ENGINES 1 – BASIC GAS LAWS

BOYLE'S LAW

- Assumes **constant temperature**
- **Product of pressure and the volume is constant** providing temperature of the gas remains unchanged.
- $P_1 V_1 = P_2 V_2$

CHARLE'S LAW

- Assumes **temperature is varied.**

- With **constant pressure**, if temperature increases then volume must increase.
- $P_1 / T_1 = P_2 / T_2$

- With **constant volume**, if temperature increases then pressure must increase.
- $V_1 / T_1 = V_2 / T_2$

GENERAL GAS EQUATION

- All three statements combined

- $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$

TRANSFER OF HEAT

- Conduction
- Convection
- Radiation

ENGINES 2 – LAWS OF MOTION

NEWTONS FIRST LAW

- A body at rest will remain at rest and a body in motion will **continue in uniform (direction and speed) motion unless it is acted on by an outside force.**

NEWTONS SECOND LAW

- The acceleration produced in a mass by the application of a force is directly proportional to the force and inversely proportional to the mass.
- **F = m x a**

NEWTONS THIRD LAW

- To every action, there is an **equal and opposite reaction.**

WEIGHT AND MASS

- Weight is the force with which the gravity of the earth attracts a mass.
- **W = m x g**
- Accel due gravity: **32.20 ft/s² or 9.81 m/s²**

FORCE

- **Force = Mass x Acceleration**
- SI Unit: N (Newton)
- Imperial Unit: lbsf (Pounds force)

DENSITY

- **Density = Mass / Volume**
- Varies with temperature and pressure

MOMENTUM

- **Momentum = Mass x Velocity**

INERTIA

- **Tendency of a body to preserve its state of rest or uniform motion.**

THRUST CALCULATION

- F = m x a

$$F = \frac{W}{g} \times a$$

- Weight of airflow through propeller is 800 lbs/s, the inlet velocity is 0 ft/s and the outlet velocity is 160 ft/s. Calculate thrust?
- Thrust is a force so equation above is used.

$$F = \frac{800}{32.20} \times 160 = 4000\ lbsf$$

ENGINES 3 – PISTON ENGINE CONSTRUCTION

BASIC PRINCIPLE

- Convert linear to rotary motion.

4 STROKE CYCLE

- A.K.A The Otto Cycle

1. INDUCTION (SUCK)

- Pressure decreases on the down stroke.
- Higher pressure outside induces the fuel / air mixture into the cylinder.

2. COMPRESSION (SQUEEZE)

- Volume decreases, so pressure and temperature both increase.

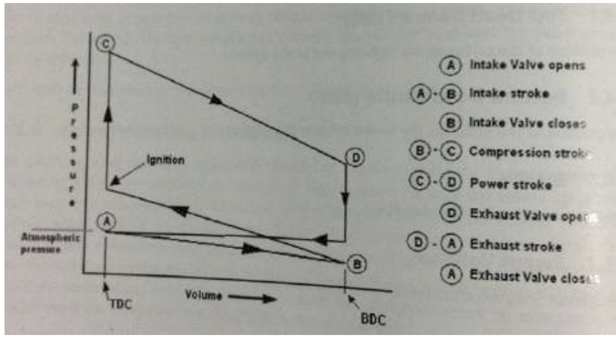
3. POWER (BANG)

- Mixture is ignited.
- Temperature increases rapidly for a short time then decreases for the rest of the stroke.
- Pressure increase pushes the piston down.

4. EXHAUST (BLOW)

- Piston rises and pushes exhaust gases out.
- **A.K.A Scavenging**

VOLUME & PRESSURE RELATIONSHIP



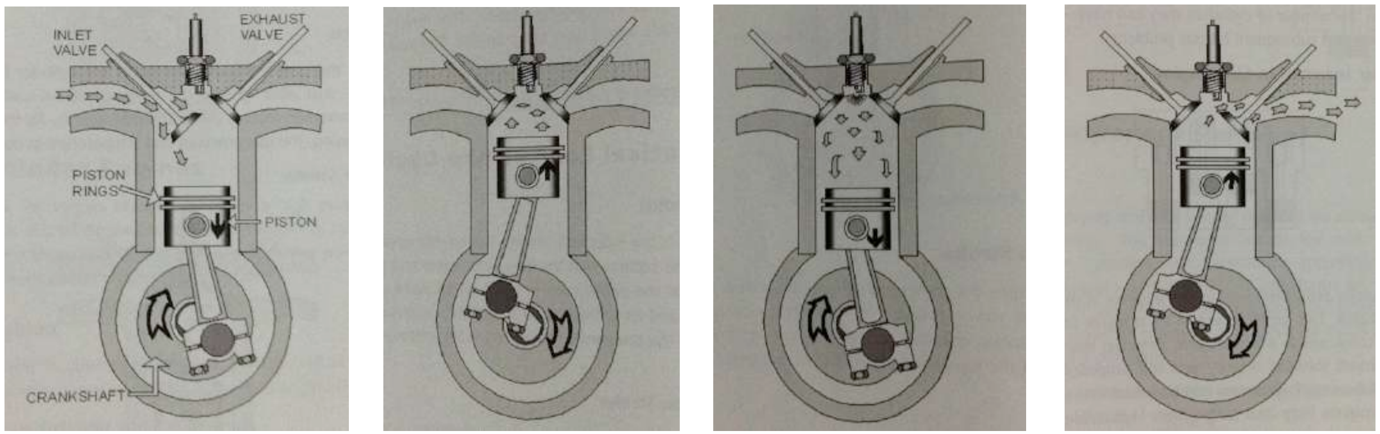
- **The above diagram is enclosed by 2 adiabatic and 2 isochoric lines.**
  - Adiabatic – No heat transfer (compression & power)
  - Isochoric – Constant volume (intake and exhaust)
- Ideally the maximum pressure occurs when combustion is complete**.**

TYPES OF ENGINES

- **In-Line Engine**
  - Poor cockpit visibility
- **Inverted In-Line Engine**
  - Improved visibility
  - Suffers from hydraulicing (turning over before start is required).
- **Radial Engine**
  - Even cylinder cooling
  - High drag profile
  - Hydraulicing still an issue
- **Horizontally Opposed**
  - Saves space
  - Good visibility
  - No hydraulicing problems

CONTANT / INTERMITTENT PROCESS

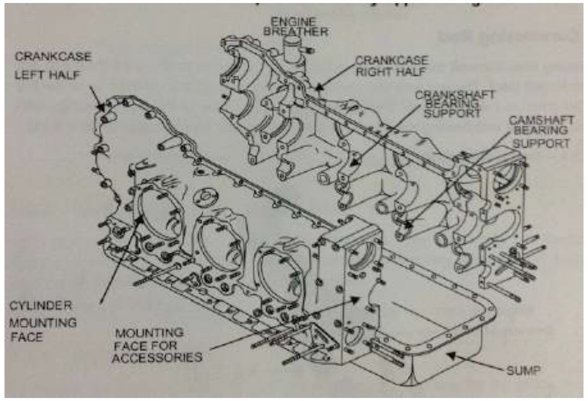
- Power output is **intermittent** (only on power stroke)
- Combustion is at **constant volume** and **varying pressure**.



ENGINES 3 – PISTON ENGINE CONSTRUCTION

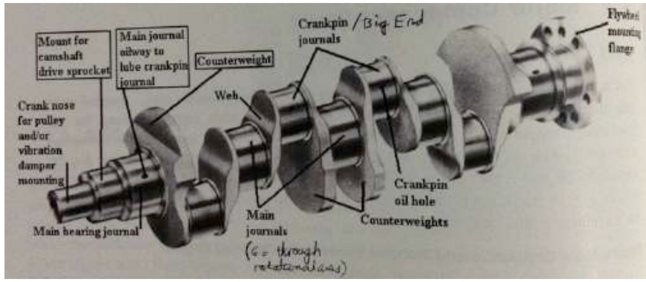
CRANKCASE

- Houses the crankshaft
- Supports the cylinders
- Provides mounting for engine accessories
- Forms an oil tight chamber
- Usually made of aluminum alloy
- A crankcase breather prevents a pressure build up inside the crankcase.



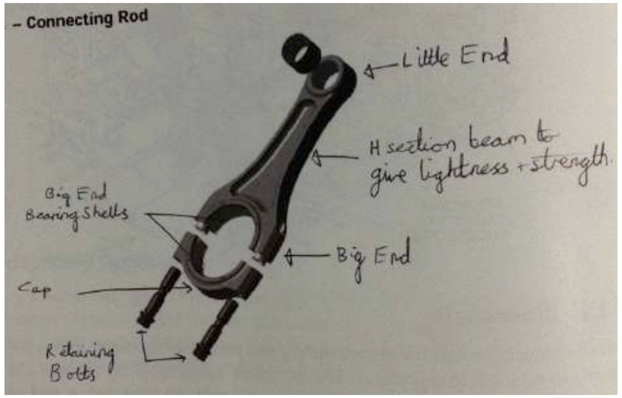
CRANKSHAFT

- Converts reciprocating linear motion to rotary motion and transmits engine torque to the propeller.
- Usually made of alloy steel.
- Oil is passed into the main journal and is transferred to the big end journals which are rotating.
- One cycle per 720 degrees of crank rotation
- **Stroke =** Distance the piston moves through
- **Throw =** Distance from main to big end journal = ½ Stroke



CONNECTING ROD

- Connects the piston to the crankshaft.
- Connected to the piston at the little end via a **Gudgeon Pin (**or Piston / Wrist Pins)
  - Fully floating to prevent uneven wear



CRANK ASSEMBLY

- Crankshaft
- Connecting Rods
- Pistons

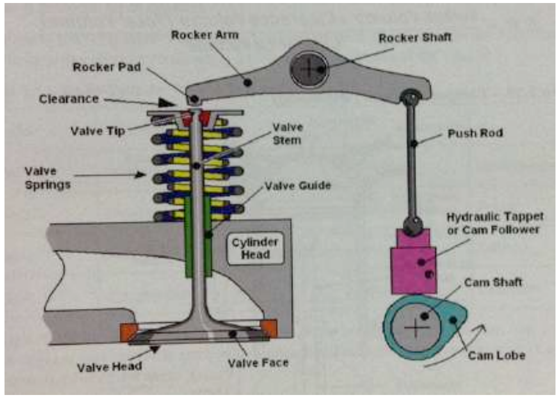
PISTON

- Usually made of aluminum alloy.
- **Top Compression Ring**
  - Gas tight fit and reduces friction.
  - Usually made of chromium steel.
  - Spring out of the groves as the cylinder wears.
- **2nd Compression Ring**
  - Seals + scrapes oils
- **Oil Control Ring**
  - Distributes oil and helps scrape it back to the crankcase.

ENGINES 3 – PISTON ENGINE CONSTRUCTION

VALVE OPERATING MECHANISM

- The camshaft rotates at ½ crankshaft speed (1 rotation for every 2 crankshaft rotations)
- **Valve clearance** is measured between the **rocker pad and valve tip.**
  - Excessive clearance results in valve opening late and closing early.
  - Ensures complete valve closure
  - Allows valve to expand when heated
- A **hydraulic tappet** can be fitted instead.
  - Self adjusting (eliminates adjustment)
  - Operates with zero clearance
- Valve springs are used to hold valves shut
  - Two springs are used for redundancy and to prevent valve floating.



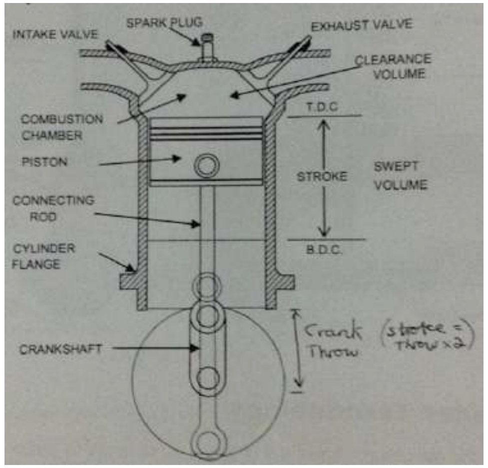
VALVE STEMS

- **Sometimes partly filled with sodium to assist with cooling.**

COMPRESSION RATIO

- **Swept Volume –** Cylinder volume contained between TDC and BDC.
- **Clearance Volume –** Cylinder volume contained between top of cylinder and piston crown at TDC.
- **Total Volume** = Swept + Clearance Volume

$$CR = \frac{Total\ Volume}{Clearance\ Volume}$$



MULTI ENGINE CYLINDER

- One power stroke per 720 degrees of crankshaft rotation.
- Power stroke every 720/# of cylinders.
- 4 Cylinders = Power stroke every 180^0
- 6 Cylinders = Power stroke every 120^0

BAFFLE PLATES

- Used to cool the cylinder.
- Creates a venturi effect.
- Wider baffle plates on the exhaust side.

INEFFECTIVE ANGLE

- The position around TDC and BDC when there is a small linear movement of the piston compared with a relatively large movement of the crankshaft.

TIMING OF IGNITION

- The ignition is timed to occur just before TDC.
- Power stroke then begins just after the rod and crankshaft have passed the vertical.

ENGINES 4 – POWER

WORK DONE

- Work = Force x Distance
- Foot-pounds (imperial)
- Newton metres (SI)
- 1 foot-pound is the work done when 1 pound is lifted 1 foot.

POWER

- Power = Work / Time
- Foot-pounds per second (imperial)
- Metre-kilograms per second
- 1 horsepower is when 550 foot-pounds of work is carried out in 1 second.
- 1 horsepower is when 33000 foot-pounds of work is carried out in 1 minute.

BRAKE HORSE POWER

- The actual amount of useful power delivered to the propeller shaft.
- The **output** of the engine.
- Measured with a friction brake

$$BHP = \frac{Force \times Length\ of\ Arm \times 2\pi \times RPM}{33000}$$

- Also BHP = Torque x RPM
- Torque can be measured at the gearbox between the engine and propeller.

INDICATED HORSE POWER

- IHP = BHP + FHP (Friction Horse Power)
- FHP is the power required to drive the accessories (mags, pumps etc) and that lost through friction.

$$IHP = \frac{PLANK}{33000\ (ft\ lbs\ /\ \mathrm{min}\ )}$$

$$IHP = \frac{PLANK}{60000\ (Nm/\ \mathrm{min}\ )}$$

- P = Indicated Mean Effective Pressure
- L = Length of stroke (ft or m)
- A = Area of Piston Crown (m2 – square Inch)
- N = Number of power stroke per min (1 cyl)
- K = Number of cyclinders

- LAK = Total swept volume of engine
  - Fixed by manufacture
  - Gives total multi-engine cylinder displacement.
  - Use $\frac{1}{4}\ \pi\ d^2$ if required for area
- We can alter P and N (rpm) in order to achieve more power.

FACTORS AFFECTING POWER OUTPUT

- Density
- Fuel / Air Mixture
- Exhaust Back Pressure
- Manifold Pressure

MIXTURE RATIO

- Weight of Air / Weight of Fuel (entering the cylinder)
- Chemical Correct = 14.7 / 1
- < 14.7 / 1 = Rich
- > 14.7 / 1 = Lean

EXHAUST BACK PRESSURE

- The pressure differential between cylinder and ambient air which prevents efficient scavenging of exhaust gas.
- **Back pressure reduces with altitude** which **improves scavenging**.

MANIFOLD PRESSURE

- Pressure between the throttle valve and inlet valve.
- Engine Off = Ambient Pressure
- Idle = 14 In.Hg
- Takeoff = 28 In.Hg
- With every 1,000 ft increase, MAP (Manifold Absolute Pressure) decreases by approx 1”

CONTROLLING POWER OUTPUT

- **Fixed Pitch Prop** – RPM + Mixture
- **Constant Speed Prop –** RPM (Prop Lever) + Mixture + MAP (Throttle Lever)

ENGINES 5 – ENGINE EFFICIENCY

MECHANICAL EFFICIENCY

- Efficiency = (Output / Input) x 100%
- **ME = (BHP/IHP) x 100%**
- This gives the percentage of power developed in the cylinder that turns the propeller (typically 80-85%)

THERMAL EFFICIENCY

$$TE = \frac{Power\ Produced\ (BHP)}{Power\ Contained\ In\ Fuel}$$

- An engine producing the same power as another but **using less fuel** has a greater thermal efficiency.
- **Typically 30%**
- **Can be increased by increasing the compression ratio (less fuel required).**
- **Sources of energy loss:**
  - Cooling of cylinder and cylinder head
  - Friction of piston inside cylinder
  - Energy carried by exhaust gas
  - Improper inlet and exhaust valve operation.

INEFFECTIVE CRANK ANGLE

- Between **± 10^0 of TDC and BDC.**
- Virtually **no piston head movement** within this period and volume is almost constant.
- Used for ignition and valve timing.
- Combustion takes place within this angle.

VOLUMETRIC EFFICIENCY

$$VE = \frac{Weight\ of\ mixture\ induced}{Weight\ of\ mixture\ which\ could\ fill\ the\ cylinder} \times 100\%$$

- **Positive effects** on mixture induced:
  - Larger valves
  - More valves per cylinder head
  - Supercharger / turbocharger

- **Negative effects** on mixture induced:
  - High RPM = More FHP = Less VE
  - Bends, obstructions etc in induction system
  - Throttle and venturi restrictions

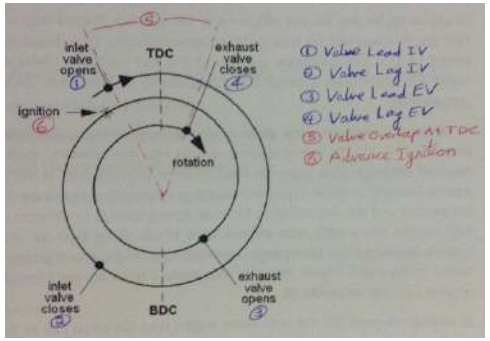
- A fuel injected engine has improved efficiency as exhaust gases do not interfere with inlets by lower density.
- **VE improves with altitude** due to reduced exhaust back pressure.
- Max VE with **low RPM and throttle fully open.**

PISTON VS DIESEL

- **Piston** = Mixture ComprimING Engine
- **Diesel** = Air Compriming Engine

VALVE TIMING

- Valves **lead and lag** which help to improve volumetric efficiency.
- Both valves are open at the end of the exhaust stroke.
  - Momentum of incoming gases helps to scavenge any remaining gases.
  - During overlap, the outgoing exhaust gas tends to reduce the pressure within the cylinder.
- **Advance Ignition** also occurs just before TDC.
  - On start, the ignition is retarded and occurs just after advanced ignition but before TDC.



ENGINES 5 – ENGINE EFFICIENCY

SPECIFIC FUEL CONSUMPTION

- Mass of fuel used, per horsepower produced, per unit of time.
- Will increase with an increase in OAT
- Lbs (or kgs) / HP / Hour

POWER OUTPUT

- In a normally aspirate engine, power output is controlled by fuel flow only.

DIESEL ENGINES

- Clearance volume much smaller giving a **higher compression ratio**.
- Uses **AVTUR** (Kerosene) rather than AVGAS
- Always **direct fuel injected**
    - Air inducted straight into cylinder on intake stroke.
    - Higher compression ratio produces higher pressure and temperature.
    - Fuel auto-ignites when introduced.
    - Assisted by glow plugs.
    - Intake system never needs heating
- There is no throttle valve.
    - An engine control unit decides how much fuel to inject.
- Diesel fuel is less inflammable than petrol.
    - Note flammable and inflammable mean exactly the same thing.
- Power is set by the fuel flow.
- Diesel engines will always produce a certain amount of soot
    - Fuel droplets coming from atomiser do not burn completely.
- Non turbocharged diesel engines have a poorer power to weight ratio than a petrol engine.
    - Heavier parts required due to the higher compression ration.
    - Therefore, produce less maximum power output when compared to a piston engine with the same swept volume.

ENGINES 6 – ENGINE CONTROLS

COWL FLAPS

- Regulate the amount of **cooling air passing over cylinders.**
- Open for takeoff and climb
- Closed for descent to prevent **thermal shock**
- Varies during climb according to CHT.

ELECTRIC PRIMING PUMP

- **Maintains a head of fuel** to the engine driven pump during critical stages of flight.
- Maintains fuel pressure should **engine driven pump fail.**
- **Prime induction system** during engine start.

ENGINES 7 – FUELS

AVGAS

- **Blue = 100 LL**
- **Green = 100**
- **Red = 80 / 87**
- AVGAS + Jet B are **flammable** and have a **low flash point**.

OCTANE RATING

- AVGAS fuel classified by octane number.
- Measure of **resistance to detonation.**
- **“Anti-knock value”**
- Higher value = More resistance
- Normal Heptane = 0
- Iso Octane = 100
- A **higher compression ratio requires a higher octane fuel.**
- Use of a too low octane rating may cause CHTs and oil temp to exceed normal ranges.
    - Can lead to detonation
- Lower octane will evaporate more easily leading to carb icing.
- A fuel of a different grade to that recommended can be used providing it is of a higher octane rating.

AVTUR

- **Diesel** (-22^0C)
- **Jet A** (-40^0C)
- **Jet A1** (-47^0C)
- Jet fuels are **combustible** and have a **high flash point.**

DIESEL KNOCK

- **Cetane Number**
- Measure of **how well it combusts**
- High cetane number = better combustion

FUEL TANK

- Vented to prevent **tank deformation** and **fuel starvation.**
- Atmospheric air can enter through the vent and **condense** due to the cold temperature in the tank.
    - Drain holes fitted to allow inspection
    - Inspection should be done at least before the first flight of each day.
    - Filling tank at end of day helps to minimise condensation.

DETONATION

- **Most likely with high CHTs**
- Use of a too lean mixture can increase likelihood of detonation
- Fuel / air mixtures **auto-ignites** and very high temperatures and pressure are created in the cylinder.
- Occurs **after sparks plugs have fired.**
- Most likely at **high MAP and low RPM.**
- **Reduce throttle and increase cooling** (rich mixture) if detonation occurs.

PRE-IGNITION

- Detonation leaves high temperatures in cyclinder.
- If mixture ignites **before sparks plugs have fired** this is pre-ignition.
- Caused by overheated hot-spots within the cylinder.

ENGINES 8 – CARBURETTOR

FLOAT CHAMBER

- Float lowers when fuel supply needs topping up.

PRESSURE DIFFERENTIAL

- Induction stroke draws air into the cylinder.
- Air flows through venturi and static pressure decreases.
- Pressure differential due to venturi draws fuel from float chamber and out of the main jet.

IDLING JET

- At low rpm, airflow through venturi is insufficient to produce pressure differential required to draw fuel from main jet.
- The closed TV creates a drop in static pressure so an idling jet injects fuel at this location instead.

ACCELERATOR PUMP

- **Injects fuel into the induction system during rapid opening of the throttle.**
- Prevents a too lean mixture.
- Piston is at TDC when throttle closed and at BDC when throttle opened.

AIR BLEED / DIFFUSER

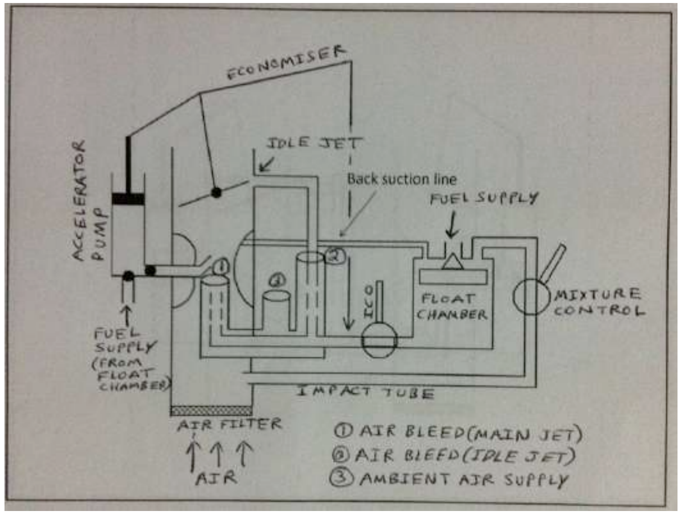
- Due to different **flow characteristics,** the mixture can become too rich when RPM is increased.
- The diffuser mixes fuel with air to ensure a constant mixture ratio over the operating range.
- Also **improves the atomization** of the fuel.
- One also fitted to idle jet.

ECONOMISER

- At **full throttle**, a slightly enriched mixture is required.
- **Prevents detonation** (high power can cause high temperatures)
- Active when TV > 85% open.
- Provides additional fuel.
- Compensates for the air bleed system that normally ensures a weak (economical) mixture at most power settings.

MIXTURE CONTROL

- Allows changes to weight of fuel with changes in weight of air (altitude changes).
- Can be of the variable orifice type which uses a **needle valve.**
- Another option is the **back suction mixture control.**
  - Varies the pressure in the float chamber between atmospheric and that near the venturi.
- **Barometric correction / altitude mixture control** = Auto Mixture



CARBURETOR FIRE

- Result of **overpriming**
- LP in carburetor **draws excess fuel back into the carburetor** causing a fire.
- **Actions in event** of carburetor fire:
  - ICO
  - Throttle Open
  - Crank

CARB HEAT CONTROL

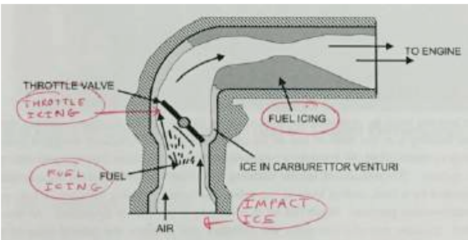
- Cold air is heated by conduction with hot exhaust.
- Warm air is less dense and mixture becomes too rich when carb heat used.
- Carb heat air is **unfiltered**.

ENGINES 8 – CARBURETTOR

CURBURETTOR ICING

- **Impact Ice**
  - Water in atmosphere coming into contact with surfaces (particularly the intake) which are below 0^0C
- **Throttle Ice**
  - Pressure drop around the TV can cause freezing of condensed water vapour.
  - Most likely at low power settings due to venturi effect.
- **Fuel Ice (Venturi)**
  - Cooling effect of fuel vaporization and expansion of air.

- Conditions of **high relative humidity** make carb icing more likely.
- Most likely to occur with:
  - OAT between -5 and $+18^0C$
  - Visible moisture present OR
  - RH > 80%
- Carb icing can occur even at OATs > 10^0C



CARB ICING INDICATIONS (FPP)

- **Lower EGT** (Due rich mixture)
- Gradual **drop in RPM**
- **Rough running engine**

CARB ICING INDICATIONS (CSP)

- **Drop in MAP** (3" – 5")
- **RPM stays constant**

CARBURETTOR FUEL STRAINER

- Essentially a **fuel filter**
- Located **upstream of needle valve**

VAPOUR LOCK

- Fuel is heated and evaporation occurs
- Vapour Pressure > Fuel Pressure leads to a vapour lock
- Occurs in the fuel feed line before reaching the engine.

EFFECTS OF APPLYING CARB HEAT

- Engine performance decreases by up to 15%
- Increases fuel burn
- If icing present, rpm will decrease then return to a higher rpm.
- Density of air entering induction system decreases
  - Mixture becomes richer

PRIMING

- Injection of fuel in the **cylinder intake ports** to assist with starting.

ENGINES 9 – FUEL INJECTION

CURBURETTOR DISADVANTAGES

- **Icing**
- **Carburetor Fire**
- **No Inverted Flight**
- **Unequal distribution** of fuel to cylinders
  - Weight of mixture entering cylinder is less (due exhaust forward mounting).

FUEL INJECTION DISADVANTAGES

- **Difficulty hot starting**
- **Vapour locks** on hot days (ground ops)
- **Problems restarting** after fuel starvation

FUEL INJECTION COMPONENTS

- **Throttle Valve**
- **Venturi dependent** on manufacturer
- **Electric Fuel Pump**
- **Engine Driven Fuel Pump**
- **Fuel Control Unit**

DIRECT FUEL INJECTION SYSTEM

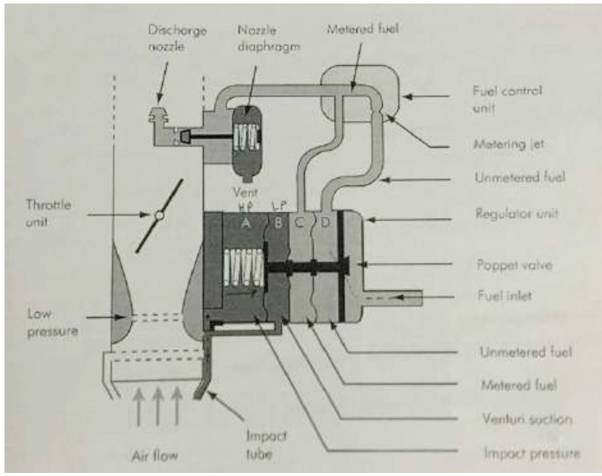
- Fuel injected **directly into cylinder** at end of compression stroke.
- **Air Compriming**
- Has a **higher fuel pressure** compared to the indirect type.
  - Fuel pressure gauge measures from the metered fuel pressure line.

INDIRECT FUEL INJECTION SYSTEM

- Fuel injected **just ahead of inlet valve**.
- **Mixture Compriming**

- **Poppet Valve opened** due pressure diff.
  - Impact pressure (HP) delivered to A
  - Venturi pressure (LP) delivered to B
- **Fuel flows into D.**
  - Travels to FCU
  - Unmetered fuel returned to C
- **Nozzle Diaphragm** allows for **constant metered** fuel injection.
  - Opens when the metered fuel pressure is greater than the spring tension.

- **A + B = Air Regulating**
- **C + D = Fuel Regulating**



ICING

- **No throttle or fuel ice**
- **Impact ice** can cause poppet valve closure
  - Result of pressure diff between A & B
  - Results in leaner mixture and rise in temperature.
- **Alternate air** used instead of carb heat.
  - Spring loaded door which will automatically open when lower pressure occurs at the air intake.
  - Also can be manually activated

ELECTRIC FUEL PUMP

- **Fuel Tank ---> Elec Fuel Pump ---> Engine Driven Fuel Pump ---> FCU**
- **Priming** during start
- **Back-up** for engine driven pump
- **Vapour suppression** at high OATs
  - Fuel may evaporate in fuel lines
  - Vapour pressure > fuel pressure = Lock
  - Elec pump pre-pressurises fuel

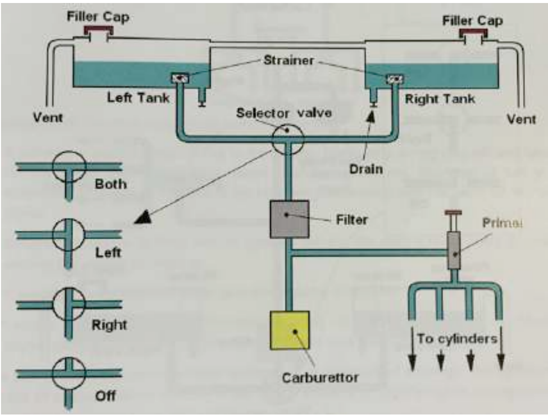
ENGINE CONTROL UNIT (ECU)

- Inputs received from **throttle position, mixture lever** and **engine RPM**.
- **Excess fuel returned** to inlet side.
  - Pump always produces more fuel than engine requires.
  - Least return at full throttle.

ENGINES 10 – FUEL DELIVERY SYSTEMS

GRAVITY FEED FUEL SYSTEM

- **Vents** fitted to tanks as the pressure in tanks decreases as fuel is consumed.
  - Prevents fuel starvation
  - Prevents structural damage to tanks

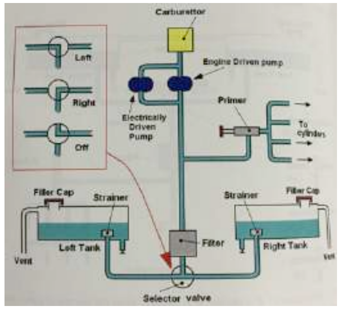


OVERPRIMING

- **Flush lubricating oil** from cylinders
- Increased risk of **carburetor fire**
- Increased risk of **flooded engine**
- **Fouls the spark plugs**

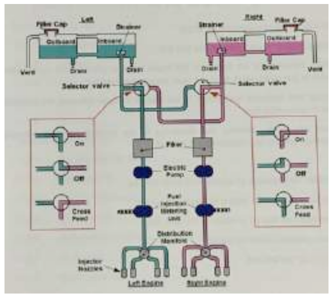
LOW WING SYSTEMS

- Requires **engine driven** and **electric pump**
- Electric pump is **DC powered (battery)** and **prevents vapour lock.**
- There is **no BOTH selection**



TWIN ENGINED SYSTEMS

- Contains **outboard** and **inboard** tanks.
- Fuel **crossfeed** is used
  - RH Tank ---> LH Engine
  - LH Tank ---> RH Engine
  - Prevent imbalance in case of engine failure.
- Fuel **transfer** only on much larger aircraft
  - RH Tank ---> LH Tank



WATER DRAIN

- AVGAS uses **water finding paste**.
- AVTUR uses **water detector**.

REFUELLING

- Always use a **higher fuel grade** – never lower. (100 instead of 100LL is ok)
- AVGAS Nozzle Diameter = 40 mm
- AVTUR Nozzle Diameter = 30 nm
- **Triple point grounding** required:
  - Aircraft
  - Nozzle
  - Fuel truck

FUEL GAUGE

- Lower ¼ marked with a red line.
- Should never be relied on as sole measure of remaining.

ELECTRIC PUMP USES (LOW-WING)

- Take-off
- Landing
- During emergencies
- In case of suspected vapour lock
- In case of failure of engine driven fuel pump

ENGINES 11 – LUBRICATION AND COOLING

FUNCTION OF OIL

- **Lubricates (reduces friction)**
- **Reduces wear** of metallic surfaces.
- **Dissipates heat** (internal cooling)
- **Seals**
- **Cushions** hammering shocks.
- **CSP adjustments** (hydraulic fluid)
- **Dissipates dirt**
- **Protects against corrosion**
- Adjustment of **waste gate** (turbo / supercharger)

OIL TYPES

- **Straight Oil**
  - Tendency to oxidise at high temps which causes it to become more viscous (more resistance to flow).
  - Reduces lubrication properties and causes sludge to form which can block filters.
  - Used for first 50 hrs in a new engine due to ability to withstand high friction forces.
- **Ashless Dispersant Mineral Oil**
  - No carbon forming problems like straight oil.
  - Universally approved for piston engines
- **Detergent Oil**
  - High cleaning effect resulting in blocked filters
  - Not normally approved in aviation.

vvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvvv

^^^

- **Synthetic Oil**
  - Used in gas turbine engine (not AVGAS)
  - Semi-synthetic used in DA42

SMOKE COLOURS

- **Blue =** High Oil Consumption
- **Black =** Too Rich
- **White =** Moisture in combustion chamber
  - Most likely with intermittent operation in cold weather

OIL GRADES

- Oil is graded according to **viscosity**
- **Higher Temperature = Lower Viscosity**
- Graded according to either **Saybolt** or **SAE** (Society of Automotive Engineers)
  - SAE = ½ Saybolt
- W = Suitable for **winter use**

MULTI GRADE OIL

- Has a **high viscosity index**
  - Gives a more constant viscosity over a range of temperatures.
- 20W / 40
  - At -18^{0}C viscosity is SAE 20W
  - At 99^{0}C viscosity is SAE 40

REQUIRED OIL PROPERTIES

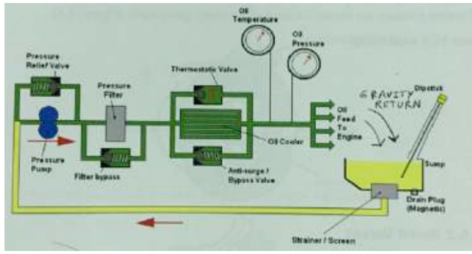
- **Optimal Viscosity** – High enough to lubricate but low enough to flow.
- **High Viscosity Index**
- **High Flash Point** – Temperature at which oil gives off flammable vapours.
- **Low carbon forming tendancies**.

LUBRICATION METHODS

- Pressure
- Splash
- Combination

WET SUMP SYSTEM

- All of the oil is carried in a sump within the crankcase.
- Drawn from sump by a **suction filter**.
- A **thermostatic valve** decides whether oil needs cooling by the **oil cooler.**
- Utilises a **gravity return** system.
- High oil temp means viscosity is too low and the lubricating layer is too thin.
- Cooler located after pump but before oil passes through the engine.



ENGINES 11 – LUBRICATION AND COOLING

OIL PRESSURE ON STARTUP

- Must register within **30 seconds**
- **Initially high** (Low temp --> high viscosity)
  - AKA Coring
- Less dissipation of heat causes a rise in temperature so you could get a high pressure and temperature reading temporarily.

WET SUMP DISADVANTAGES

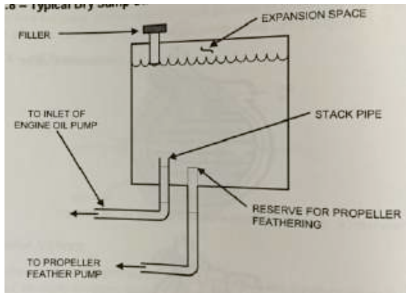
- **Limited amount of oil**
- **High oil temperatures and shorter oil life**
- **Not suited for radial and aerobatic a/c**
- Is simple and cheap however.

DRY SUMP (4 PUMPS)

- **OPP (Oil Pressure Pump)**
  - Draws oil from sump
- **OSP (Oil Scavenge Pump)**
  - Located in supply line
  - Capacity = OPP x3
  - Supply oil has larger volume as it aerates (mixes with air) and froths.
- **Governor Pump**
  - Engine lubricating oil used to change pitch of CSP.
- **Feathering Pump**
  - Electrically driven
  - Used to feather prop when engine fails
  - An accumulator can be installed to auto-feather

DRY SUMP TANK

- **Vent Fitted**
  - Prevents excessive pressure building
- **Air Expansion Space** required
  - Allows for expansion and foaming
  - Allows air to be separated from oil (due to aeration)
- **Tank Never Full**
  - There will always some oil in the engine.
- **Feathering Oil**
  - 'Protected' from the main outlet to ensure there is always an emergency supply.



RELIEF VALVE

- Since the pump is engine driven, a constant flow of oil is output.
- A relief valve is located after the OPP and return oil to pump inlet if pressure too high.

OIL PRESSURE GAUGE

- Reads the pressure of oil on the outlet side of the pressure pump.

OIL COOLER

- Between OSP and tank.
- Thermostatic valve decides whether oil needs cooling before returning to tank.
- Oil temp sensor is located **after the cooler**

OIL FILTER

- Between OPP and engine.
- Removes contaminants.
- Bypass valve required to ensure a continuous flow if filter becomes blocked.

MAGNETIC DRAIN PLUGS

- Fitted to tank to pickup ferrous particles.
- Warn of impending mechanical failure.
- Inspected manually after landing.
- **Chip detector** can be installed to provide cockpit indication.

- **Spectrometric Oil Analysis Program** can also be used where sample is sent to lab.

CHT GAUGE

- Measures temperate of the hottest cylinder

COOLANT MIXTURE

- 70% water, 30% ethylene glycol

ENGINES 11 – LUBRICATION AND COOLING

MALFUNCTIONS

- **Fluctuating Oil Pressure**
  - Oil level too low (pump drawing air)
- **Low Oil Pressure**
  - Leak / Block
  - Faulty PRVs
- **High Oil Pressure**
  - Aeration
  - Faulty PRVs
- **Low Oil Temperature**
  - Expected on start
- **High Oil Temperature**
  - Bearing friction
  - Low oil supply
  - Gauge malfunction if no change in oil pressure
- **Low Oil Pressure + High Oil Temperature**
  - Oil Leakage
  - Land ASAP

OIL PRESSURE & TEMPERATURE

- Low Oil Temp = More Viscous = Higher Pressure
- High Oil Temp = Less Viscous = Lower Pressure

OIL LEVEL CHECK

- **Wet Sump –** 15 to 20 mins after shutdown
- **Dry Sump** – Check immediately after flight

COOLING

- **High CHTs must be avoided**
  - Risk of detonation
  - Reduction in VE (weight of air less)
  - Risk of vapour lock (radiation causes vaporisation before carburetor)
- Piston engines can be **air** or **liquid** cooled.

CYLINDER FINS

- Provide cooling by using **ram air**
- **Baffle plates** surround fins to increase velocity of ram air, **improving cooling.**
- **Increase the cylinder and head surface areas.**

COWL FLAPS

- Control airflow through the engine, thus helping to control the CHTs.
- **Open for max cooling** during start-up / idle / takeoff / climb
- **Partially closed** during cruise
- **Closed** during descent

THERMOCOUPLE

- Used to measure CHTs
- The voltage induced is proportional to the temperature difference between the two ends.
- **Gasket used at spark plug**

ACTIONS ON HIGH CHT

- Reduce power and level off
- Increase speed if possible (more airflow)
- Set mixture fully rich
- Open cowl flaps
- Carb OFF

PRO'S & CONS OF AIR COOLING

- **Advantages**
  - Lighter
  - No risk of leakage
- **Disadvantages**
  - Uneven cooling of cylinders
  - Cooling aids required
  - Thermal Shock

ICE ACCRETION & EGT

- **Float Type**
  - Less Air => Richer Mixture
  - EGT Decreases
- **Fuel Injection**
  - Poppet Closes => Leaner Mixture
  - EGT Increases

HIGH CHT

- **Inadequate cooling**
- **Poor baffle plate installation**
- **Improper ignition timing**
- **Wrong fuel grade (detonation)**

ENGINES 11 – LUBRICATION AND COOLING

LIQUID COOLING

- Cylinders and cylinder areas have a double jacket and **coolant circulates under pressure within the jacket.**
- **Components Required:**
  - Coolant Reservoir
  - Pump
  - Radiator (Cooler)
  - Hoses
- A **fan** can also be installed to provide aid in cooling on the ground when ram air is not present.

- **Advantages**
  - Uniform cooling
  - Second heat exchanged for use in cabin heat / window demisting
  - Consistent regulation of engine temps

- **Disadvantages**
  - More expensive
  - Heavier
  - More complex and require more mx
  - Leakage can lead to overheat

VAPOUR LOCK

- Higher Altitude = Lower Temperature = Fuel boils at lower temperature = Increased chance of vapour lock.

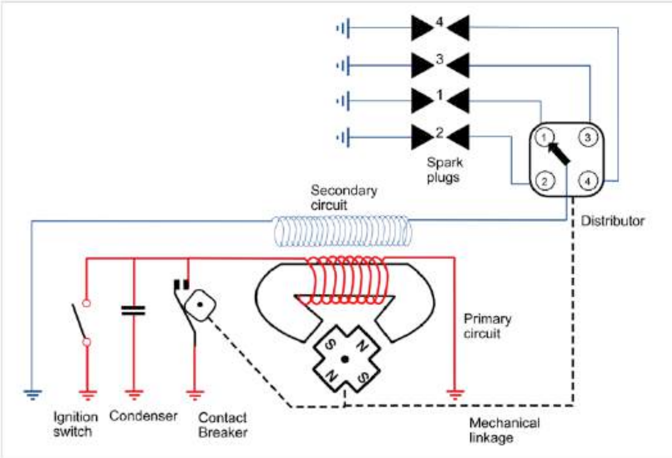
ENGINES 12 – IGNITION SYSTEM

BASICS

- Operate **independently of the aircraft electrical system once started.**
- It is a **high tension system**
- **Each engine has two magnetos.**
    - One magneto for upper spark plugs and one for the lower spark plugs.
- **A magneto is essentially a:**
    - Self-contained generator
    - Step-up transformer (Low volts in, high volts out)

MAGNETO OPERATION

- **Primary Winding –** Few turns of coil but thick wiring.
- **Secondary Winding –** Many turns of coil but very thin wiring.
- The **magnetic rotor, contact breaker** and **distributor** are all driven by the camshaft so rotate at ½ crankshaft speed.
- The **magnetic rotor** induces an EMF within the **primary winding.**
- When a spark is required, the **contact breaker opens** to breaks the primary circuit causing the magnetic field to rapidly collapse.
- The collapsing induces a **much higher EMF (low current) within the secondary winding** which is sent to the distributor.
- Distributor sends the secondary current to the spark plugs in the correct sequence.
- It is an **AC current** which is generated.



IGNITION SWITCH

- When OFF, the switch is closed and the primary current flows to earth (grounded)
- When ON, the switch is open and the primary current is allowed to flow via the contact breaker.
- If the ground wire is broken then a **live mag** can be present (ungrounded)
    - If a broken ground wire touches the engine / airframe body, it effectively grounds the magneto and turns off the MAG.

CAPACITOR / CONDENSER

- **Prevents arcing** between the points on the contact breaker by providing a path of least resistance to the current.
- **Enhances collapsing** of the magnetic field, thus intensifying the current in secondary winding.
- A **shorted capacitor** will not permit the engine to be started.

CONTACT BREAKER

- 4 Cylinders = 4 Points (Square)
- 6 Cylinders = 6 Points (Hexagon)

ADVNACED IGNITION

- Combustion takes place between advanced ignition and the point of highest pressure just after TDC (+10^0)
- In this region, volume is relatively constant so it is termed **'constant volume'** combustion.
- Spark normally occurs 30^0 before TDC.
    - Higher RPMs require a more advance ignition to be most efficient although in reality the timing is fixed.

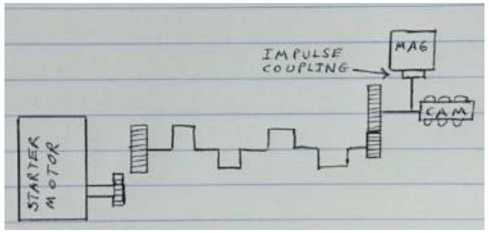
IMPULSE COUPLING

- **Ignition is retarded on start** due to the **very low RPMs.**
    - Also prevents kickback.
- A spring within an **impulse coupling** is wound up as the starter rotates the engine.
    - When released, an extra strong retarded spark is provided for start.
    - As engine rpm increases, flyweights close in due to centrifugal force and ignition operates normally

ENGINES 12 – IGNITION SYSTEM

STARTER MOTOR

- Used to turn the crank assembly on start.



DEAD CUT CHECKS

- Looking for a **drop but no stop** on each mag.
- Ensures there is control over the magnetos before doing the run up checks.
- Carried out at **low rpm**
  - Prevents too great a torque force if there is a failed mag and a pilot quickly reselects BOTH.

RUN UP CHECKS

- Typically carried out at **75% of max rpm.**
- Looking for a **fall on each mag within tolerances.**

SPARK PLUGS

- Categorised by temperature range they are expected to operate within.
- **Hot Plugs**
  - Smaller
  - Transfer very little heat to cylinder
  - Usually used on engines with low operating temperatures.
- **Cold Plugs**
  - Bigger
  - Transfer a lot of heat to cylinder
  - Usually used on engines with high operating temperatures

HIGH TENSION (HT) BOOSTER COIL

- Battery is used to **boost voltage within the primary winding**.
- When field collapses an even greater voltage occurs within secondary winding.
- Used on larger engines.

SWITCHING OFF MAG

- Grounding the primary circuit and therefore the secondary circuit.

DUAL IGNITION

- **Allows for reliability and improved combustion efficiency.**

STOPPING A LIVE MAG

- **Shut off fuel supply**

CARBON FORMATION

- **Excessive carbon formation in the cylinder head may cause the engine to fail to stop.**

ENGINES 13 – ENGINE INSTRUMENTS

MAP

- Pressure between throttle valve and inlet.
- Two capsules used, one sealed and other open to manifold pressure.
- As MAP increases, the density of the air the cylinder increases.
- Will always be less than ambient in a normally aspirated engine.
- **Prop level should always be ahead of throttle.**
  - Avoid a high MAP, low RPM situation as it will result in high cylinder pressures causing detonation.

EGT

- Used to make adjustments to **mixture ratio.**
  - Lean = Higher EGT
  - Rich = Lower EGT

INDUCTION SYSTEM TEMP GAUGE

- Yellow arc indicates icing most likely.
- Carb heat will bring it to green arc although continued application could lead to overheating.

FUEL FLOW GAUGES

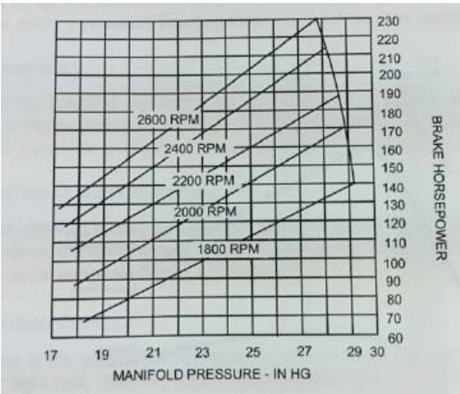
- Essential a pressure guage.
- Works on principle that pressure drop through a fixed orifice is proportional to the fuel flow through it.

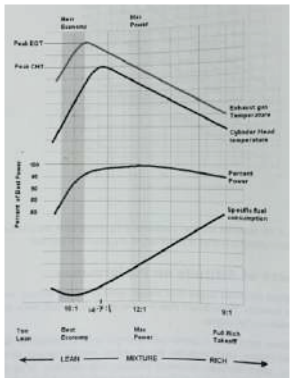
ENGINES 15 – ENGINE PERFORMANCE

RPM + MAP RELATIONSHIP

- **RPM + MAP = BHP (Power)**
- On a fixed pitch prop, the throttle controls both the amount of power and rpm.
- On a CSP:
  - Prop Level = RPM (Tachometer)
  - Throttle = MAP (MAP Gauge)

- **As RPM increases, MAP decreases**
  - Pistons suck more air
  - Greater suction results in lower pressure





FUEL / AIR RATIO

- **AKA Stochiometric Mixture**
- **Highest CHT occurs at chemically correct 14.7/1**
  - High risk of detonation at this temperature means we normally operate slightly lean or rich of 14.7
  - Assume highest EGT as well for EASA
- **Best Economy occurs at 16/1**
  - Lower risk of detonation
  - Best specific fuel consumption
- **Best Power occurs at 12/1**
  - Allows the most power to be obtained for any given throttle setting.

- Note operation **lean of peak EGT** results in a wide range of percent power.
  - Different CHTs due to unequal cooling in a horizontally opposed engine can result in uneven power outputs from each cylinder.

TAKEOFF & DETONATION

- Carb heat cold and rich mixture used to aid in cooling to prevent detonation.

TANK VENT BLOCKAGE

- Consider if engine stops shortly after starting.

MIXTURE USAGE

- If the mixture is not leaned as altitude increases:
  - Density of air entering the carburetor decreases
  - Fuel flow increases
  - Amount of fuel entering remains constant however

- In a NAE at a constant RPM, if the mixture is not leaned, as altitude increases:
  - Density of air entering the carburetor decreases
  - Amount of fuel entering decreases (since throttle would have been increased)

- Climbing requires leaning and descending requires richening.
- Caution when leaning to avoid high CHTs and EGTs
- The EGT gauge is used to assist with setting the mixture.
- High CHTs result from a lean mixture.
- Richness of the mixture is the real mixture ratio relative for the theoretical ratio.

SPARK PLUG FOULING

- Most likely during the climb with an excessively rich mixture.
- Can also occur due to prolonged running at low RPM (when on ground and in descent)

ENGINES 17 – POWER AUGMENTATION DEVICES

PURPOSE

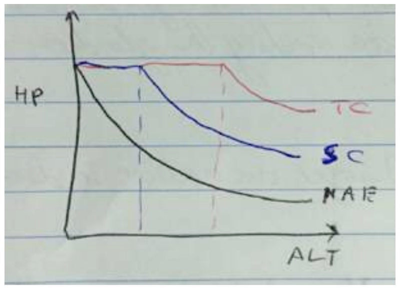
- **Prevent a power decrease** with changes in height, pressure, temperature and RH.
- **Artificially raises the MAP**

TYPES

- **Supercharger**
  - Internally driven by crankshaft
  - Compresses Mixture
  - Downstream of carburetor
- **Turbocharger**
  - Externally driven by exhaust gas
  - Compresses Air
  - Upstream of carburetor

OUTPUTS

- The supercharger is limited by engine rpm.
- Turbocharger provides augmentation to a greater altitude.

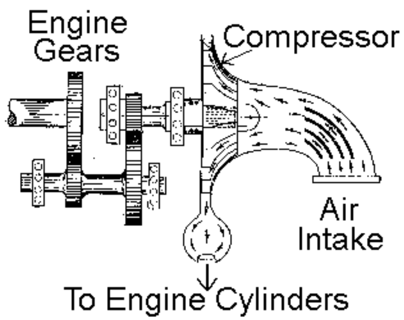


COMPRESSION RATIO

- **A lower CR** is required when engine is fitted with a power augmentation device.
- **Prevents engine damage**

SUPERCHARGER OPERATION

- Crankshaft is used to drive a centrifugal / radial compressor.
- The compressor draws air in and is **accelerated radially.**
- **Air enters at the eye of the impeller and leaves it almost at a tangent to the periphery.**
- **A diffuser with a divergent passage** causes pressure to increase as it leaves the diffuser.

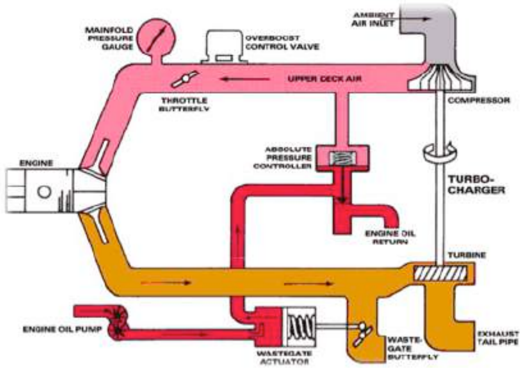


GEARING (SUPERCHARGER)

- Low gearing at low altitude
- High gearing at high altitude.

TURBOCHARGER OPERATION

- **Waste gate** is used to divert exhaust gas over a **turbine.**
- **Fitted in parallel with the turbine.**
- Turbine rpm is increased with more exhaust gas which in turn drives a compressor on a common shaft.
- The waste gate is controlled by a **density controller and evacuated bellow**.
  - Open at low ALT
  - Close at high ALT (more deflection)



VALVE TIMING (TURBOCHARGER)

- **Increased back pressure** requires valve timing be altered.
- Longer overlap required to help improve scavenging.

ENGINE TYPE

- Both types of augmentation are used on **fuel injected** engines (direct / indirect)

ENGINES 17 – POWER AUGMENTATION DEVICES

INTERCOOLER (TURBOCHARGER)

- The divergent passage creates a rise in temperature.
- On high performance engines, air must be cooled before entering the carburetor.
- Intercooler fitted.
- Prevents detonation.
- Not required on supercharger as mixture is already cooled from evaporation (fitted downstream of carburetor)

TURBO LAG (TURBOCHARGER)

- When throttle is changed, there is a lag before the exhaust system effects the turbine.

BOOST INDICATOR

- Centred on zero and indicates right if MAP is above seal level pressure and left if below.
- Alterative display of the MAP gauge.
- Either can be used to prevent over boosting of the engine.

SUPERCHARGED VS NAE AT MSL

- Power is required to drive the impeller (compressor blades) so power output is slightly less than a NAE at sea level.

ADVANTAGES OF BOTH SYSTEMS

- Higher takeoff mass possible
- Shorter runway operation
- Flying at higher altitude possible

TURBOCHARGERS = MORE EFFICIENT

- Harness exhaust energy
- Deliver more oxygen to engine
- Lower fuel flow at higher altitude
- Climbing higher is possible

PART THROTTLE

- Part throttle must be used on both types for takeoff at sea level to prevent overboosting.
- Newer engines automatically adjust for this.

WASTE GATE SEIZURE

- MAP will decrease as you near the critical altitude.

EXHAUST BACK PRESSURE

- Climbing with constant MAP, RPM and mixture settings will cause power output to increase due to reduced EBP.
- The air density behind the throttle valve will increase in this instance.
    - MAP constant => Pressure constant
    - Temp decreases => Density Increases

RATED POWER

- **Maximum power at which continuous operation is permitted.**

FUL THROTTLE HEIGHT

- At a given rpm, the altitude up to which a given MAP can be maintained.

RATED / CRITICAL ALTITUDE

- Full throttle height for a rated MAP and it's associated RPM.
- Therefore the height at which max power is produced.

RATED ALTITUDE

- Full throttle height for a rated MAP and it's associated RPM.
- Therefore the height at which max power is produced.

TAKEOFF POWER

- Max allowable power for takeoff.
- Time, rpm and temperature limited.

CRITICIAL RPM

- An RPM range in which severe vibration can occur.

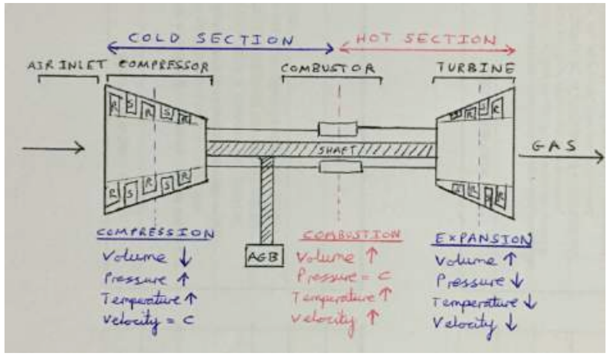
ENGINES 17 – POWER AUGMENTATION DEVICES

BEST POWER CONDITIONS

- Cold
- Dry Air
- High Pressure

ENGINES 1 – GAS TURBINE ENGINES

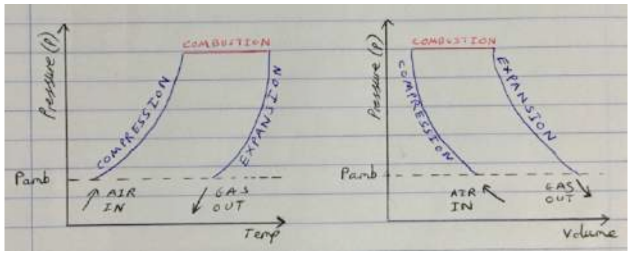
BASIC CONSTRUCTION



BASIC OPERATION

- By expelling air rearwards, an equal and opposite reaction forward will occur.
- $F = m \times (V_{EXIT} - V_{ENTRANCE})$

BRAYTON CYCLE



COMPRESSOR TYPES

- Compressor and turbine are **axial types.**

Piston Engine	Gas Turbine
Intermittent	Continuous
Constant Volume	Constant Pressure

TURBINE TYPES

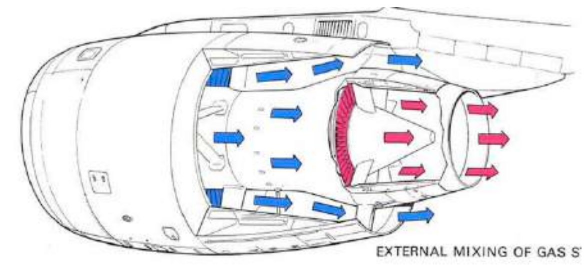
- **Thrust Producing**
    - Turbo Jet
    - Turbo Fan
- **Torque Producing** (Connected to gearbox)
    - Turbo Prop
    - Turbo Shaft

TURBO PROP / TRUBO SHAFT

- Can be **direct drive** or **free turbine** type.
- Direct drive is where a common shaft drives the compressor, turbine and propeller.
- Most commonly however, the **free turbine design is used:**
    - An additional turbine, not connected to any compressor is installed.
    - This drives a reduction gearbox which is used to turn the propeller.
    - More power can then be delivered to the prop as it is not lost as kinetic energy whilst driving the compressor.

BYPASS RATIO (BPR)

- On a **turbo fan,** an **aerodynamic splitter** divides incoming air into a hot stream and a cold stream.
- The **cold stream** does not take part in combustion but accounts for approx 85% thrust.
- The **hot stream** is used for combustion as accounts for about 15% thrust.
- So, it can be seen the majority of thrust comes from accelerating air. The combustion is merely used to drive the turbine and hence the compressors required to accelerate the air.
- **BPR = Cold Stream / Hot Stream**
- **A low BPR would be 2:1** (For every 1 kg passing through combustion chamber, 2 kgs passes around the combustion chamber.
- **A high BPR would be 10:1**



ENGINES 1 – GAS TURBINE ENGINES

PSUEDO - BYPASS RATIO

- A turbo-jet can be considered to have zero BPR since all the air is used in the combustion process.
- A turbo-prop / turbo-shaft can be considered to have an almost 100:1 BPR since none of the air that passes through the combustion chamber provides thrust.
- This is just a comparison however. In reality, these types do not rely on the BPR principle like a turbo-fan does.

HOT STREAM DIVISION

- The hot stream is further divided.
- Approximately **25% used for combustion**
- Approximately **75% used for cooling**

TURBO JET VS TURBO FAN

- **A Turbo Jet** takes a small massflow and imparts a large acceleration.
- **A Turbo Fan** takes a large massflow and imparts a small acceleration.
- Due to the high fuel consumption and noise generated by turbojets, they are no longer in use.

PROPULSIVE EFFICIENCY

- At low airspeeds, the turbo-prop is most efficient.
- At high airspeeds, the turbo-jet is most efficient.
- In the **mid-speed range** where most transport aircraft operate, the **by-pass engine is most efficient.**
- It can be either of the low BPR type (usually used by military aircraft) or the high BPR type (used by commercial aircraft)
- Note that the turbo-prop has a **limited efficiency** whilst the other types do not.

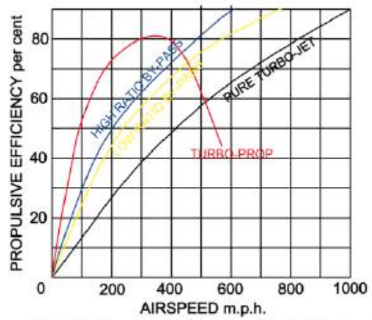


Figure 13.12 The Propulsive Efficiencies of Gas Turbine Engines

SPOOLS

- Describes the **number of shafts** present.
- Each shaft will have its own compressor and turbine.
- They **operate separately** so each has it's own RPM designated by N1, N2, N3 etc.
- More spools provide a **higher compression ratio** thus reducing fuel consumption.

- **N_1 = Low Spool = Fan + LPC + LPT**
- **N_2 = High Spool = HPC + HPT**

ENGINE STATIONS

$P_0 T_0$ = Ambient
$P_1 T_1$ = Inlet
$P_2 T_2$ = L.P.. Compressor Delivery
$P_3 T_3$ = H.P. Compressor Delivery
$P_4 T_4$ = Turbine Entry
$P_5 T_5$ = H.P. Turbine Exit
$P_6 T_6$ = L.P. Turbine Exit
$P_7 T_7$ = Exhaust
$P_8 T_8$ = Propelling Nozzle
N_1 = L.P. Compressor / Turbine
N_2 = H.P. Compressor / Turbine

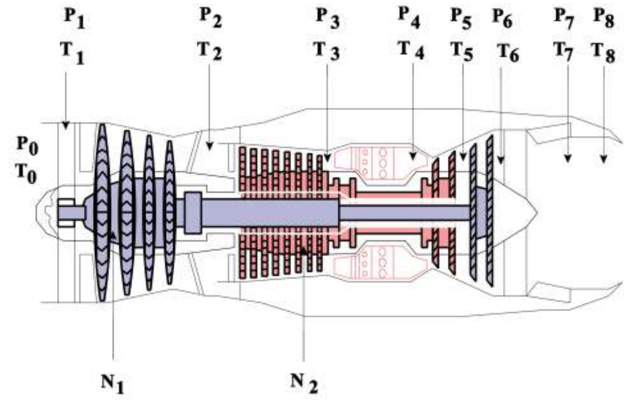


Figure 13.10 A Twin Spool Low Ratio By-Pass Turbo-Jet

TERMINOLOGY

- EPR (Engine Pressure Ratio): P_7 / P_2
- ITT (Intermediate Turbine Pressure): T_5
- TIT (Turbine Inlet Pressure): T_4
- CIT (Compressor Inlet Temp): T_2
- CDP (Compressor Discharge Pressure): P_3
- CPR (Compressor Pressure Ratio): P_3 / P_2
- IEPR (Integrated Engine Pressure Ratio)

ENGINES 1 – GAS TURBINE ENGINES

FAN

- The fan is used to accelerate the cold stream which produces 85% thrust.
- It is connected to the same shaft as the LPC and LPT.

THRUST SETTING PARAMETERS

- **EPR / IEPR / N_1** can be used as a thrust setting parameter.
- Primary indication varies depending on engine manufacturer.
- If one method fails then the other can be used instead. A single indicator failure is not a no-go item.

OAT INCREASE

- At a given rpm, if OAT increases the volume of air entering will remain constant but density of air will reduce.
- Mass flow therefore reduces.
- This is sensed by the CPR
- Computers will automatically adjust as required to ensure a constant mass flow.

GAS GENERATOR / CORE ENGINE

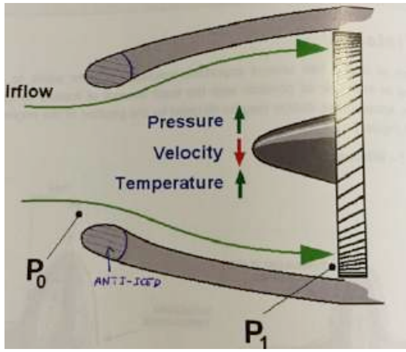
- Consists of the N_2 spool + combustion chamber

ENGINES 2 – ENGINE CONSTRUCTION

AIR INTAKE

CONSTRUCTION

- Forms part of the **aircraft structure** and is separate from the engine.

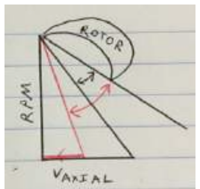


PURPOSE

- Provide **turbulent free air** which is evenly distributed to the face of the compressor.
- Must do this with **minimum drag.**

COMPRESSOR STALL

- Should airflow become turbulent in the intake, the axial velocity of air into the compressor will be reduced.
- If this reduction is too great, a high AoA can occur at the rotor blades and a **compressor stall** results.

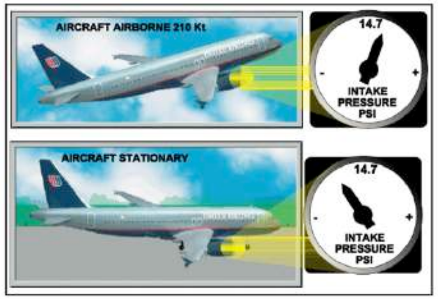


ANTI-ICE

- Fitted to the **leading edge lip** of the intake
- **Prevents turbulent airflow** from forming
- Can utilize hot air / electrical heating / hot exhaust as the method of anti-ice.

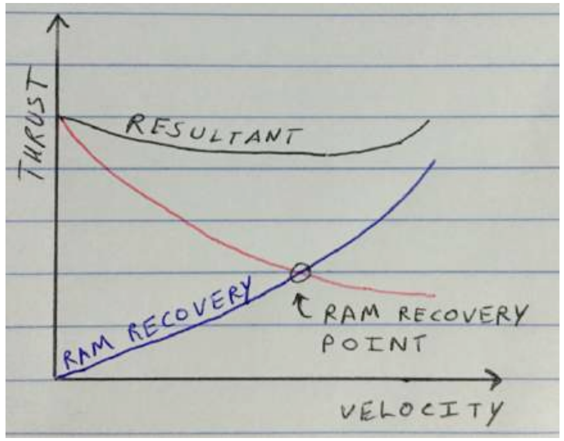
RAM RECOVERY

- A **subsonic intake is divergent**
- When stationary with engine running, there is a high velocity of air through the intake.
    - Ambient Pressure > Intake Pressure
- As the aircraft speed increases during flight, the **dynamic pressure increases** and eventually ambient pressure and intake pressure are equal.
- The point at which this occurs is known as **ram recovery.**
- As aircraft speed increases further, the increased pressure at the intake causes the compression ratio of the engine to increase.
    - More thrust is now produced without an increase in fuel flow.



RESULTANT THRUST VS VELOCITY

- Consider $F = m \times (V_{EXIT} - V_{ENTRANCE})$
- As the velocity increases, $\mathbf{V_{ENTRANCE}}$ **increases** thus producing less thrust.
- However, ram rise causes the **mass flow to increase.**
- The **net result** is that thrust is almost constant with changes in velocity.



BLOW IN DOORS

- At **low velocities and high thrust settings** they are opened to **increase mass flow of air.**
- They are spring loaded and when the pressure is sufficiently high within the intake they are forced to close due to the **pressure differential.**

ENGINES 3 – COMPRESSORS

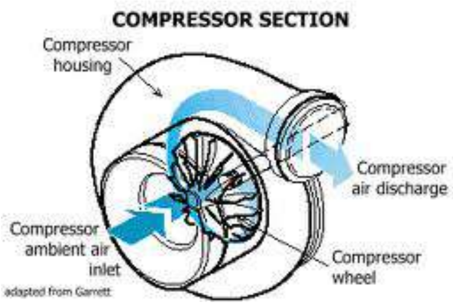
CENTRIFUGAL FLOW COMPRESSOR

INTRODUCTION

- AKA **Radial Flow Compressor**
- Used mainly for the following:
  - Turbo-prop
  - Air Cycle Machines
  - Turbo-Chargers

OPERATION

- Turbine is used to rotate the impeller at high speed.
- **Air enters via the eye of the impeller.**
- Air is then **accelerated radially** so it's velocity increases.
- The **impeller vanes are divergent** in order to **raise the pressure** of the air.
- Air leaves the impeller and enters a **divergent duct.**
- Here, the kinetic energy added to the air flow is now **converted into pressure energy.**
  - 50% of pressure rise occurs across impeller section and 50% in the diffuser section.
- **Rotating guide vanes** deliver air smoothly to the impeller.



ADVANTAGES

- Simple
- Robust
- Short Length
- Less prone to stalls and surges

DISADVANTAGES

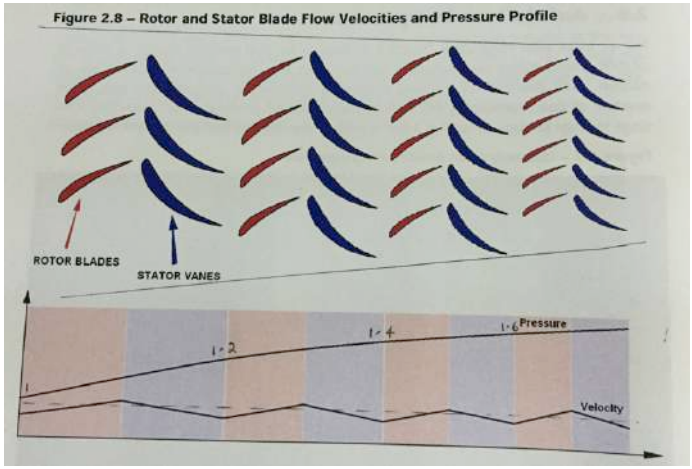
- Broad frontal area
- Low mass flow (cannot cope with high MF)
- Poor compression ratio
- High specific fuel consumption

AXIAL FLOW COMPRESSOR

OPERATION

- Multiple **stages**, each consisting of a **rotor then stator** are present.
- Rotors accelerate the air in the direction of rotation and **add kinetic energy** to the airflow.
- The divergent rotor blades result in a **pressure increase.**
- Air is passed to stators which are slightly more divergent than the rotors.
- Kinetic energy converted to pressure energy and temperature also increases.
- The stators are fixed however so there is a **decrease in velocity.**

- The net effect through each stage is that velocity stays virtually constant and pressure increases.
  - <u>10 – 20% pressure rise</u> through each stage
  - <u>25^0C temperature rise</u> through each stage



CONVERGENT DUCT

- Since pressure is lower at the inlet compared with inside the compressor due to rise in pressure, there is a tendency for airflow to want to reverse direction (flow from high to low).
- Convergent duct **maintains the axial velocity.**
- The slightly reduction in pressure that results from this is more than offset by the rise through each stage.

- So, **rotors and stators are divergent but the duct is convergent.**

INLET GUIDE VANES

- Direct airflow onto the first set of rotor blades.

ADVANTAGES

- Small frontal area
- High mass flow
- High CPR + Low SFC

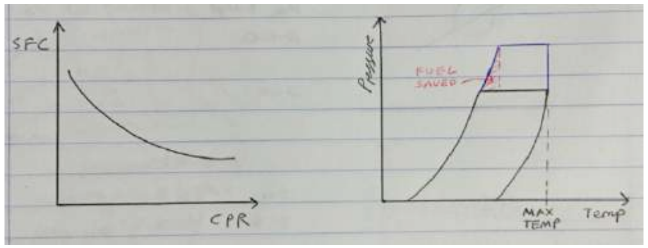
ENGINES 3 – COMPRESSORS

DISADVANTAGES

- Expensive and complex
- Prone to stalls and surges
- Easily damaged

SFC VS CPR

- The higher compression ratios offered by the axial compressor results in a **lower specific fuel consumption.**
- This is because **less fuel is required** at the combustion stage assuming the temperature is not increased.
- Since only a small pressure rise occurs across each stage, **more stages and multiple spools allow for higher CPRs.**



BLADE TIP CLEARANCE CONTROL

- **Abradable seals** are located between the rotor blades and the compressor casing.

- When blades are installed, **zero clearance** is provided.
- Engine is run and the rotor blades wear the seals so **minimal clearance is obtained.**

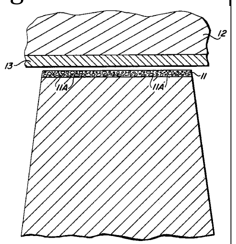


FIG. 1

ACTIVE CLEARANCE CONTROL

- Used on the LPT & HPT.
- **Prevent radial growth** of turbine casing due to increased temperatures.
- **Cooling air** is metered round the outside of the casing.

AXIAL / RADIAL FLOW COMPRESSOR

DESIGN

- Air passes through an **axial compressor before entering a radial compressor** which gives it a 'boost'
- Mainly used on **turbo-prop / turbo-shaft**

AXIAL AIRFLOW CONTROL

COMPRESSOR STALL

- Occurs when the **axial velocity is too low** resulting in a large angle of attack.
- A low velocity results when the **volume of air increases** as this effectively blocks the forward progress of the air.

LOW RPM

- Can give rise to **compressor stall.**
- CPR falls as RPM decreases.
- Volume increases as pressure decreases.
- Axial velocity decreases.

HIGH OAT

- Can give rise to **compressor stall.**
- **Poisson's Law** shows how an increase in ambient temperature causes the CPR to decrease:

$$\left(\frac{T_3}{T_2}\right)^{3.5} = \frac{P_3}{P_2}$$

- Volume increases as pressure decreases.
- Axial velocity decreases.

COMPRESSOR STALL CAUSES

- Operation below design RPM
- Excessive Fuel Flow (Slam Acceleration)
  - Too high temperature leading to volume increase.
- Turbulent Airflow
- Contaminated / Damaged compressor components
- Excessively Lean Mixture
  - Less fuel but RPM still high due to lag

ENGINES 2 – ENGINE CONSTRUCTION

STALL INDICATIONS

- Increase in EGT
- Increase in vibration level
- Erratic RPM
- Banging sound
- RPM loss
- Yawing of aircraft

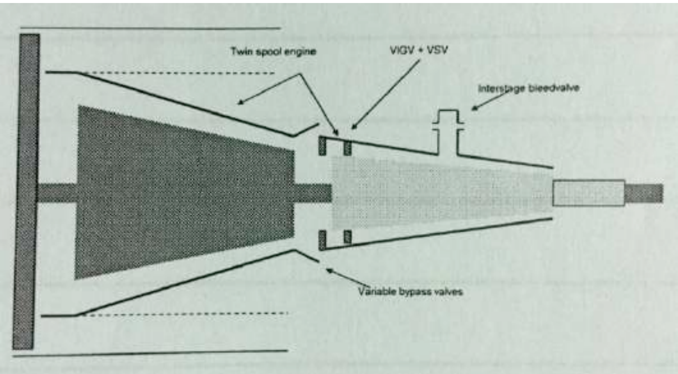
STALL VS SURGE

- **Stall limited to 2/3 stages.**
- **Surge** is a stall **across all stages.**
    - Produces flames in both inlet and exhaust.

STALL RECOVERY

- **Close throttle gradually** to restore RPM / axial velocity combination.
- Consider shutdown if problem persists.

PREVENTING STALL / SURGE



INTERSTAGE BLEED VALVES

- **Located within the HPC**
- At low rpm (on start) the pressure increase across the stages is too low and a high volume results.
- IBVs vent excess air to atmosphere.
- They are **open on start** and **close with increasing RPM.**

VARIABLE INLET GUIDE / STATOR VANES

- The **inlet guide vanes plus the first 5/6 stator vanes within the HPC are variable.**
- At **high OATs they can be closed** in order to decrease the volume, thus preventing the velocity decrease and associated stall.
- They are also **closed at low RPMs** to reduce the volume and a fully open at high RPMs.
    - Can also think of them being closed in order to maintain optimal AoA with decreasing velocity.

- Connected via a **unison ring**
- Controlled via an **actuator** with fuel as the hydraulic fluid.

VARIABLE BY-PASS VALVES

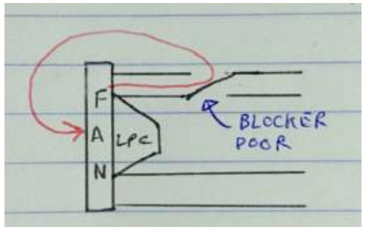
- **Fitted between the LPC and HPC**
- **Prevent stalls within the LPC**
- **Vent excess air to the cold stream**

- On start, the LPC takes a while to get up to speed so the pressure is low and volume high.
- **VBVs open on start** to prevent axial velocity decreasing and stalling the LPC.

VARIABLE BY-PASS VALVES

- During a deceleration, the **LP spool lags** behind the HP spool and remains at a higher RPM.
- **VBVs momentarily opened during deceleration.**

- **During thrust reverse, VBVs are fully open to prevent a re-ingestion stall.**
- Blocker Doors AKA **Cascade Vanes**



FLOW & POWER MATCHING (MUTLI-SPOOL)

- **Flow Matching –** HPC can cope with volume of air being delivered by the LPC.
- **Power Matching** – Power required by compressor is equal to power delivered by turbine.
- **Both are matched whenever RPM is stable**.

ENGINES 3 - COMPRESSORS

BLEED AIR EXTRACTION

- Taken from an **IP and HP stage of the HPC.**
- Results In
  - Reduced Thrust
  - Increased EGT
  - Increased SFC

DIFFUSER

- Located between the compressor and combustion chamber.
- **Decreases velocity** in order to prevent **flame extinction**.
- Further **increases pressure** of the airflow.
- Is **the point of highest pressure** within an engine.

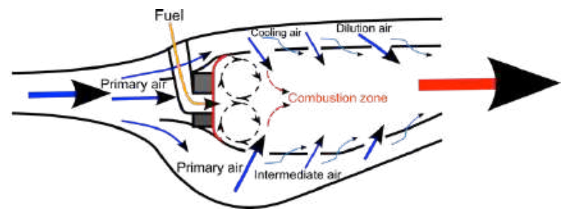
ENGINES 4 - COMBUSTION

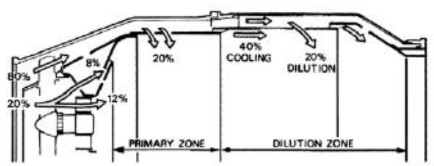
GAS BEHAVIOUR

- **Highest temperature** occurs during combustion.
- Takes place at an **almost constant pressure**
  - Ensures turbine receives an almost constant stream of gas.
  - Never increases pressure or this could cause compressor stall, thus damaging compressor as well as combustion chamber due high temp.

PRIMARY & SECONDARY AIRFLOW

- The hot stream is divided into a primary airflow and secondary airflow.
- The **primary airflow** is **20%** of the hot stream
  - Used for actual combustion
- The **secondary airflow** is **80%** of the hot stream.
  - Used to provide cooling (60%)
  - Used to stabilise the flame and keep it horizontal (20%)
  - Enters the combustion section via slots and holes in the liner.





SWIRL

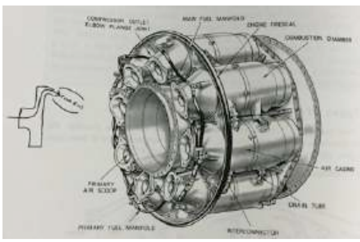
- **Swirl vanes** decrease velocity of air entering the chamber and impart a whirling motion to the air.
- **Swirl chamber** in fuel nozzle also imparts a whirling motion on fuel but in the opposite direction.
- **Improves mixing and combustion.**

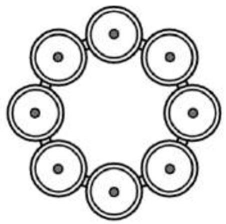
COMBUSTION CHAMBER TYPES

MULTIPLE CAN

- Used in **radial compressors**
- It is **angled to the diffuser**, thus resulting in **deflection losses.**

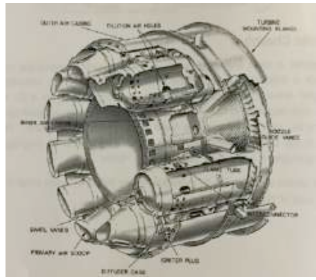
- Multiple cans are connected together with **interconnectors**.
- **One fuel nozzle in each can.**
  - Thermal shock can occur across turbine if fuel nozzels go u/s
- **Ignition** only present in **two cans.**
  - Ignition only used on start / TO & LND / anti-ice conditions.

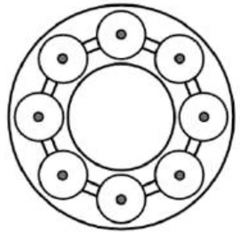




CAN-ANNULAR / TURBO-ANNULAR

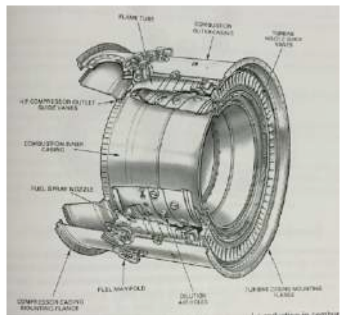
- Used in **axial flow compressors**
- Now **in line with compressor and diffuser** so no deflection losses.
- Cans are **closer together**
- Cans are surrounded by a **single outer casing**

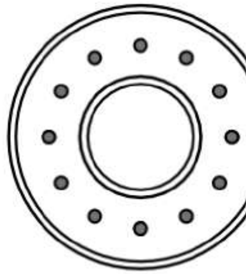




ANNULAR CHAMBER

- Main type in **axial flow compressors**
- Single flame tube
- **2 igniters** and **lots of fuel nozzels**
  - Prevents thermal shock
- Considerable **weight saving** and **less cooling air required.**

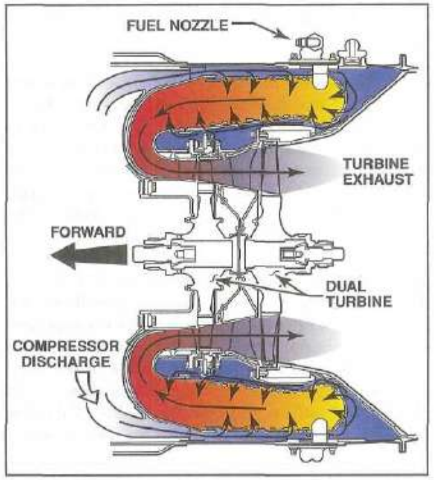




ENGINES 4 - COMBUSTION

REVERSE FLOW TYPE

- Used in **turbo-prop / turbo-shaft**
- Occupies a **very small space**
- **Lots of deflection losses**



OTHER

POWER CHANGES

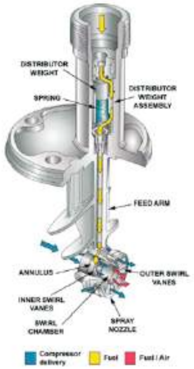
- Power changes are achieved by **altering the amount of fuel injected** into the combustion chamber.
- More fuel injected leads to increase in turbine rpm.
- Turbine rpm increase causes compressor rpm to increase and more air is accelerated.

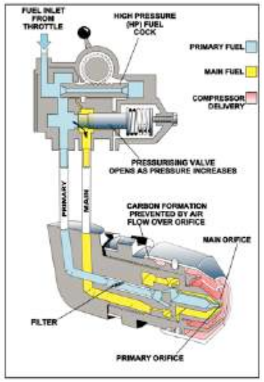
AIR / FUEL RATIO

- Within the primary combustion zone, a ratio of 15:1 must be ensured.
- The overall ratio within the combustion chamber can be as high as 130:1 however.

FUEL NOZZLE'S

- **Simplex** nozzles have a single delivery orifice.
  - Optimised for high fuel flows so provide poor atomization at low fuel flows.
- **Duplex** nozzles have a single delivery orifice.
  - A primary orifice (small opening) is used at lower pressures.
  - A main orifice is also used at high pressures.
- Annular chamber **has 2 simplex nozzles** near the igniters and the **rest of the duplex type.**





FUEL DRAINS

- Located at the lowest point within the chamber.
- Normally held shut by combustion pressure
- Automatically opens when compressor stops
- Take approx. 30 seconds to drain fuel

WET START

- EGT – No Increase
- Fuel Flow - Positive

- Suggests a failed igniter.
- Close HP fuel cock.
- Allow fuel drains to operate (30 seconds)
- Begin blow out procedure
  - Start without fuel and ignition
  - Allows compressors to blow out fuel within the engine.
- After 2 -3 minutes, attempt normal start on second igniter.

HOT START

- Occurs due to **excessive EGTs following a wet start** when fuel has not been drained sufficiently.

DRY START

- EGT – No Increase
- Fuel Flow – No Increase

- Suggests a closed HP cock
- Shut down and await mx action.

NET THRUST

Net Thrust = Gross Thrust – Ram Drag

ENGINES 5 - TURBINES

PURPOSE

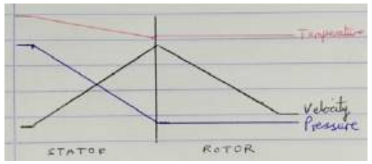
- Converts pressure and kinetic energy into mechanical energy for **driving the compressor.**
- In free turbine engines, a turbine is also used to **drive a reduction gearbox.**

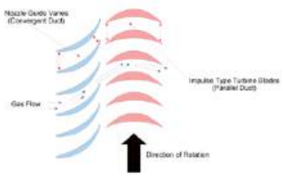
STATORS & ROTORS

- A turbine stage is a **stator followed by a rotor.**
- The **stator converts pressure to kinetic energy** and directs the airflow.
- The **rotor coverts kinetic to mechanical energy.**
- The **stators are fixed and not adjustable** like in the HPC.

IMPULSE / ACTION TYPE TURBINE

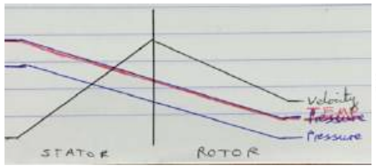
- **Stators = Convergent**
- **Rotors = Uniform**
- Used for turbine starter motors rather than the engine itself.
- Only **1 stage** is used.

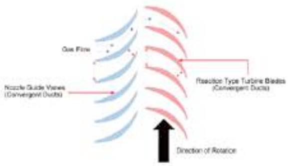




IMPULSE / REACTION TYPE TURBINE

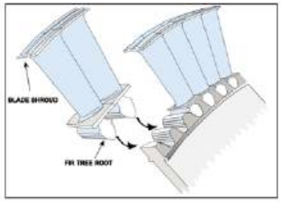
- **Stators = Convergent**
- **Rotors = Convergent**
- Rotor blades are now twisted from root-tip.
  - At the root they are of the impulse type
  - At the mid section they are 50% reaction
  - At the tip they are 100% reaction
- Due to the convergent rotors, there is a **less of a velocity drop** through the rotors.
- **Multiple stages** can be used.





ROTOR BLADE FITTING

- Fitted with a **loose fit** to prevent sonic fatigue.
- **Fir tree connection** used.
- **Blades are flexible** and change shape slightly due to the high velocities.
- **Shrouding** is used to **prevent tip looses.**

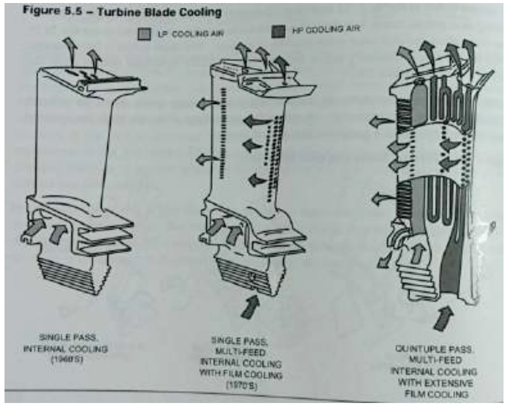


TURBINE BLADE COOLING (1st STAGE HPT)

- **Convection** – Air from the last stage of the HPC passes inside the blade from root to tip.
  - Last stage is used as the temperature is highest => prevents thermal shock.
- **Impingement** – Air passes through holes in the leading and trailing edges.
- **Film** – Air flows around edges of blade.

- **Thermal Barrier Coating** – Used to increase the resistance of the turbine blade to the high temperatures.

- These methods allow blades to operate in temperatures **exceeding their melting point** since the hot air is prevented from contacting the blade surface by film cooling etc.



TURBINE BLADE COOLING (REST OF HPT)

- Since the temperature is much lower in the subsequent stages of the HPT, **only convection cooling is utilised.**
- Air is now **extracted from an earlier stage** within the HPC.

ENGINES 5 - TURBINES

ACTIVE CLEARANCE CONTROL

- Turbine casing will expand quicker than the blades due to different materials.
- **Cooling the turbine casing** prevents pressure looses when clearance becomes too great.
- Ultimately **improves SFC.**
- **Not utilised to full extent on start / shut-down** to prevent too rapid shrinking.

DIVERGING ANNULUS

- Larger blades requires at the aft stages to obtain maximum mechanical energy from the decreasing pressures.

MAX TEMPERATURE

- The maximum temperature the turbine can handle is what **determines the thrust limit of the engine.**
- Temperature is measured by **thermocouples**

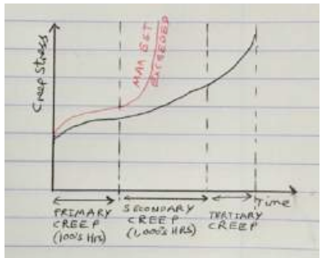
- On startup, internal cooling is not yet effective since pressure is not sufficient across the HPC.
- EGT must be carefully monitored on start.
- If EGT exceeds the limit, start should be **aborted and the recovery time noted.**
- FCOM consulted for next actions (restart / mx)

BLADE SPEED & TEMPERATURES

- High temperatures in the turbine **increase the local speed of sound.** It is therefore possible for the blades to rotate at speeds higher than 330 m/s but remain sub-sonic.
- Blade lengths are kept **as short as possible** to **reduce the rotational tip velocity.**

BLADE CREEP

- Creep is the **elongation of the blade beyond it's elastic limit.**
- This occurs due to the **high temperatures and centrifugal loads** they are subjected to.
- The blade is removed prior to the tertiary creep stage.
- Exceeding the max EGT causes the stresses to increase, considerably reducing the lifetime of the blades.



- **Abradable shroud** maintains optimum clearance as the blades elongate over time.

ENGINES 5 – EXHAUST SYSTEM

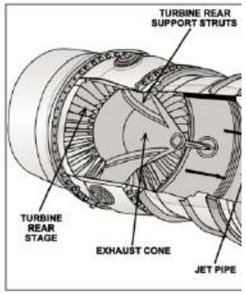
AIRCRAFT STRUCTURE

- The exhaust, like the air intake, forms part of the aircraft structure.

TURBO JET EXHAUST SYSTEM

EXHAUST CONE

- Exhaust cone + support struts + divergency between cone and casing **reduce turbulence and back-flow.**
- A hole on the exhaust cone allows air for bearing sealing to enter the exhaust.

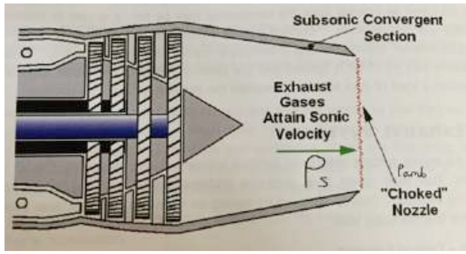


CONVERGENT EXHAUST NOZZLE

- **The exhaust nozzle is convergent to increase velocity** of the air.
- The highest velocity within the turbojet occurs at the **exhaust nozzle.**

CHOKED NOZZLE

- The air will attain **sonic velocity** but be unable to increase any further within a convergent duct
- In cruise conditions, when velocity is max, a **choked nozzle** will occur.
- This creates a build up of static pressure at the exhaust nozzle and the **pressure differential between exhaust and ambient is increased.**



- Total trust is a product of air acceleration, fuel acceleration and pressure thrust ($P_{SJ} - P_{amb}$)
- In the cruise, **pressure thrust** results from a choked nozzle and **increases the total thrust.**

NOISE

NOISE

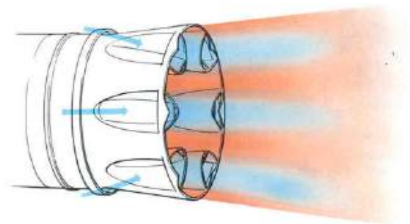
- The high velocity of exhaust air impacts ambient air and noise is generated.

IGV LOCATION

- IGVs were **moved from the LPC to the HPC** to reduce noise.

MIXING OF GAS STREAMS

- In bypass ratio engines, mixing the slow cold stream with the fast hot stream helps to slow the exhaust velocity and reduce noise.
- Internal mixing is better than external mixing as the mass flow is increased thus improving SFC.
- One method of internal mixing is via the use of a **corrugated exhaust.**



ENGINES 5 – EXHAUST SYSTEM

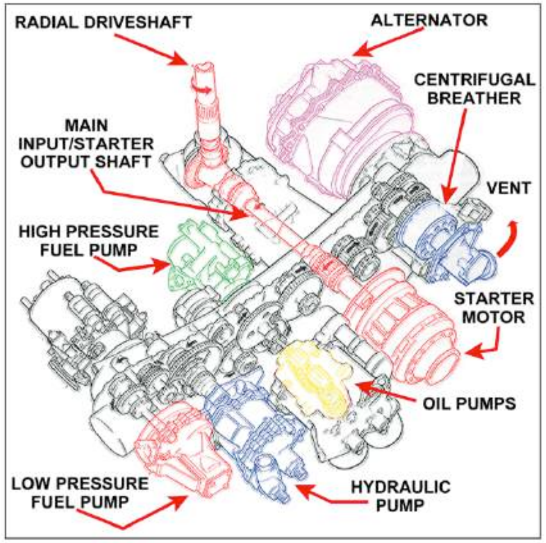
ACOUSTIC PANELS

- **Tiny holes** in the engine nacelles create **a film of air that acts a lubricant.**
- Air flowing through the engine does not contact the surface material, therefore reducing impact noise.

TURBO-FAN VS TURBO-JET NOISE

- Turbo-fan imparts a **small acceleration** to a larger mass of air thus reducing the exit velocity of air.
- Furthermore, the **kinetic energy extracted to drive the fan** is substantial and the exit velocity is further reduced.

ACCESSORY GEARBOX



PURPOSE

- Each engine has it's own AGB.
- The **AGB is driven by the HPC shaft** via an internal gearbox.
- Provides power for:
  - Hydraulic Pumps
  - Pneumatic Pumps (Roots Blower)
  - Electrical Generators
  - Fuel Pumps
  - Oil Pumps
  - Tachometers

STARTER MOTOR

- Starter motor is **connected to the AGB.**
- **APU is started via 28V DC**
- **Bleed air from APU** is provided to **impulse type turbine** within the starter motor.
- Turbine drives the HP spool for engine start.

ADDITIONAL AGB

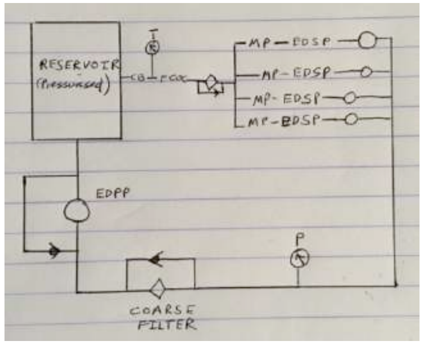
- A second AGB can also be powered from the IPC on some engines.

QUILL DRIVE

- Accessories are connected to the AGB via a quill drive to prevent failure of the whole AGB.

ENGINES 6 – OIL SYSTEM

OIL SYSTEM LAYOUT



- **EDPP –** Engine Driven Pressure Pump
- **EDSP –** Engine Driven Scavenge Pump
- **MP –** Magnetic Plug
- **FCOC –** Fuel Cooled Oil Cooler
- **CB –** Centrifugal Breather

OIL CONSUMPTION

- **Synthetic Oil is used in the system.**
- Oil consumption is lower in a gas turbine as oil does not enter the combustion chamber.
- Oil is used for lubrication only rather than sealing **(air does the sealing.)**

NOTES

EDSP > EDPP due to aeration.

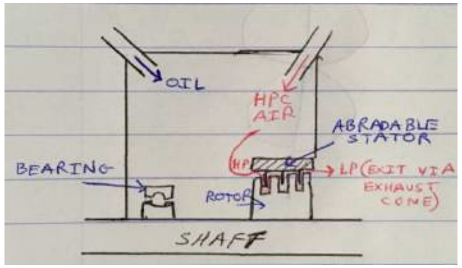
- **Centrifugal breather** extracts air from the oil that enters whilst in the bearing compartment. Air is dumped overboard.
- **Oil temp and oil pressure lights are connected** so both illuminate at the same time.

FILTRATION

- **Primary filtration** is the combined scavenge line which uses a fine filter.
- **Secondary filtration** is after the pressure pump and is a coarse filter.
  - Prevents blockage in case the fine filter is by-passed.

BEARING COMPARTMENTS

- Bearings are contained in bearing compartments.
- Compartment is sealed by air using a **labyrinth seal.**
- A **small leakage is permitted.**



CARBON SEALING

- Carbon seals can also be used where sealing is provided using a **pressure plate and springs.**
- **No leakage is allowed with this method.**

OIL GULPING

- It is usual for oil quantity indications to fluctuate.
- QTY will decrease with increasing RPM
- Low oil pressure can temporarily illuminate in transient accelerations / decelerations.

OIL MAKING

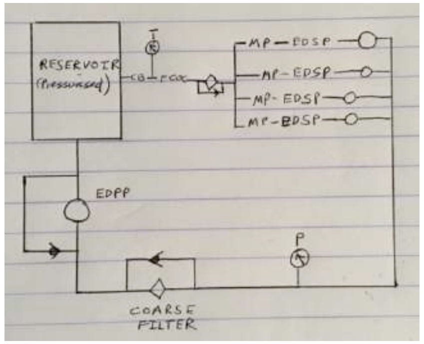
- An abnormally high oil QTY can be **indicative of a leak within the fuel / oil heat exchanger.**
- Fuel enters the oil return lines.

BEARING TYPES

- **Ball Bearing** = Radial + Axial Loads
- **Roller Bearing** = Radial Loads

ENGINES 6 – OIL SYSTEM

OIL SYSTEM LAYOUT



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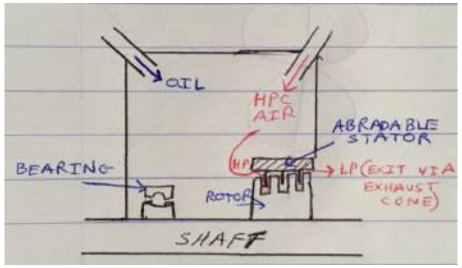

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ENGINES 7 – INTERNAL AIR SYSTEM

PURPOSE

- **Bleed Air (Customer Services)**
- **Internal Air Flows**
- **Turbine Blade Cooling**
- **Active Clearance Control**

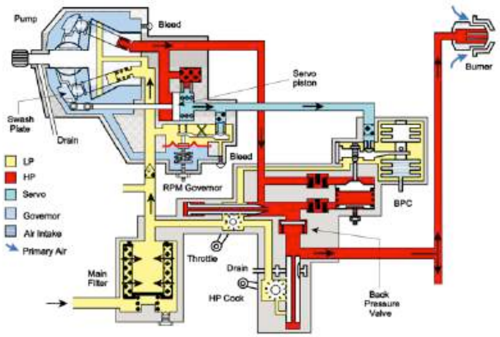
ENGINE OVERHEAT

- If the EGT drops when the throttle is retarded, an overheat is present.
- If the EGT remains high when the throttle is retarded, a fire is likely present.

ENGINES 8 & 9 – FUEL SYSTEM

HYDRO-MECHANICAL FUEL SYSTEM (FCU)

- The HP fuel pump output depends on **the speed of rotation and swash plate angle.**
- Swash plate angle depends on the **servo fuel pressure which is controlled via the FCU** (Fuel Control Unit)
- Fuel flow is measured downstream of the FCU and HP cock.
- Various devices within the FCU adjust the fuel flow for a given thrust setting in response to changes in:
    - CIT
    - Ambient Pressure
    - TAT
    - CDP
    - etc



ELECTRONIC ENGINE CONTROL SYSTEM (EEC)

- This is the next 'step up' from a purely hydro-mechanical system.
- A **supervisory EEC** uses a computer to receive the various inputs and commands the hydro-mechanical FCU as required.
- The biggest advantage of the supervisory EEC is **limit protection.**
- In the event of EEC failure, the pilot can revert to hydro-mechanical control at any time.

FADEC

FADEC

- FADEC = **Full Authority Digital Engine Control**
- This is the best and most modern system in use.
- The hydro-mechanical FCU is no longer required.

ENGINE CONTROL UNIT

- Within the FADEC system is an **ECU (Engine Control Unit).**
- **Two ECUs (A & B)** are installed for redundancy.
- In the event of both ECUs failing, the FADEC will revert to a **safe condition** where:
    - Fuel flow to minimum
    - VSVs fully open
    - Oil cooler wide open
    - Active Clearance Control Cut-Off

OPERATION

- **Position of throttle lever sets the desired EPR.**
- EPR is a measure of the mass flow through the engine and therefore the power produced.

- The FCU works out based on all it's inputs the **N1 Request.**
- This is the N1 speed required to obtain the desired EPR.

- The fuel flow is altered as required to achieve the N1 request and hence the set EPR (thrust setting)

N1 TARGET

- The FCU computes the **maximum thrust available at any one time.**
- This is known as the N1 Target.

PMA

- A **Permanent Magnetic Alternator** powers the FADEC system and is separate from main AC.

ENGINES 10 - STARTING

STARTING

TYPES OF STARTERS

- **Electrical** – EG/ APU
- **Starter / Generator** – EG/ 787
- **Air Turbine Starter** – Most Common

AIR TURBINE STARTER

- A source of **pneumatic air** is required to drive the turbine in the starter motor.
- The air can come from:
  - APU
  - GPU
  - Engine Cross Bleed

- The starter will disengage when the N2 RPM > Starter Motor RPM

IGNITION SELECTOR

- Igniters A & B are available for use.
- Normally, one is used for the outbound and the other for the return sector to minimise wear.
- An override is provided to allow for use of both igniters for in-flight restart or none in the case of a blow out procedure.

START SEQUENCE

- Ignition selected to either A / B
- Starter switch engaged to open starter valve
- **Starter amber light illuminates** (if not then shut down)
- At approx 15% N2 HP fuel cock is opened which also activates the igniters
- Time to light is observed
- Engine accelerates to self-sustaining RPM (approx. 35% N2)
- At approx. 45% N2, the starter and ignition are deactivated and the start light should go out.
- Starter and ignition selected to off once ground idle RPM is obtained.

START MALFUNCTIONS

MULTIPLE START ATTEMPTS

- Max of 3 start attempts usually allowed
- A cooling off period is required between each attempt to allow the starter to cool down.

WET START

- Fuel and no ignition
- Fuel flow but no EGT increase

DRY START

- Ignition but no fuel
- No fuel flow or EGT increase

HOT START

- When **max EGT is exceeded**
- **Common causes:**
  - Following a wet start
  - Low air pressure to air starter
  - Strong tailwind causing LPT and hence the LPC to rotate resulting in a disturbed airflow.
  - Early opening of the HP fuel cock

HUNG START

- **RPM stagnates below self-sustaining rpm with high EGT**
- Could develop into a hot start so **a shutdown is required.**

TORCHING

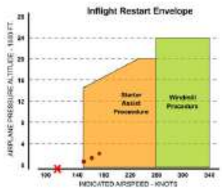
- **Excessive fuel burnt in jet pipe**
- Usually follows a wet start
- Start continued to burn off excess fuel

IN FLIGHT RESTART

- If airspeed is fast enough, windmilling RPM will be sufficient to start without the pneumatic starter.

- If too fast however flame extinction can occur.

- Relight envelope should be consulted.



ENGINES 11 – REVERSE THRUST

TURBO JET VS TURBO FAN

- **Turbo-Jet** deflects the hot exhaust gases
- **Turbo-fan** deflects the cold stream

DELFECTION

- It is not possible to fully reverse the airflow due to aerodynamic constraints **but typically a 45⁰ deflection is achieved.**
- Therefore, the **effective power in reverse thrust is proportionally less** than the power in forward thrust for the same throttle angle.

DEFLECTION METHODS

- **Clamshell**
  - Pneumatically operated
- **Bucket**
  - Pneumatically operated
- **Blocker Doors (Cold Stream Reverse)**
  - Actuated by an air motor

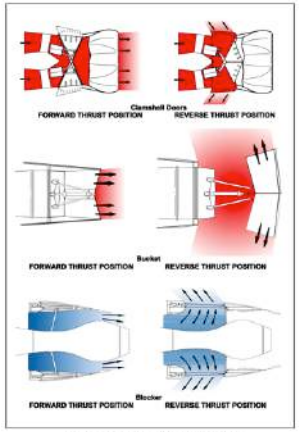


Figure 22.1 The Three Types of Reverse Thrust Systems

TURBO PROP

- Plane of Rotation 0^0 -> Flight Fine 18^0 = Taxi
- Flight Fine 18^0 -> Flight Coarse 45^0 = Flight RNG
- Reverse (-ve) -> Plane of Rotation 0^0 = Reverse

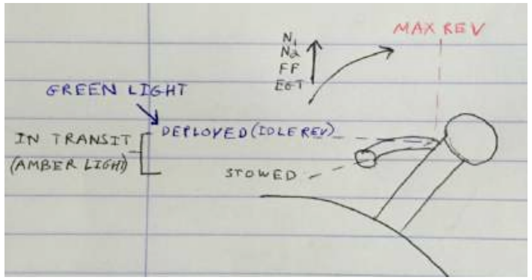
- **Flight Range = Alpha Range**
  - Prop acts as a CSP

- **Taxi + Reverse = Beta Range**
  - Prop acts as a variable pitch propellor

- Reverse (-ve) -> Plane of Rotation 0^0 = Reverse

JET ENGINE CONTROLS

- **Amber light shows whilst in transit** from stowed to deployed.
- **Green light** shows when blocker doors are deployed and reverse thrust is available.



ENGINES 12 – GAS TURBINE OPS

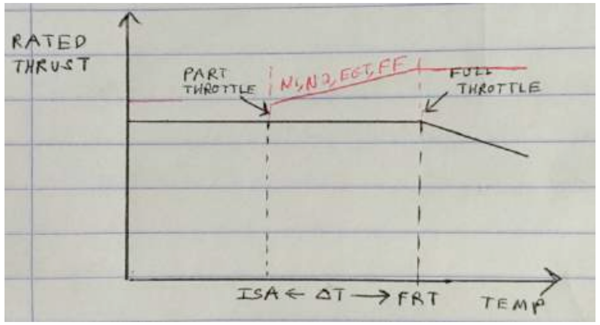
THRUST SETTINGS

- **Takeoff Thrust –** Max thrust from engine. Time (5 min), rpm and temperature limited to reduce blade creep.
- **Go-Around Thrust** – Normally slightly less than takeoff thrust but can be the same.
- **Max Continuous Thrus**t – Thrust setting can be used continuously.
- **Max Climb Thrust** – Max Cont. Thrust giving the best climb angle.
- **Max Cruise Thrust** – Less than Max Cont. Thrust to prolong engine life

FLAT RATED POWER

- Allows engines to achieve a constant performance in non standard temperatures.

- In ISA conditions, the power of the engine is 'held back'.
- With increasing temperatures, fuel flow gradually increases to maintain a constant rated thrust.
- Once the flat rated temperature is reached, EGT limitations prevent further increase in fuel flow and thrust decreases.



RPM INDICATIONS

- **N1 Spool is** measured at the **LPC** by means of a **pulse generator.**
- **N2 Spool** is measured at the **AGB** by a **tachogenerator** (also serves as PMA for FADEC).

ENGINE DISPLAYS

- **Primary –** EPR, N1 & EGT
- **Secondary** – N2, N3 & FF

TURBOPROP INDICATIONS

- N1 (LPC + LPT)
- N2 (Free Turbine => Prop)
- EGT
- Torque

VIBRATION INDICATIONS

- Measured in **mills** (1 mill = 0.001")

ENGINES 13 – PERFORMANCE

THRUST FORMULA

$$Net\ Thrust = m\left(V_j - V_i\right) + A_j\left(P_j - P_{amb}\right)$$

- m = Mass flow of air
- V_j = Exhaust gas velocity
- V_i = Inlet gas velocity
- A_j = Area of jet pipe
- P_j = Static pressure in jet nozzle
- P_{amb} = Ambient pressure

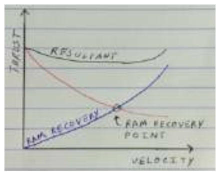
NET THRUST VS GROSS THRUST

- When stationary with max power, V_i is zero
  => $Gross\ Thrust = m\left(V_j\right) + A_j\left(P_j - P_{amb}\right)$

- When the aircraft begins to move, V_i begins to increase and thrust is reduced due to ram drag.
- Net Thrust = Gross Thrust – Ram Drag

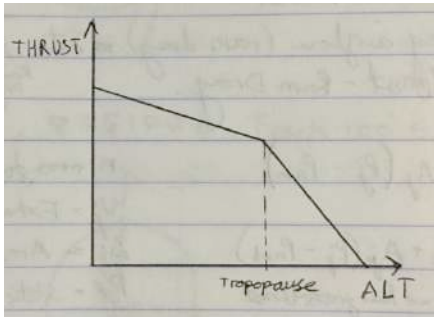
RESULTANT THRUST (VELOCITY INCREASE)

- **Ram Drag** causes net thrust to decrease due to the increase in V_i
- **Ram Rise** causes net thrust to increase due:
  - Increase in mass flow (m)
  - Increase in inlet pressure which with the same compression ratio causes P_j to increase as well.
- **Resultant** of the two shows that thrust remains nearly constant with increase in velocity.



THRUST & ALTITUDE

- Pressure decreases with increasing altitude, which causes density to decrease.
- Temperature decreases with increasing altitude which causes density to increase.
- Overall, density decreases as the pressure has a greater effect than temperature on density.
- Once above the tropopause, temperature is constant so no longer acts against density decreasing.



ENGINES 14 – APU

COMPRESSORS

- **Single Spool**
- **2 Centrifugal Compressors**
  - One used by the engine
  - One used for APU bleed

AC GENERATOR

- Since the APU runs at a constant RPM, **no CSU / IDG is required.**

VARYING LOADS

- Increased loads are catered for by the FCU increasing the fuel flow.
- With increased loads, RPM increases and VSVs are opened.

FIRE DETECTION SYSTEM

- Manning of flight deck not required whilst the APU is in operation.

- APU will auto shutdown in event of malfunction and can also automatically deploy fire extinguisher.
- Emergency shut off button installed on NLG

ENGINES 15 - PROPELLORS

PROP GOVERNOR

- The balance between the **speeder spring** (tension set by prop lever position) and the centrifugal force of the **flyweights** is used to govern propeller blade angle.
- **On Speed** = Equilibrium
- **Over Speed (**RPM too high)
  - Blade angle increased => more drag in POR and rpm decreased as required
- **Under Speed** (RPM too low)
  - Blade angle decreased => less drag in POR and rpm increased as required

DOUBLE ACTING PROPELLOR

- Used in **old systems**
- The natural tendency of the **centrifugal turning moment** is to decrease the blade angle.
- Oil pressure is delivered to both sides of the actuator.
- **Fine Pitch** achieved by:
  - Reduced oil pressure & CTM
- **Coarse Pitch** achieved by:
  - High oil pressure to overcome CTM

- The natural tendency of this system in an engine failure is to turn to fine pitch (due to CTM).
- An **electric feathering pump** ensures the CTM is overcome and the prop is set to the feathered position in event of engine failure.

SINGLE ACTING PROPELLOR

- Used in **new systems**
- The CTM is balanced by a **counterweight**
- Oil pressure only on one side of the actuator. The other side includes a spring.
- **Fine Pitch** achieved by:
  - High oil pressure (overcome spring & counterweight)
- **Coarse Pitch** achieved by:
  - Spring and counterweight

- The natural tendency of this system in an engine failure is to turn to coarse pitch as desired due to the spring force and counterweight.

FEATHERING SYSTEMS

- **Manual Feathering**
  - Used in-flight
  - Achieved by use of the prop lever
- **Auto Feathering**
  - Used for takeoff and landing
  - Single Acting – Dump valve opens and bleeds oil pressure when torque is sensed to be too low.
  - Double Acting – Electric feathering pump is energised

PITCH LOCK SOLENOID

- Prevents blade angle decreasing below flight fine pitch whilst in flight.
- When weight on wheels, a solenoid removes the lock and beta range is now available.

PROPELLOR BRAKE

- On aircraft with large propellers, they could rotate in the wrong direction when feathered.
- Prop brake holds it in a fixed position.

PROPELLOR SYNC

- Reduces **sonic fatigue** and enchances **pax comfort**
- The governor of the slave engine is trimmed to achieve the same rpm as the master engine.
- When difference is greater than 1%, system is deactivated to ensure slave does not follow master in event of engine failure.

SYNCROPHASING

- Further **refinement** once props are in sync by achieving the optimal **phase difference** between left and right propellors.

ENGINES 15 - PROPELLORS

REDUCTION GEARING

- Reduces drive speed to ensure the top of the prop does not exceed the **local speed of sound.**

TORQUE MEASUREMENTS

- **Electronic Measurement**
  - Twist of shaft is proportional to the torque produced by the engine.
- **Mechanical Measurement**
  - Small axial movement of reduction gearbox causes oil pressure to change and indicate torque.

- Torque measurements are used to feed the autofeather and autoignition system logic.

ENGINE INSTRUMENTS

PRESSURE SENSING

PRESSURE MEASUREMENT

- **Aneroid –** Low Pressure Measurements
  - Manifold Pressure
  - Fuel Booster Pump
  - Air Intake
- **Bellows –** Medium Pressure Measurements
- **Bourdon –** High Pressure Measurements

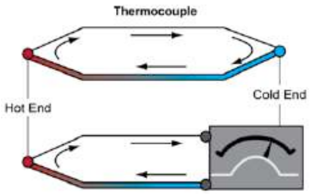
TEMPERATURE SENSING

BI-METALLIC THERMOMETER

- Based on the different **coefficient of expansion** between two materials.

THERMOCOUPLES

- Two **dissimilar metals** are joined together.
- There is a cold end and hot end.
- With a change in temperature at the **hot end**, an **EMF is induced**
- The EMF is measured at the **cold end** which stays at a **constant temperature.**
- **No power source** is required except for internal gauge lighting.
- **E = K x T**



RATIOMETER

- Based on the predictable change in the electrical **resistivity** of materials.
- Utilises a **wheatstone bridge** principle.
- Below 600^{0}C they provide better accuracy than thermocouples.
- Their main advantage is they are **independent of the supply voltage.**

FUEL QUANTITY SENSING

FLOAT TYPE

- **Simplest Design**
- Measures **volume**
- Requires **DC Power**
- Affected by **attitude, acceleration and temperature** however.
- Pressure does not affect volume since fuel is incompressible.

CAPACITANCE TYPE

- Measures **mass**
- Requires **AC Power**
- The capacitance of the **fuel and air** in the tank is measured.
- Fuel has a dielectric strength more than twice than that of air so the capacitance is proportional to the fuel level.
- **Temperate compensation** achieved by measuring **density**.
- **Capacitance = EA/D**
- Measured in **Farads**

FUEL FLOW MEASUREMENT

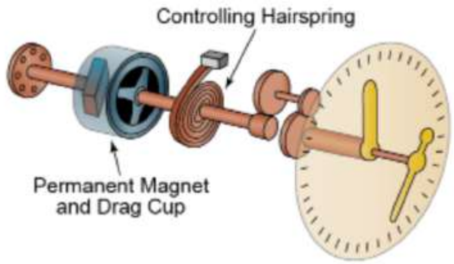
PADDLE WHEEL

- Paddle wheel is placed in the fuel flow and the number of impulses generated is measured.
- **Volumetric flow** is normally measured.
- **Mass flow** can be measured on more advance systems by taking **density** into account.

TACHOMETER

MECHANICAL TACHOMETER

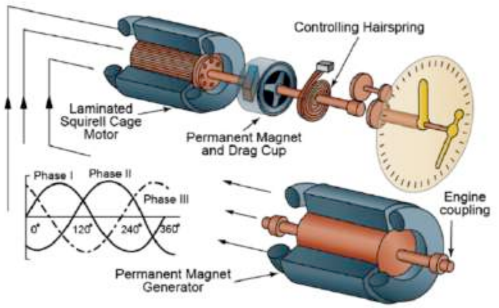
- On the end of the input shaft from the engine, **a permanent magnet** is housed within a **non-magnetic drag cup**.
- As the magnetic rotates, a magnetic torque causes the drag cup to rotate.
- Drag cup is connected to a flexible drive shaft that attached to the RPM indicator.
- **Compensation device** typically adjusts for variations in temperature.



ENGINE INSTRUMENTS

ELECTRICAL TACHO-GENERATOR

- Input shaft drives a **3 Phase AC Generator**
- **Frequency** of the AC current is proportional to the RPM.
- AC current is fed to an **AC motor** which turns a permanent magnet.
- Principle is now the same as the mechanical tachometer from this point onwards.



- Single phase AC can be used instead of 3 phase
- **DC** can also be used instead of AC
  - Simpler transmission of information
  - Spurious currents possible due to commutator installation

- **System Advantages**
  - Independent of aircraft electrical system
  - Independent of line resistance when 3 phase AC is used
  - Multiple indicators can be used in the same unit

ELECTRONIC IMPULSE COUNTING

- No connection to the input shaft
- A **phonic wheel / fan blade** rotates above a permanent **magnet sensor.**
- A magnetic flux is induced which generates **square pulse signals**.
- Frequency of signals is proportional to rpm
- **AC power supply required**

VIBRATION MONITORING

VIBRATION MONITORING

- Operates similar to an **accelerometer**
- A permanent magnet remains fixed and a coil is attached to the interior casing.
- Vibration of the coil induces an EMF
- Voltage is **amplified** then rectified to **filter unwanted frequencies**
- Indication is displayed in cockpit in the form of a **direct continuous readout**
- **Vibration amplitude at a given frequency** is indication.