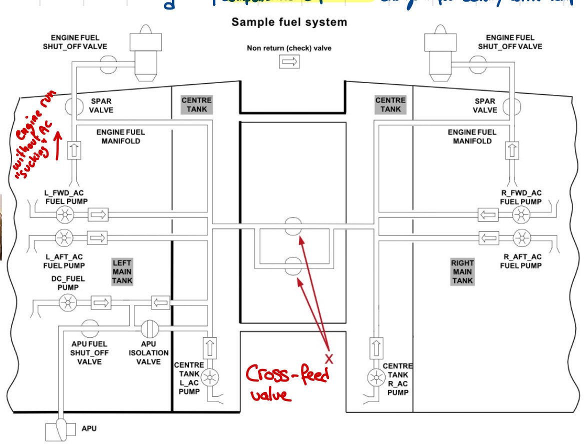
Piston engine

- Flash point:
  - Lowest temperature of vapor at which ignition occurs at flame contact
  - Vapor ignites in contact with flame and extinguishes immediately
- AVGAS usually used for reciprocating piston engines
  - AVGAS 100 Green
  - AVGAS 100LL Blue
  - AVGAS 80 Red
- MOGAS: increased risk of carburetor icing
- Transport aircraft wing tanks:
  - Integral, built internally into the aircraft structure, saves weight and space
- Small aircraft:
  - Fuel stored in wing
  - 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 minimized 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 and 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 and the engine or at the outlet of the high pressure filter
  - Fuel quantity measured with dielectric change between fuel and air $C = \frac{\varepsilon \cdot A}{d}$ | Compensated capacitance change in fuel density with temp
- Solenoid valve: Electrically operated/activated
- Cross-feed valve
  - Ensures all fuel on board is available to any engine
  - Adjusts fuel distribution
- Fuel control unit FCU
  - Protected from debris by the fine filter located between the high pressure fuel pump and governor unit
- Fuel heater



  - Located at the engine
  - Prevent risk of ice formation from water contained in the fuel at low temperatures
- LP booster pump:
  - Avoid vapor locking and prevent cavitation/bubble accumulation of the HP fuel pump
  - Electrically driven centrifugal pumps → 20-100 PSI
  - Direct feed lines to engine at positive pressure 115V AC
- HP booster pump
  - Driven by engine
- DC fuel pump: can only feed the APU
- Fuel tanks
  - Ventilation: Prevent low pressure or excessive overpressure in the tank
    - vented through air intake on underside of the wing

  - Pressure kept ambient
  - 2% of total tank space in each individual tank vent space
- Baffles
  - damp out movement of the fuel in the tank
- baffle check valve prevent movement to wing tip

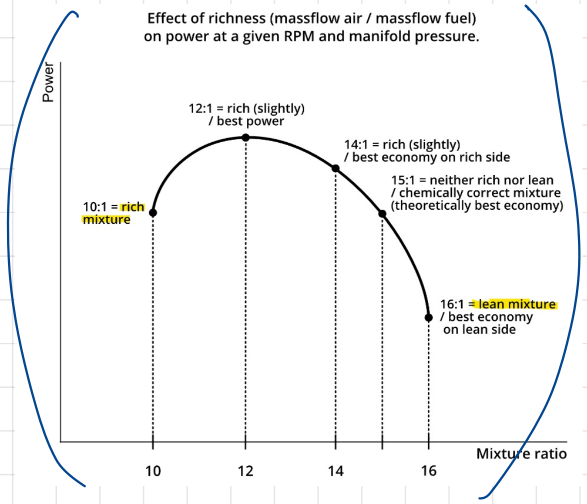


- Feed box → increase fuel level at boost pump and prevents cavitation

- Refuelling
  - Pressure refuelling
  - Automatic fueling 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 and using documentation
  - Automatic fueling shut off valve stops fueling as soon as a certain fuel level is reached
  - Bonding to earth should be made before filler cap removed
  - Via unique point, underwing refuelling center
- Fuel dumping
  - Required on aircraft where MTOW > MLW
  - Fuel dumping to a predetermined safe value
- Special fuel consumption schedules: Minimize wing G-load and preserve main tanks for landing
- Jet fuel
  - Transparent
  - Density ~ 0.8 kg/L
  - Freezing and flash point JET B < JET A1 < JET A

	JET B [°C]	JET A1 [°C]	JET A [°C]
Freezing point	-60	-47	-40
Flash point	-20	38	38
Density (kg/l) at 15°C	0.75 - 0.8	0.78 - 0.83	0.78 - 0.83

- Total centre tank fuel pump failure might lead to all or part of centre tanks to be unusable
- Drum
  - Heavy container
- Bladder
  - Flexible reservoir
- Integral
  - Inside of the wing (wet wing)



09 Electrics   15 - 18.75%

General, definitions, basic application: circuit breakers, logic circuit

Power: $P = V \cdot I$ [W] rate of doing work   115 V 400 Hz

$P = \frac{E}{t}$

$U = R \cdot I$

- Relay: Electromagnetically operated switch
- Circuit breakers (resetable):
  - Are used in both AC and DC
  - Trip free: Doesn't allow contacts to be held until fault is rectified
  - Magnetic: Fast, Quick tripping response
  - Thermal: Slow, Protects the system in the event of overload/overheating or prolonged (transient) overcurrent
- Fuses (not resetable):
  - Current limiter: Allow a short term overload before rupturing
  - Rating in amperes
  - Higher rating = in a healthy system OK
- Logic gates:
  - OR gate: any or all
  - AND gate: all or nothing
- Separate shielding of electrical wire within a cable bundle (wire harness) → eliminates electromagnetic induction from other wires in the bundle

- Electrical bonding:
  - Safe distribution of current
  - Protect against lighting
  - Reduce radio interference
  - Provide a single earth for electrical devices
  - Set aircraft to a single potential
  - No such thing as electrostatic potential
- Static discharger
  - Wicks safely dissipate static charge
  - On wing and tail tips
  - Reduce radio interference
  - Limits risk of transfer of electrical charges between aircraft and electrified clouds

Batteries

+ 24A means being charged

⚠ Thermal runaway ↳ withholded by metal box

- Capacity = Ampere hour (5 Ah = 5 amps during 1 hour) ↳ not dependent on voltage

NiCad
- Weighs less than lead-acid batteries
- Higher risk of thermal runaway
- Electrolyte = Potassium hydroxide
- Monitored for excessive temperature caused by decreasing voltage
- Reduced charging time ⊕
- Constant output voltage ⊕
- Good storage capability ⊕

Lithium ion
- Laptop fire → use appropriate hand extinguisher
- Considered unsafe when internal short circuit
- ⚠ Overheating during charging → self ignition
- Dangerous when extreme internal pressure

Lead acid battery
- 1 cell output: 2-2.2V
- Any cell breaks → whole battery unserviceable

- When battery discharged, voltage decreases under load

Generation
- AC → DC : TRU / Rectifier   Memo: AC→DC R(ock)-ectifier
- DC → AC : Inverter

$$RPM = \frac{Frequency \cdot 2 \cdot 60}{\text{no poles}}$$

- Frequency of alternator current depends on its rotation speed
- AC alternators have fixed induced windings (stator), dynamos have fixed inductor (field) coil and moving rotor
- Frequency "wild": Output frequency varies with engine speed
- Starter warning light: doesn't mean it's turning (only energized)

Star-connected
- Line voltage = $\sqrt{3}$ phase voltage
- Line current = Phase current

Generator Control Unit (GCU)
- permanent indication to record failure
- all commands from control panel applied via GCU except dog clutch release

Constant speed drive (CSD):
- Drives generator at a constant speed
- Ensures electric generator maintains a constant frequency
- Can be disconnected from drive shaft ↳ in case of overheat / low oil pressure
- Requires voltage controller / regulator to maintain constant voltage under variable load
- Can only be reset on the ground
- CSD only needs to be disconnected if engine running

Voltage regulator
- Controls current
- Controls output voltage at varying loads and speed
- Controls power required for field excitation of main rotor
- Increase excitation current when load increases

Distribution

Loads sharing on aircraft busbar connected in parallel
- Both real and reactive loads must be matched
- Voltage almost equal
- Aircraft structure as return path to earth
  - Single pole circuit
  - Weight saving
  - Easy fault detection
  - Reduction of short-circuit risk

AC
- Advantages:
  - Flexibility in use
  - Lighter weight of equipment
  - Easy to convert to DC
  - Easy maintenance of machines

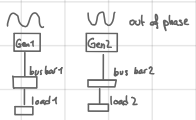
DC
- DC generators connected in parallel to provide maximum power

- HOT BUSSES and DIRECT BUSSES: Directly connected to battery
- Measured power: KVA and KVAR

Gen Control Breaker GCB and Generator Control Relay GCR
- Over excitation / over voltage / under excitation / Gen fault / Fire shut-off → Exciter breaker and generator breaker open
- Underspeed: Only generator breaker open

Paralleled generators
- (generators connected on same bus bar)
- Equal voltage
- Equal frequency
- Same phase rotation
- Voltage of same phase
- One generator at a time supplying individual parts of the split bus bar

Unparalleled generators:
- phase unimportant
- bus tie breaker allows power to be supplied to failed AC gen busbar



Electrical motors
- DC starter motor: Series wound
- Reverse direction of rotation by reversing polarity of stator or rotor
- DC generator armature runaway → current ↘ torque ↘ (motor spins very fast)
- If rotor of motor seize → current stator ↗ current rotor ↗ torque ↗ (i.e. more load tries to compensate with more current)

$$torque = \frac{Voltage \cdot current}{RPM} = \frac{Power}{RPM}$$

$$T = \frac{U \cdot I}{H}$$

- Alternator rotor coil: DC
- Alternator stator coil: AC

"Disconnect" generator from busbar

10 Piston engines

6 - 7.5%

General

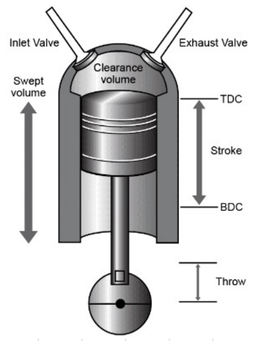
$$\text{Compression ratio} = \frac{\text{Total volume (piston BDC)}}{\text{Clearance volume (TDC)}}$$

Engine capacity (Total displacement) = Piston area · piston stroke · no. cylinders $= \frac{\text{swept volume}}{\text{no. cylinders}}$

Power = Torque · RPM

Piston engines
- Thermal efficiency ≈ 30%
- Power measured by friction brake: Brake horse power
- Crank assembly: Crankshaft, pistons and connecting rods
  ↳ Transforms reciprocating movement into rotary motion,
  ↳ twice speed of camshaft
- Camshaft: rotates at half the speed of crankshaft   Memo: Calm-shaft rotates slower
- Torque measured at the gear box located between engine and propeller
- Specific fuel consumption: Mass of fuel required to produce unit power / unit time

Piston engine terminology
- Swept volume: volume displaced by piston in single stroke → length stroke · piston crown area
- Total volume: Swept volume + clearance volume
- TDC Top Dead Center
- BDC Bottom dead center



Diesel engine
- higher compression ratio than petrol engines ↳ higher thermal efficiency
- less flammable than petrol
- No mixture control
- Power set/determined by fuel flow only
- No throttle valve
- intake system never heated because it's injection
- Soot: fuel droplet from atomiser do not burn completely
- Produces less maximum power output (no turbocharger) than petrol engines

Fuel

Octane rating
- Characterizes the resistance to detonation
- You can use a higher rating (not lower otherwise detonation)
- Higher compression ratio = higher octane required

Vapor lock
- Limitation on maximum operating altitude
- Vaporizing of fuel prior to reaching the engines
- Blockage of fuel line by fuel vapour bubble
- heat produces vapor bubbles that block

Fuel check
- Before first flight of the day

Engine fuel pumps
- Used during:
  - Take-off
  - Landing
  - Emergency
  - Suspected vapor lock
  - Failure of engine fuel pump

Detonation
- Increase with:
  - low octane rating
  - High cylinder head temp (CHT)
  - Engine overheat
  - Too weak/lean air fuel mixture ratio
  - Low RPM
- You want good anti-knock capability (resistance to detonation)
- If detonation: 1) Reduce throttle and manifold pressure 2) enrich mixture
- Detonation (mini-explosion) takes less time than normal combustion

Pre-ignition:
- mixture ignited before spark
- occurs at high RPM

Carburettor/injection system
- Function: Supply correct air-fuel mixture at all speed
- Float type carburettor based on difference air pressure at venturi throat and air inlet ↳ creates suction for fuel flow
- Mixture controller varies fuel supply only (not air)
- Fuel strainer is positioned upstream of needle valve

Icing conditions
- Most likely at venturi and throttle valve
- May form at OAT > +10°C
- First indication in constant speed propeller is decrease of manifold pressure

Carburettor heat
- When applied, density of air reduces (warm) ⇒ mixture is rich ↳ reduction RPM if fixed pitch!
- equipped with diffuser (compensating jet) for constant mixture

Altitude mixture control / barometric correction
- Purpose: maintain correct weight fuel-to-air ratio when altitude increases / decreased air density

Primer pump
- Provides additional fuel for engine start
- Safest priming is injection of fuel in cylinder intake ports
- Excessive priming to be avoided because:
  - Risk of engine: · fire · flooding
  - Fouls the spark plugs
  - Washes off the lubricant from cylinder walls

Accelerator pump
- Temporarily enrich mixture by pumping more fuel into induction system during rapid throttle movement

Diffuser/compensating jet
- Maintain constant mixture at low and high power setting

- Safest way of priming is with injection of neat fuel into inlet manifold

Cooling system
- Air cooled engines: use Ram air; fins increases cylinder and head surface area
- Cowl flaps: Cools CHT ↳ increases performance   CHT: measures temperature of hottest cylinder using thermocouple

Lubrication systems
Used to:
- Reduce internal friction and provide cooling
- Lubrication, cooling, cleaning, engine protection, hydraulic operation

- NRV non-return valve = check valve
- Temperature sensor: Detects temperature after oil cooler

Ventilation
- Prevents excessive pressure from building in a tank
- Air space in top of tank is for expansion and foaming

Dry sump:
- Stack pipes, both at bottom of tank ↳ Shorter stack pipe supplies an emergency supply (feathering system)

Oil viscosity:
- tendency of liquid to resist flow
- Depends on oil temperature

- Oil cooler fitted in return line after scavenge pump

Oil pressure gauge
- measures pressure of the oil on the outlet side of the pressure pump

Ignition system
- Small aircraft use high tension system
- Magnetic ignition: low tension booster coil supplies low voltage current to primary circuit
- Dual ignition: Improves reliability, combustion efficiency and reduce detonation
- Distributor: distributes secondary current to the sparking plugs

Magneto
- Principle: Breaking primary circuit to induce low amp, high voltage current → distributed to spark plugs
- Primary current from self contained electromagnetic induction system
- Receive electrical energy from rotating permanent magnets

Magneto selector OFF
- Grounds primary (more important) and secondary circuit
- If disconnected ground wire ↳ can not shut down engine with ignition to off ↳ Cut-off fuel supply

Impulse magneto coupling
- Provides stronger spark on TDC for engine start
- inhibited at high RPM by centrifugal force
- Provides retarded (slower timing) spark

Contact breaker
- Control primary circuit of magneto
- Spark plugs produce spark when contact breaker open
- Contact breaker opening → rapid magnetic flux change in primary coil

Capacitor/condenser
- induces very high voltage across secondary windings
- prevents arcing across the breaker points
- Intensify current in secondary winding (stores energy)

Mixture
- Chemically correct ratio (fuel : air) 1:15, MAX EGT
- Fuel/air ratio or mixture = $\frac{\text{Mass fuel}}{\text{Mass air}}$
- Richness ratio = $\frac{\text{Real mixture}}{\text{Theoretical mixture}}$

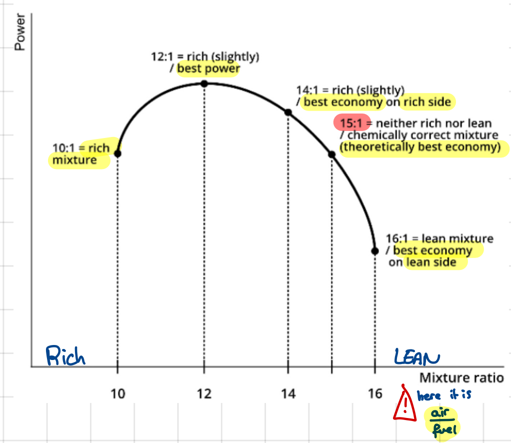
Altitude increase
- Reduce fuel flow to account for air density decrease
- ⚠ amount of fuel stays constant

Altitude reduced
- Increase fuel flow

Enriching
- Low CHT
- Makes starting possible and cools engine at idle
- Too rich causes → fouling of spark plugs ↳ black smoke

Leaner/weak
- High CHT

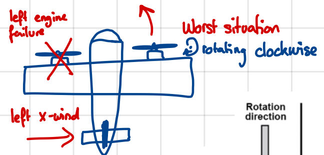
Effect of richness (massflow air / massflow fuel) on power at a given RPM and manifold pressure.



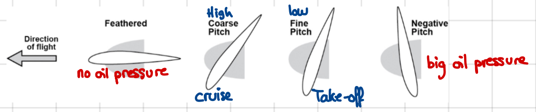
Aeroplane: propellers

Constant speed propeller

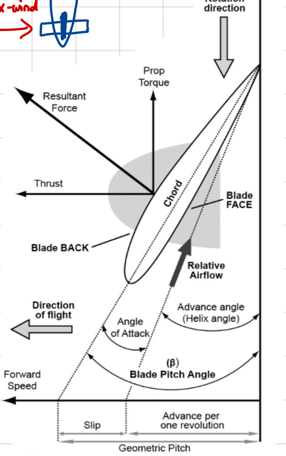
- Operated hydraulically by engine oil
- Advantage: maintains max prop. efficiency over wide range of airspeed



- Engine failure, no feathering system → blades move to smallest blade angle by centrifugal twisting moment and/or spring force
- Single-acting pitch control unit
  → oil pressure turns prop. blades towards smaller pitch angle



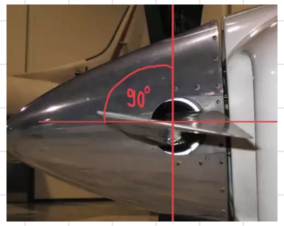
blade angle = angle between ref chord line and prop plane of rotation



- Blade angle increases with → increasing TAS
  → increasing MAP
- Take-off is low/fine pitch and forward prop. lever position

Feathering

- Blade pitch at 90°
  angle between reference chord line and prop. plane of rotation



- Unfeather by electric unfeathering pump
- Manual feathering by pulling prop. lever rearward
- Feathering pump: electrically driven, supplies prop. with oil under pressure when engine is shut down
- high pitch → feather direct

Torque

- proportional to axial load
- measured by axial forces

Propeller reduction gear

- keeps prop. rotation speed within range good performance

Performance and engine handling

- Cold and dry at high pressure: best power
- Humidity bad: decrease piston engine power because air density decreases

Normally aspirated engine: (Not turbo or super charged)

- MAP constant, power increase with increasing altitude
  (increase in air density behind throttle valve, lower back pressure)
- RPM constant, MAP decrease with increasing altitude, (decreasing air density)
- Monitor only RPM on fixed pitch

Engine overload:

- Avoided by increasing RPM before increasing MAP
  (Mixture – RPM – Throttle/Manifold) MRT

Turbocharger

- Purpose: Maintain power at altitude
- monitored by MAP only
- Advantage over supercharger is that it uses exhaust gas energy (which would be lost)
- Advantage: power less affected by altitude

Driven by
exhaust gas energy
↓
centrifugal turbine
↓
radial compressor
on common shaft

Waste gate

- Seized: May cause MAP to exceed in descent and MAP decrease in ascent
- Completely closed: all exhaust gas are directed to turbine

Supercharger

- Purpose: Maintain power at altitude
- enters centrifugal compressor at eye of impeller and leaves tangent to periphery
- intercooler between supercharger and inlet manifold to minimize risk of detonation
- Radial compressors

FADEC

- Automatically adjusts ignition timing when RPM varies
- Expect a crank switch
- Engine controls:
  - FADEC computer
  - Engine mode selector
  - engine master selector
  - power levers providing digital inputs

  } for pilot power/throttle only
- Redundancy with two computers

Rated power:
max horsepower at specified RPM and MAP

11 Turbine 19 – 23.75%

General

Bypass ratio = $\frac{\text{Bypass mass flow}}{\text{HP compressor mass flow}} = \frac{\text{inlet flow} - \text{HP compressor flow}}{\text{inlet mass flow} - \text{bypass mass flow}}$

external airflow mass (cold)
internal airflow mass (hot)

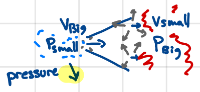
Gas turbine engine Expansion: pressure to mechanical

- Combustion takes place continuously at constant pressure
- Static thrust:
  - Product of exhaust gas mass flow and exhaust gas velocity $T = m_{gas} \cdot V_{gas}$
  - is zero when plane not moving since V=0
- Jet engine thrust: $T = \underbrace{m \cdot (V_j - V_v)}_{\text{Specific thrust}} + \underbrace{A \cdot (P_j - P_0)}_{\text{Pressure thrust}}$
  (m: air mass flow; V_j: jet velocity; V_v: airspeed; A: exhaust crosssection; P_j: jet exhaust static pressure)
- Max gas temp limited by turbine

Specific thrust
As speed increases, specific thrust lowers
as Δv diminishes

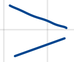
memo: exhale through mouth
wide = hot
close = cold

Divergent duct:



- Speed and dynamic pressure ↓
- Static pressure and static temperature ↗
- Total temperature and total pressure constant

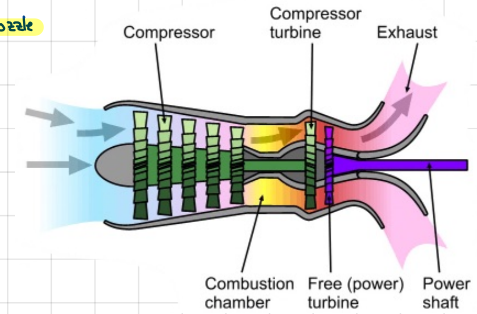
Convergent duct



- V ↗, P ↘, T ↘

Bypass turbine engine

- Single spool axial turbine: velocity greatest on exit from propelling nozzle
- At subsonic → better efficiency than prop or straight engine
- noisiest part: jet efflux
- Starter and igniter → ignite air-fuel mixture
- Specific fuel consumption:
  - Kg/h/shaft power
  - has the effect of lower specific fuel consumption: gas velocity ↘ mass flow ↗
- Efficiency:
  - chemical power tranformed into propulsive power (T·V)
  - Thermal efficiency increases with decrease in ambient air temperature
  - Ram air = increase efficiency

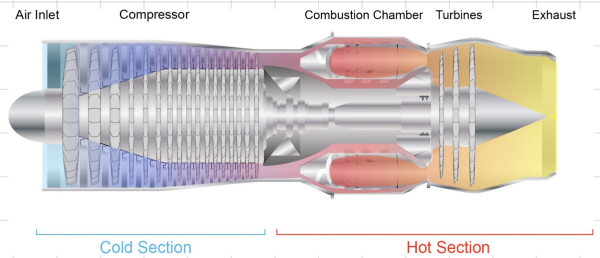


Constant speed propeller and free power turbine

- Free turbine
  = turbine that does not drive compressor
  - Power shaft mechanically connects to → free turbine
    not compressor
  - Depends on rotational speed of gas generator (but not connected)

- Power setting increase
  - Gas generator speed ↗
  - Blade angle/pitch ↗
  - thrust and EGT ↗
  - HP spool ↗
  - free power turbine constant
- RPM increase
  - Gas generator speed constant
  - free power turbine ↗

Main-engine components



Ram effect

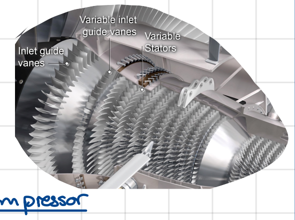
- air at intake is compressed, flow velocity decreases

Intake

- Function: reduce airflow velocity
- Divergent: increase static pressure in front of fan
- Blow-in-doors: additional air at high power and low airspeeds
- Unfavorable: Max Take-off thrust, zero speed, strong cross-wind
- Divergent → increase static pressure to improve ram recovery

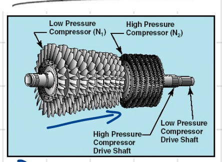
Variable inlet guide vanes (move to add angular flow)

- VIGVs in front of HP compressor with variable stator vane (VSV) control compressor airflow
- Fewer VIGV and VSV required when using 3 spools instead of 2
  ↳ prevent compressor stall at low RPM



Axial flow compressor

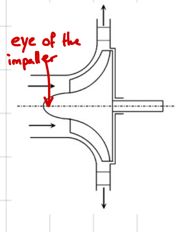
- Typical ratio 35:1, single axial stage 1.2:1
- Pressure ratio depends on number of stages
- Tapered design to maintain constant axial speed in cruising flight
- More expensive $$ and vulnerable to FOD
- Each stage compresses little but overall big airflow compression



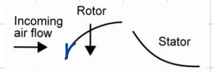
Decrease in size from LP to HP
→ sustain axial velocity

Centrifugal compressor

- Typical ratio 12:1, single axial stage 5:1
- Diffuser divergent, V ↘ P ↗
- High pressure ratio by stage
- Large diameter



Compressors Rotor, Stator



Think of FA/18 intake you can spin rotors

- Compresses air, P ↗, V ↘
- multiple stages required because one stage not enough shaft power
- Compressor blades take a rigid position because of resultant of aerodynamic and centrifugal forces
- Bleed valve / Variable bypass value
  - Prevents stalls in the LP compressor
  - Counters compressor surge at low RPM
  - increase at the early stages and decrease airflow across the rear stages

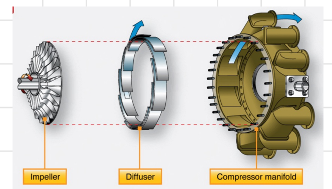
Compressor surge

- Controlled with anti-ice bleed valves
  with fuel flow (FCU – Fuel Control Unit)
- Occurs at low RPM of axial compressor at front stages

Compressor stall

- Caused by low axial flow velocity relative to rotor speed (low RPM)
- Indicated by Turbine Gas Temperature TGT increase (less airflow) and change in vibration
- Low RPM → front stage (stall) low airflow speed, high AOA
  low RPM, not compressed a lot so air comes back to front and stalls
- High RPM → rear stage (stagnation) high RPM, acceleration
  high RPM, air is too compressed and can't move at rear → stagnates
- high AOA of rotor blades

- **Diffuser** memo: Di-vergent
  - Decrease flow velocity and Increase air temperature before entering combustion chamber
  - P ↗ V ↘



Combustion chamber

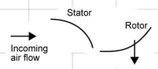
- Primary air to the fuel nozzle area for combustion
- Secondary air required to cool inner casing. Active cooling: minimize gap with blade
- Can type combustion chamber: Need only two igniters as chambers interconnected
- Drain valve: removes unburned fuel from the combustion chamber
- Annular type: thermal load distribution, reduced thermal stress

location:
LP fuel filter : HP fuel pump : fuel control unit

Swirl vanes:

- Reduce axial flow to stabilize flame front
- Generate swirl for better mixture
- Not increase air pressure

Turbine Stator, Rotor (inverse)



- Pushes air, P ↘, V ↗
- less stages than compressor because high power output

Impulse turbine > = convergent, parallel

> Nozzle:	V ↗	P ↘	T ↘
= Rotor Blade:	V ↘	P →	T →

Reaction turbine >> convergent, convergent

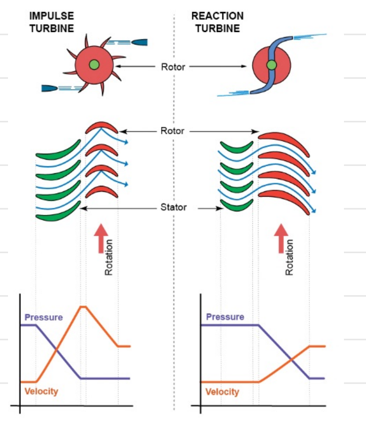
> Nozzle:	V ↗	P ↘	T ↘
> Rotor:	V ↗	P ↘	T ↘

- rotational action caused by convergent areas between turbine blades

Turbine blade

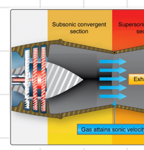
- Most common: Impulse/reaction type
- Inner half of blade is impulse type, outer is reaction
- Tip shrouds: increase turbine efficiency

- turbocharger waste gate in turbine, max RPM when closed



Exhaust

- Nozzle purpose: accelerate exhaust gas to high velocity → big thrust
  design: correct balance of pressure and velocity to prevent flow separation



Ice formation

- Prevented by using compressor bleed air

Additional components and systems

Reverse thrust

- just the cold (fan) air
- Warning light: reverse doors unlocked

Clamshell

Bucket

Cold stream Cascade

Cold stream pivoting doors

Reverse thrust alert

- Reverse doors unlocked / stowed with reverse lever in stowed / deployed position

Ignition system

- Starter + ignition
- High altitude and cold → Sparks of large intensity
- Used for ground start, in-flight relight, turbulence, heavy precipitation but not throughout or acceleration
- Sequence:
  - Starter on
  - Ignition on → before
  - HP fuel valve on
  - Light up
  - Self sustained speed
  - Starter disconnect
- Redundancy: 2 exciter units and 2 igniter plugs   memo: redundancy always 2
- Continuous ignition mode: Low intensity power when flameout risk
- Vibrator: provide DC current to the transformer to facilitate generation of high voltage to igniter
- Air starter disengaged by coupling with N2 and centrifugal forces

Accessory gearbox units

- Shear neck: to prevent engine failure in case of mechanical failure
- Run by HP shaft
- provides variety of services and support for engine in the airframe (APU)
- lubricated by oil
- Drives:
  - Tacho-generator N_2
  - AC generator and its CSD
  - Oil pumps
  - Hydraulic pumps
  - HP fuel pumps

Full authority digital engine control (FADEC)

- Throttle Lever Angle (TLA) provid electricaly
- Includes engine over-speed and EGT protections
- Single fault tolerant
- Power source = engines
- Can't shut down engine
- Checks all input and output data
- if failure → engine defaults to "safe" or "idle"

Engine oil system

- Oil filter clogged: Differential pressure opens bypass valve of main oil filter
- Reservoir usually at the front of engine to heat air intake
- Scavenge pump volume > pressure pump to ensure engine sump remains dry
- Magnetic plug collects ferrous particles
- Chip detector indicates metal particles in oil, warns of impending failure

Oil to fuel heat exchangers

- cools oil and heat fuel
- Uses engine oil to fuel from LP area
- Internal leakage: Fuel leaks into oil, causing oil level to rise

Engine fuel system

- If fuel pump fail, only gravity fed so some parts may be unusable
- Primary input of fuel control system: N2, compressor discharge pressure, compressor inlet temperature, fuel shut-off, TLA
- High Pressure Shut-off Valves (HPSOV) open to deliver fuel to fuel nozzle after ignition is activated
- Pressurizing and dump valve: admits fuel to nozzle only if fuel pressure is high enough for atomization

Seals

- labyrith seals: Seals not completely tight, allowing some movement between rotating and static parts

Flat-rated

- When OAT higher than flat-rated temp, thrust limited by max temperature on turbine blades

Engine operation and monitoring

EGT

- Sensed between gas generator turbine and free power turbine

Turboprop

- Negative/reverse/braking (β-range): propeller supplies negative thrust and absorbs engine power
- Turboshaft engine power measured with turning moment, proportional to horse power
- Torque meter situated between engine and propeller
- Alpha range
  - flight range to max power
- Control:
  - Propeller lever → prop RPM
  - Fuel lever → torque, turbine temperature

Abortive/Hung start

- Failure to accelerate to idle speed
- Cause by:
  - Too low pneumatic pressure
  - ignite fuel before starter has sufficiently accelerated the engine
- No N_1 altough N_2 may accelerate normally
  - ↳ stabilizes lower than normal RPM and increased EGT
- Procedure = shut down engine

Hot start

- Caused by:
  - early starter cut-out
  - fuel mis-scheduling
  - Strong tail wind
  - long time at low RPM but continues to accelerate
  - turbine temperature may exceed limitation

- Starting sequence
  - Air (windmilling): Rotation - ignition - fuel

Engine ratings

- Max take-off thrust (TOGA)
- Max continuous thrust
- Max climb thrust

- Rupture of LP shaft: causes LP turbine over-speed as turbine feeds LP compressor and there will be excess power
- Flight idle > ground idle for go-around
- Vibration indicate spool imbalance
- Pressure relief valve not sealing correctly results in low oil pressure
- Prior to shutdown:
  - Ground idle allows core temperature to stabilize
  - Prevents seizure of rotor blades in their seals
- Re-ignition depends on airspeed and altitude
- Tailpipe fire: fuel puddle in turbine, causes visible jet flame
- Gas turbine engine trending: enhances maintenance planning and detect anomalies

Performance aspects

Pressure altitude

- if pressure altitude increase, thrust decreases
  specific fuel decreases / remain fairly constant

EPR

- Jet pipe total pressure to compressor inlet total pressure
- EPR constant: Thrust decrease when altitude increases
- EPR setting maintains thrust irrespective of engine wear due to ageing

$$EPR = \frac{\text{exhaust pressure}}{\text{Compressor inlet pressure}}$$

Bleed air

- Turbine temperature increases
- EPR reduces
- EGT rises
- Decrease aircraft performance and power
- Fuel flow increases

Flat rated engines

- Provides constant max take-off thrust up to a certain OAT
- OAT ≤ flat rated temperature → Thrust lever not at maximum stop
- If OAT higher than flat rated temp ⇒ temperature limitation on turbine

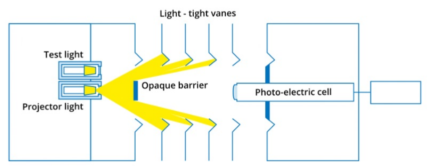
APU

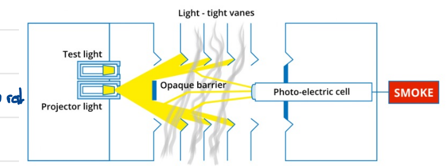
- Monitor fault status
- Protections:
  - High TGT/EGT
  - overspeed
  - low oil pressure
  - high oil temp
  - APU fire
- must be able to operate at high altitude
- electric starter (battery)
- Generator
  - 3 hase 115 V, 400 Hz
- Does not provide hydraulic

12 Protection and Detection system   3 – 3.75%

Smoke detection

- Installed in upper cargo compartment
- photoelectric cells = smoke detectors, detects light diffusion
- Labyrinth optical detector = light reflects towards the photosensitive cell and the labyrinth has a shielding function
- Ion detector = smoke detector
- For long-range flights, installed in: Cargo hold, toilets, avionic bay, crew rest





Fire-protection system

Fire extinguishers

- Halon (most common)
  - ↳ interrupts combustion
  - → flame inhibitor
  - → not corrosive
- Power plant / engine → operated by electrically fired cartridge (squib) rupturing a seal in the bottle head

Fire detection type:

1) Continuous loop firewire (resistance and capacitance type)
   - if inner core contacts outer casing (short circuit) → alarm triggered
     - ↳ resistance decreases
     - ↳ leakage current increases
   - Low resistance and low capacitance = faulty loop
   - Testing: wiring and warning are tested
2) Bimetal strip detector
   - includes delay in the event of false alarm due to vibration closing the contacts
   - arranged in parallel and are closed during a fire
3) Gaseous fire detection system
   - A closed tube filled with gaz that expands when heated
   - Decrease in loop pressure can cause a fault

Fire handle

- Opens exciter control relay and the generator breaker
- Arms extinguisher system
- Closes LP valve of fuel system, fuel supply isolated via pilot action
- Closing of isolation and de-icing values

Rain protection system

- Rain repellant + wipers
  - Uses hydrophobic chemicals preventing droplets from adhering to window surface
  - Should be sprayed only with heavy rainfall
- Bleed air not used here
- Coating applied by manufacturer

13 Oxygen system
3 - 3.75%

Cockpit, portable and chemical oxygen system

- Never use with grease! → catch fire in presence of oxygen
- Automatically presented at 15'000ft to crew and PAX

Chemical oxygen generators for cabin (electric door)

- 12-20 minutes
- incorporates a heat shield
- Advantages:
  - Easier maintanance
  - Less explosions
- Disadvantages:
  - Flow can't be modulated
  - Less capacity
  - poor autonomy

Gaseous oxygen source for cabin (pneumatic door)

Protective breathing equipment

- 100% oxygen supplied above 32'000ft or manually
- Protects crew members against fumes and noxious gases

Smoke hood

- covers whole head with continuous oxygen

Smoke mask

- covers whole face with on demand oxygen

Cockpit/flight deck oxygen system

- uses a separate bottle
- Regulator in normal/dilute:
  - Mixture of cabin air and oxygen
  - Shouldn't be used when smoke in cockpit
  - above a certain altitude, will provide 100% oxygen
- Emergency = 100%
  - continuous flow