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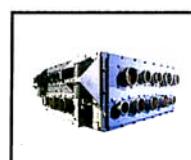
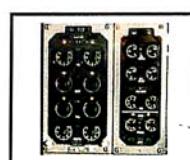
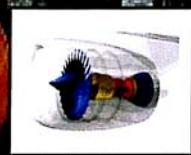
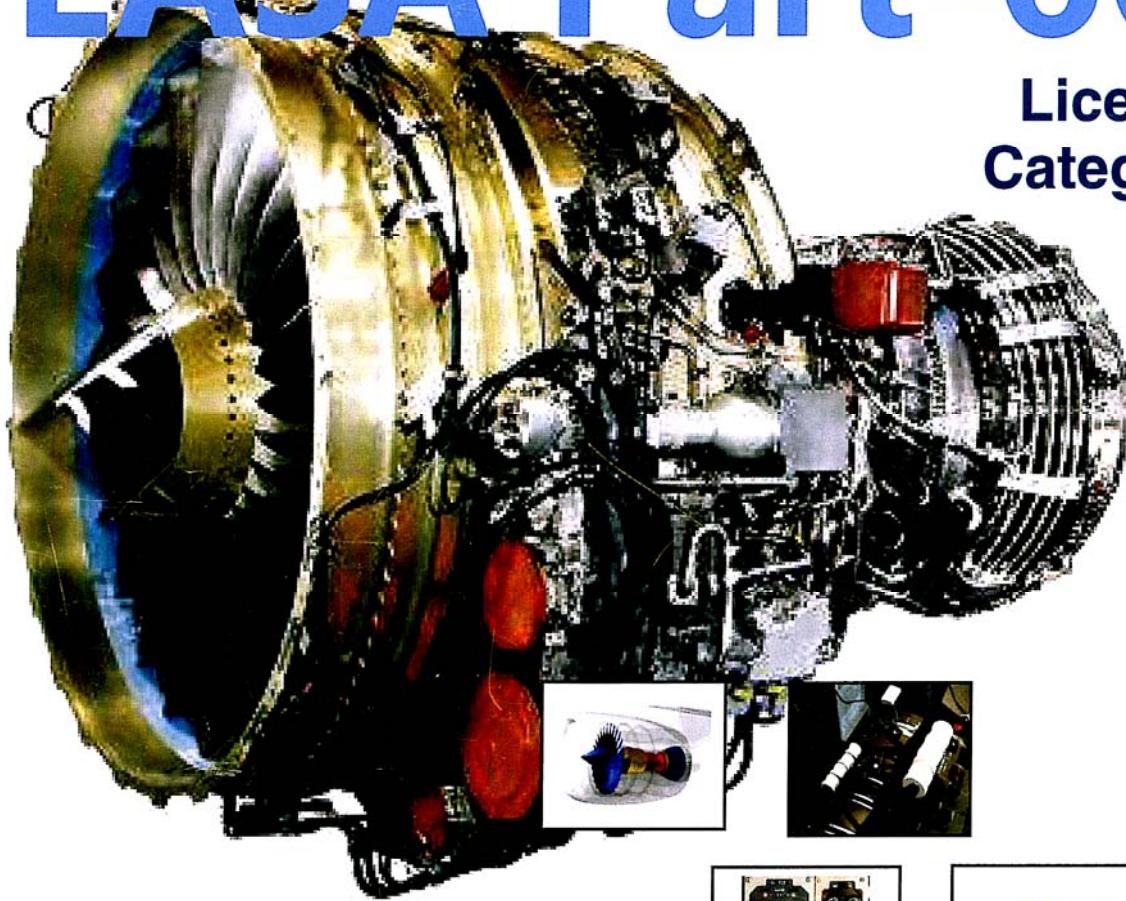
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Gas Turbine Engine

for

EASA Part-66

Licence
Category
B1



Volume 2



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Gas Turbine Engine

15.14 Engine Indication Systems

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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.14 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.14 - Engine Indicating Systems

Cockpit Displays

Analogue

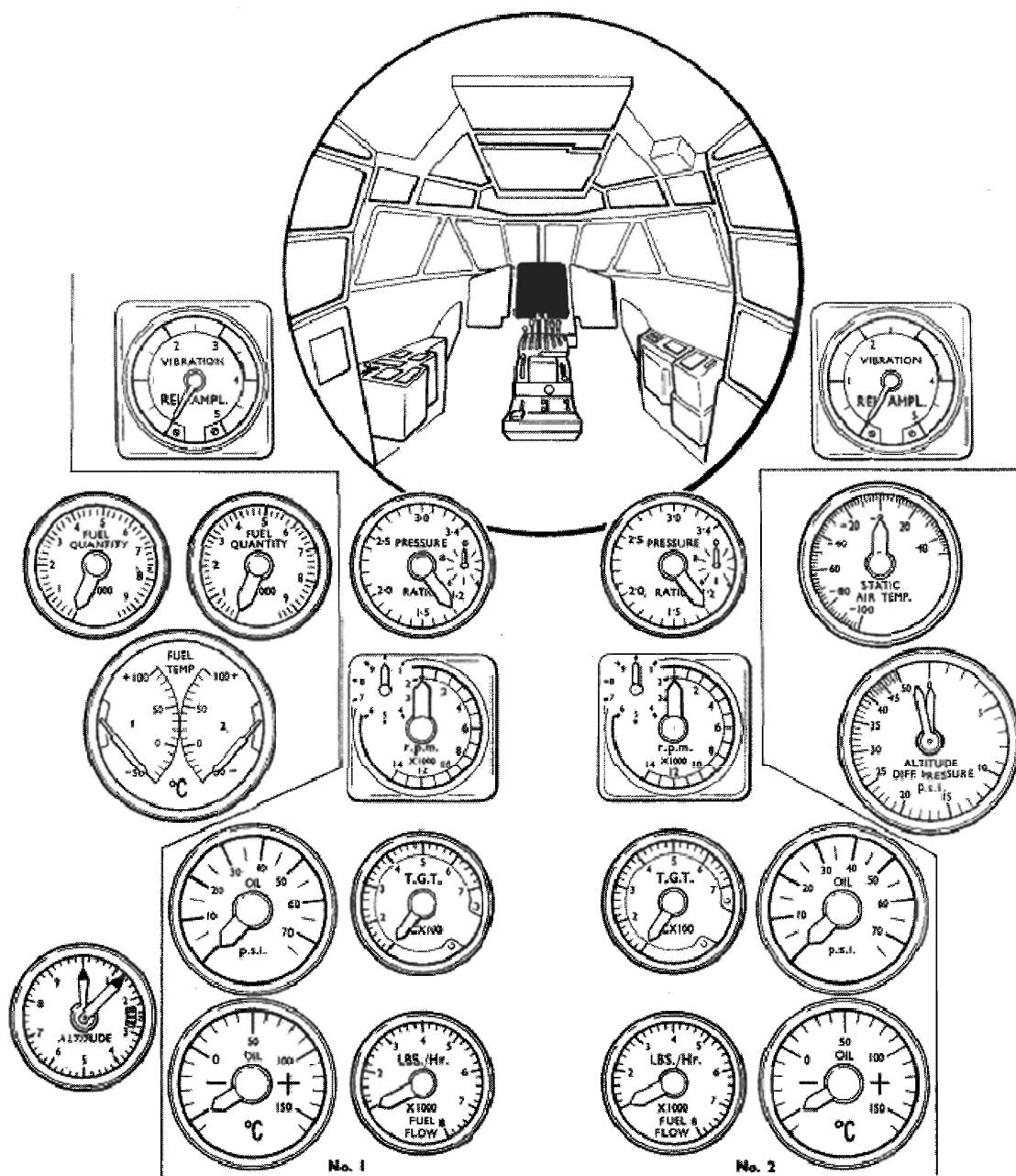


Figure 14.1: Analogue engine indication



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Figure 14.2: Analogue engine instruments (B737)

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Electronic Indicating System

Display of engine performance and condition parameters has changed dramatically in terms of presentation, with the advent of the glass cockpit. Instead of individual analogue dials the flight deck display is now show digitally on flat screen displays.

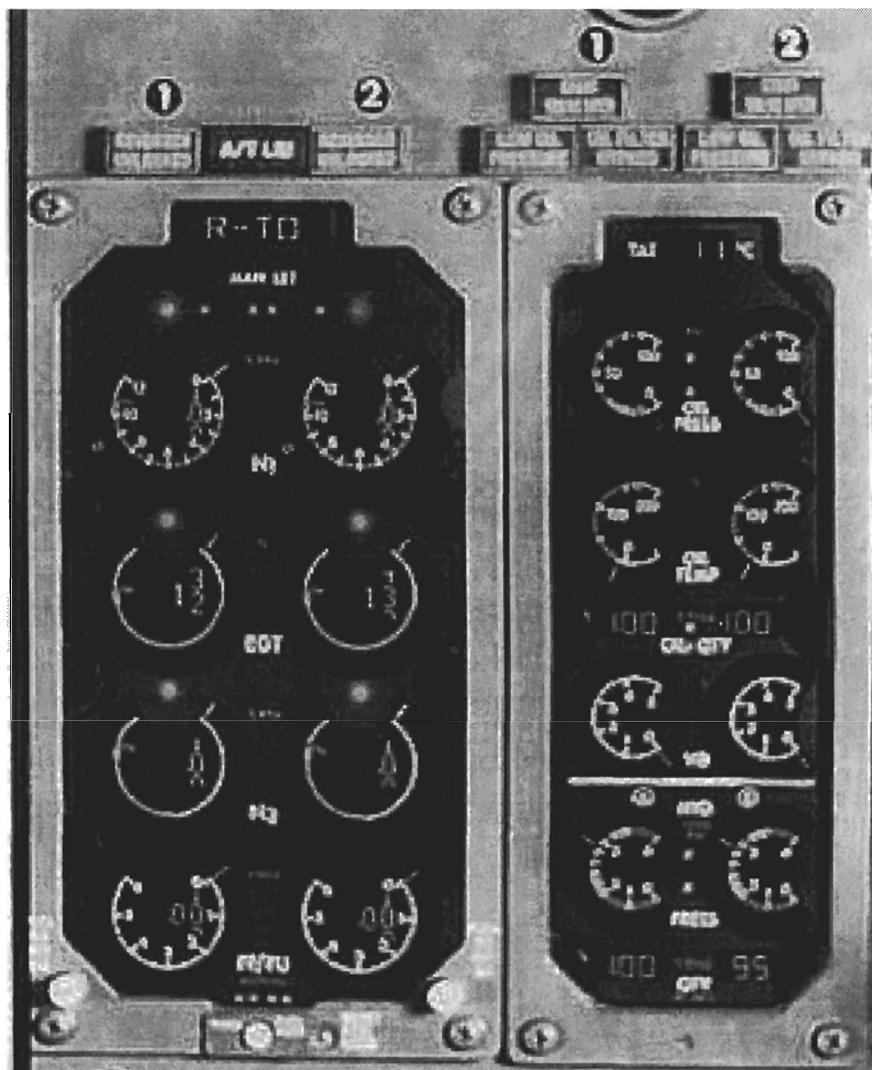


Figure 14.3: Electronic engine indications (B737)



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EICAS and ECAM

Boeing aircraft use a system called EICAS (Engine Indicating and Crew Alert System) and Airbus use a system called ECAM (Electronic Centralized Aircraft Monitor). In both cases whilst the flight deck instrument display has changed the system sensors have not changed dramatically and the principles of operation are the same.

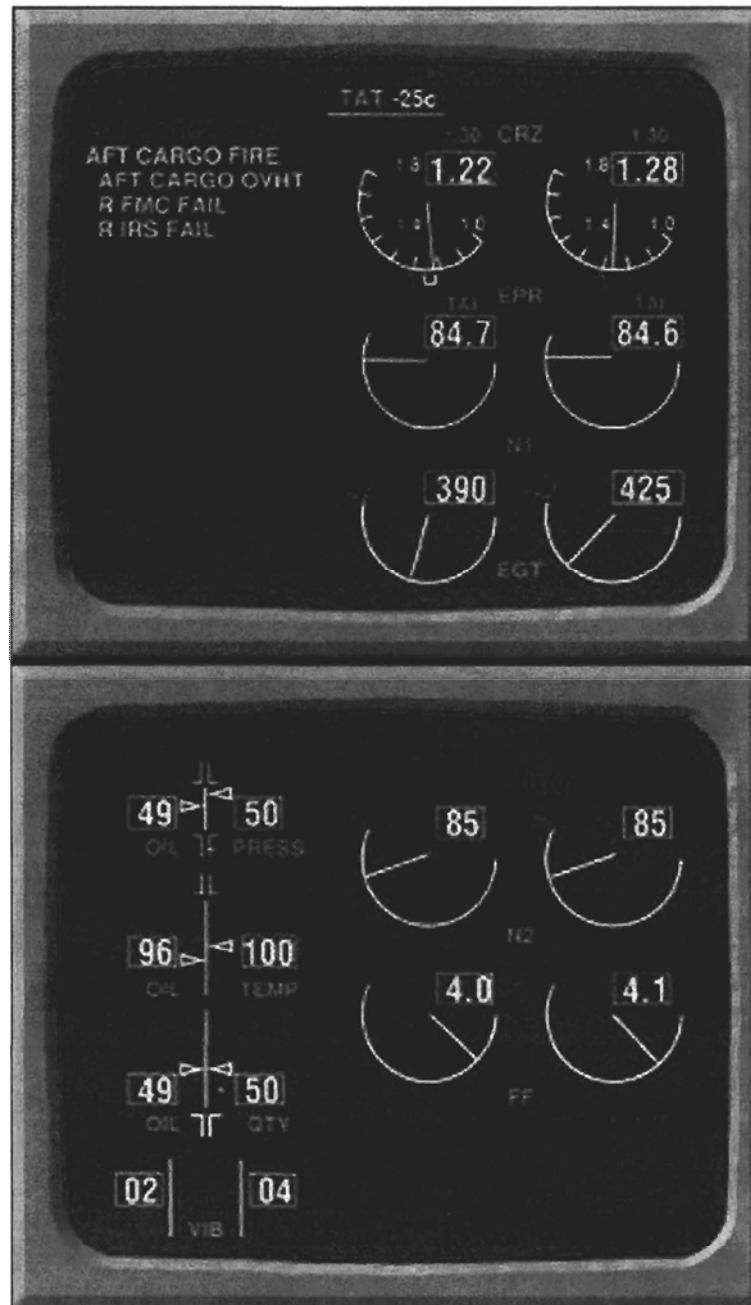


Figure 14.4: Typical EICAS screens



Temperature Measurement

There are two types of sensors:

- Thermocouple sensors
- Resistance Bulb thermometers

Thermocouple

Works exactly the same way as the EGT system and requires no external power. There is likely to be only one thermocouple however - this is the reason that **Iron and Constantan** is sometimes used as the dissimilar metals as they give a greater current flow per degree Celsius than **Alumel/Chromel**.

Resistance Thermometers

Resistance thermometers are used as the sensing device for both Wheatstone bridge and DC Ratiometer circuits. The device is usually a platinum or nickel wire sensor wound on a former made of an insulating material such as mica. This assembly will be enclosed within a steel tube. The resistance of the wire will increase with increasing heat and hence it will act as the variable resistance element of either of the above instrument types.

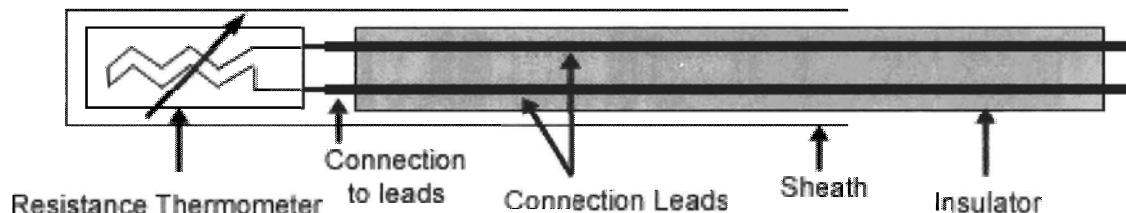
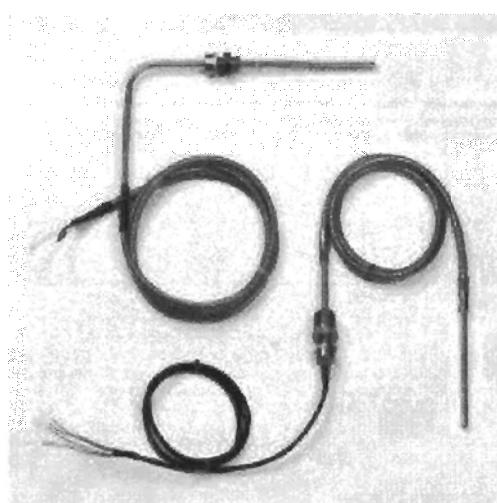


Figure 14.6: Resistance thermometer probe



Resistance thermometers can often be found with double windings to act as dual channel devices in a single unit, particularly for FADEC controlled engines.

Figure 14.7: Resistance thermometer probes

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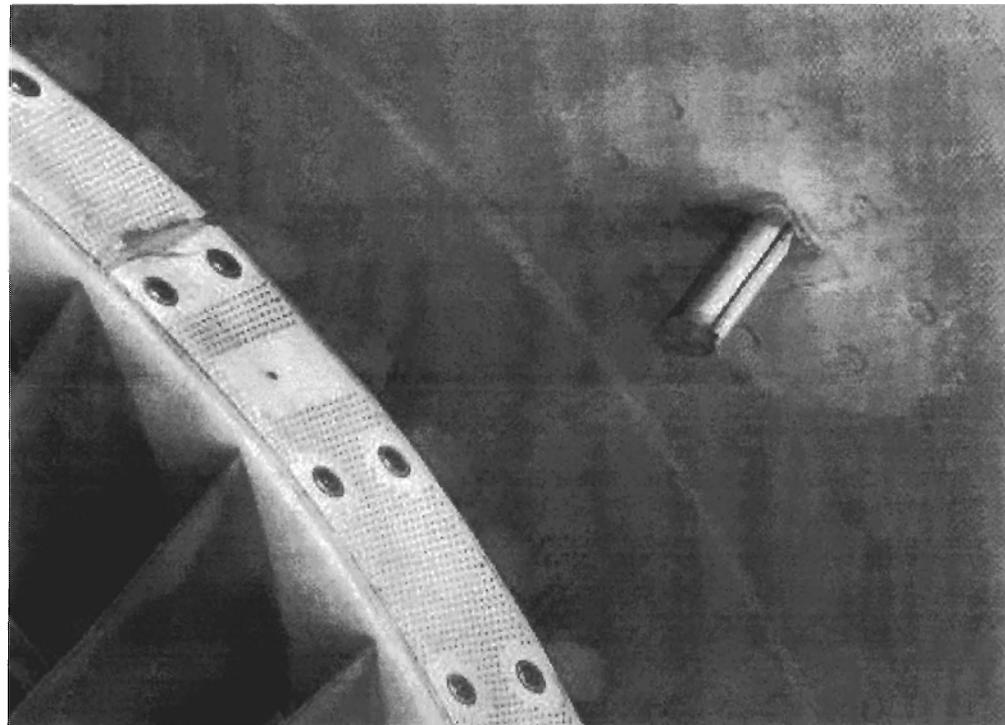


Figure 14.8: Fan inlet temperature sensor in the CFM56-3 engine intake (B737)

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Wheatstone Bridge Temperature Sensor

A Wheatstone bridge circuit consists of three fixed resistors and one resistance thermometer whose resistance varies with temperature.

When power is applied to a Wheatstone bridge circuit and all four resistances are equal, no difference in potential exists between the bridge junctions. However, when the variable resistor is exposed to heat, its resistance increases, causing more current to flow through the fixed resistor R_3 than the variable resistor R_4 . The disproportionate current flow produces a voltage differential between the bridge junctions, causing current to flow through the galvanometer indicator. The greater the voltage differential, the greater the current flow through the indicator and the greater the needle deflection. Since indicator current flow is directly proportional to the temperature, an indicator calibrated in degrees provides an accurate means of registering temperature.

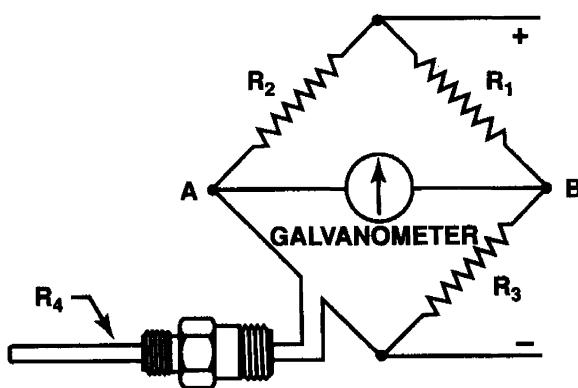


Figure 14.9: Wheatstone Bridge

DC Ratiometer

A ratiometer circuit measures current ratios and is more reliable than a Wheatstone bridge, especially when the supply voltage varies. Typically, a simple ratiometer circuit consists of two parallel branches powered by the aircraft electrical system. One branch consists of a fixed resistor and coil, and the other branch consists of a variable resistor and coil. The two coils are wound on a rotor that pivots between the poles of a permanent magnet, forming a meter movement in the gauge.

The shape of the permanent magnet provides a larger air gap between the magnet and coils at the bottom than at the top. Therefore, the flux density, or magnetic field, is progressively stronger from the bottom of the air gap to the top. Current flow through each coil creates an electromagnet that reacts with the polarity of the permanent magnet, creating torque that repositions the rotor until the magnetic forces are balanced. If the resistances of the temperature probe and fixed resistor are equal, current flow through each coil is the same and the indicator pointer remains in the centre position. However, if the probe temperature increases, its resistance also increases, causing a decrease in current through the temperature-sensing branch. Consequently, the electromagnetic force on the temperature sensing branch



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decreases, creating an imbalance that allows the rotor to rotate until each coil reaches a null, or balance. The pointer attached to the rotor then indicates the oil temperature

Ratiometer temperature measuring systems are especially useful in applications where accuracy is critical or large variations of supply voltages are encountered. Therefore, a ratiometer circuit type temperature sensing system is generally preferred over Wheatstone bridge circuits by aircraft and engine manufacturers.

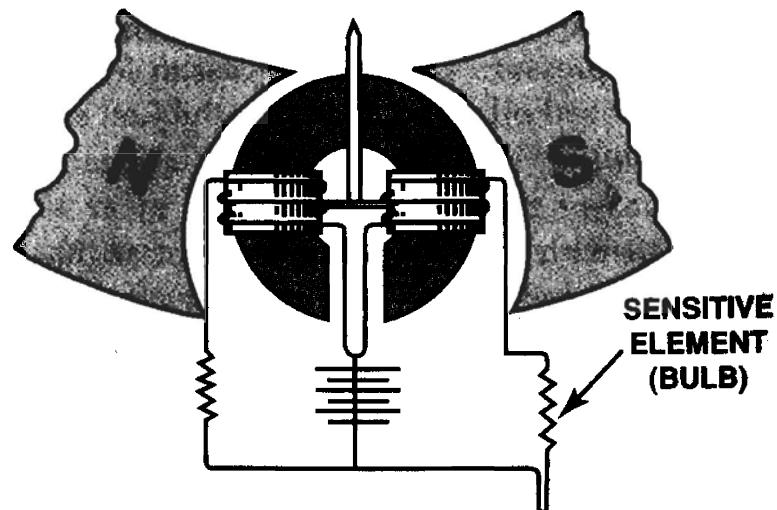


Figure 14.10: DC Ratiometer

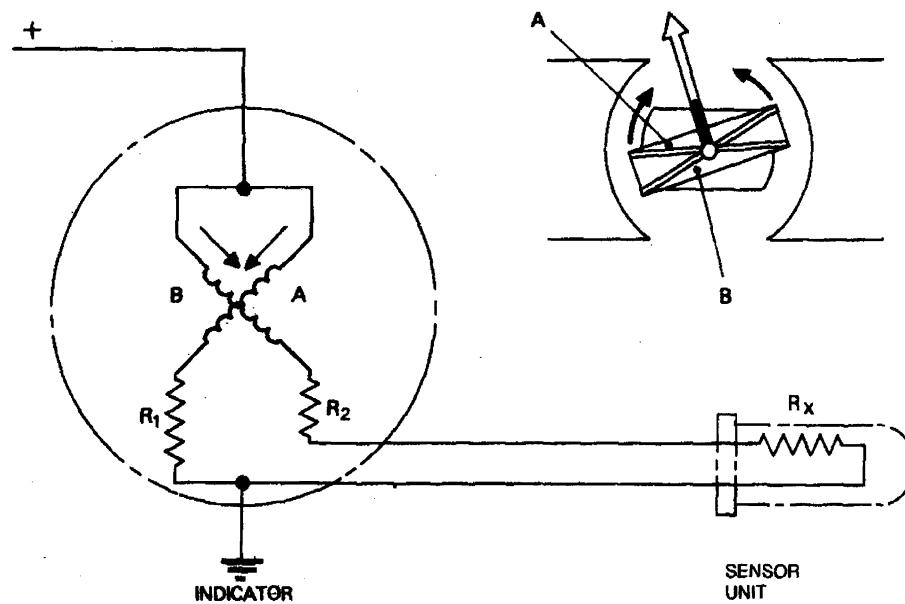


Figure 14.11: DC Ratiometer

Notes:

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Variation in input voltage does not affect readout

An open circuit in the sensor will cause the instrument to go to FSD

A short circuit in the sensor will cause the instrument to go to a minimum (off-scale) position

A hairspring is not required (as in a moving coil instrument), any hairspring used is only to take the needle indicator off scale

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Exhaust Gas Temperature

The temperature of the exhaust gases is always monitored closely during engine operation, especially during the starting cycle when overheat damage is most prevalent. Hot section temperature is considered the most critical of all engine-operating parameters because an out of limit condition can render the engine unserviceable in a matter of seconds. The temperature gauge in the flight deck, when labelled **Turbine Inlet Temperature** (TIT), indicates the temperature is being monitored forward of the turbine wheel(s). When labelled **Interstage Turbine Temperature** (ITT), it indicates that the temperature is being monitored at some intermediate position between adjacent turbine wheels; and when labelled **Turbine Outlet Temperature** (TOT), it indicates the temperature is being taken aft of the turbine wheels.

A generic term of **Exhaust Gas Temperature** (EGT) is commonly used for all of the above

The Thermocouple

If two wires of any different metals are joined together at both ends as shown, then heat is applied to one of the junctions, a very small current will flow around the wires. The reason for this, is the fact that every metal has a different electrical potential to the next, or a different amount of free electrons, or even a deficiency of free electrons compared to other metals. The heating of one of the junctions, known as the hot junction allows free electrons from the wire with the greatest electrical potential, to flow into the wire of the lesser electrical potential - this is known as the Seebeck Effect. The flow of electrons is continuous for as long as the heat is applied and is directly proportional to the amount of heat applied. The current flows right around through the cold junction and back to the hot junction in a complete loop. Although the current is very small, it can be measured at any point in the loop by a sensitive ammeter.

Note that no external electrical supply is needed.



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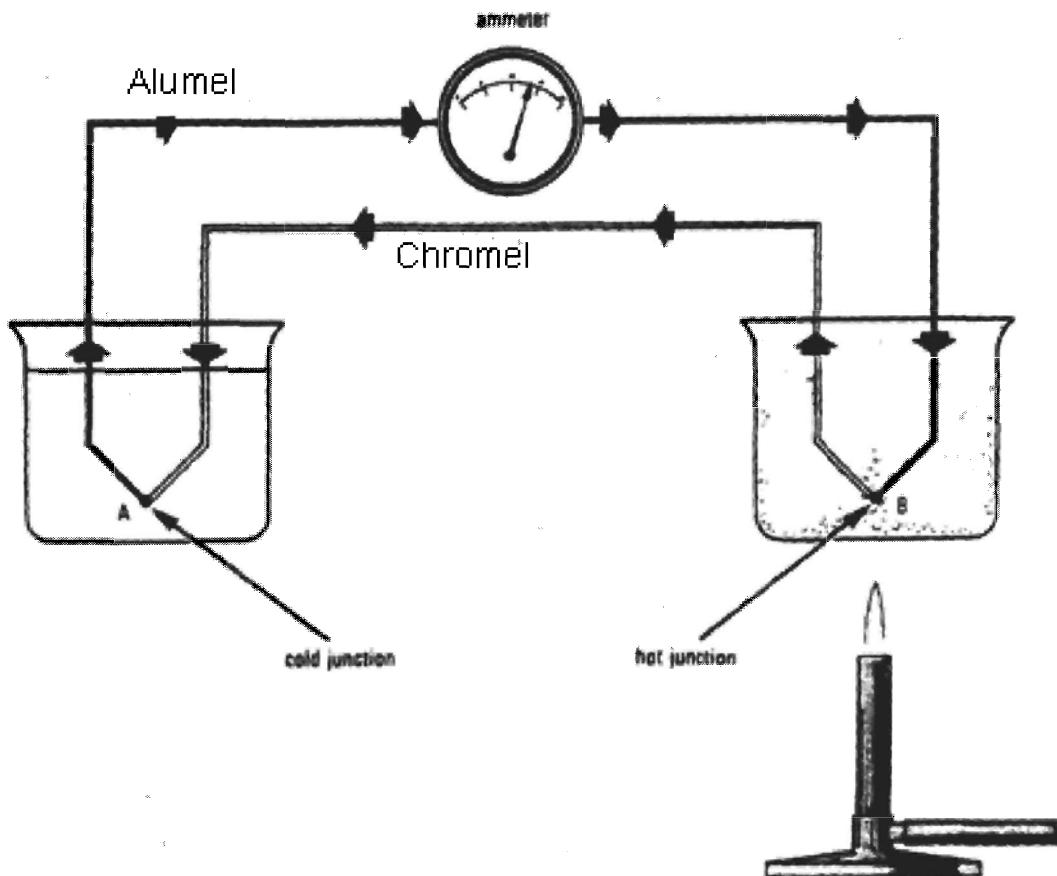


Figure 14.12: The Thermocouple Principle



The exhaust gas temperature EGT system for a turbine engine is similar to that for a reciprocating engine except that several thermocouples are used. These are arranged around the exhaust so they can sample the temperature in several locations.

For accurate temperature indication, the reference junction temperature must be held constant. It is not practical to do this in an aircraft instrument, so the indicator needle is mounted on a bimetallic hairspring in such a way that it moves back as the cockpit temperature increases. This compensates for reference junction temperature changes.

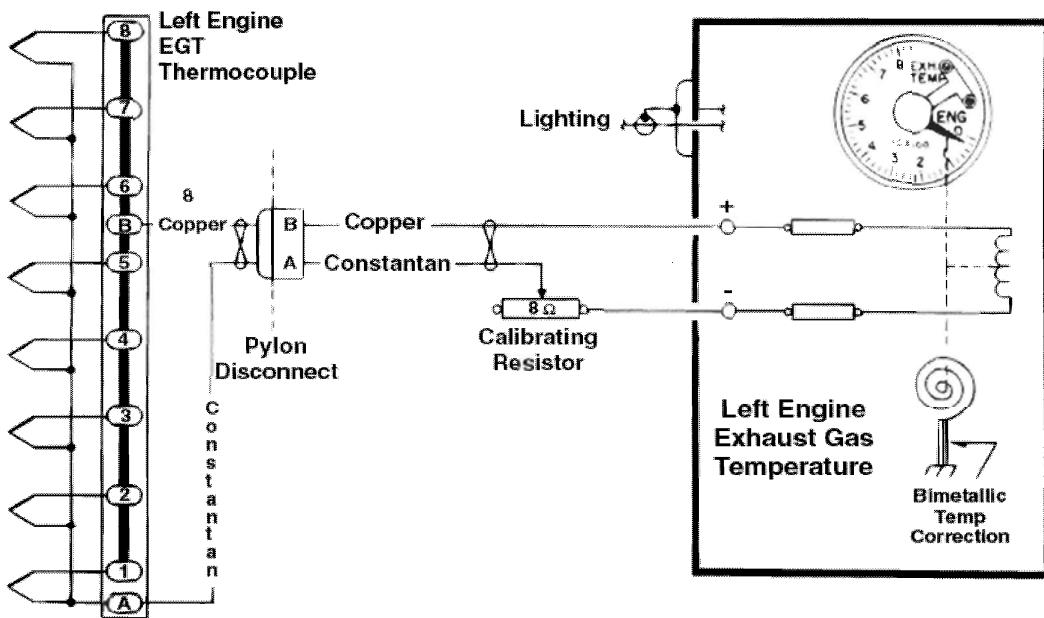


Figure 14.13: EGT Indication (Copper Constantan)

Small indicators operate without any additional electrical power except for the illumination. For more complex indicators, electrical power supply is used for the amplifiers and motors inside the indicator.

- Chromel (alloy of chromium and nickel)
- Alumel (alloy of aluminium and nickel)



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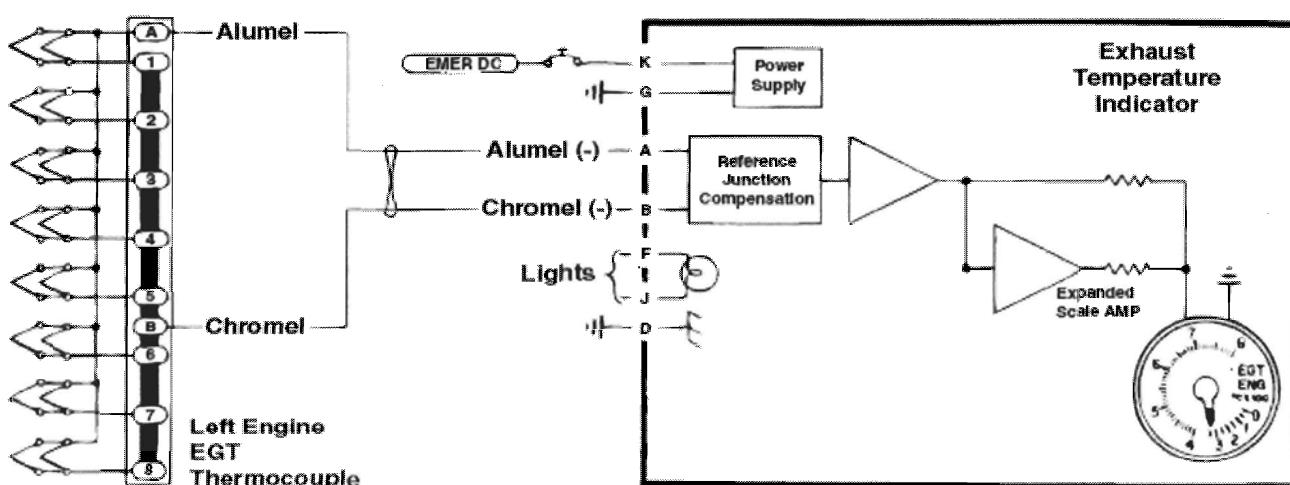


Figure 14.14: EGT Indication (Chromel Alumel)

Figure 14.13 shows a typical aircraft system. Its features are as follows:

1 The two different metals used are; Nickel Aluminium (Alumel)
Nickel Chromium (Chromel)

Alumel has an excess of free electrons and is usually colour coded GREEN

Chromel has a deficiency of free electrons and is usually colour coded WHITE

These metals are used as a standard in the aircraft industry, not because they give the best current flow per degree centigrade, but because they are most reliable.

2 There are at least eight thermocouple placed in parallel around the exhaust and each within a casing which helps to protect the delicate wires from the hot gases. In this way, a thermocouple may burn out and it will not affect the sensitivity of the system.

3 All the thermocouples come together at a common cold junction which is where the indicator is situated. The indicator is a sensitive ammeter but indicating degrees Celsius instead of amps. This is a moving coil ammeter and is very delicate. During transit of the instrument, the terminals should be shorted by a piece of copper wire. This will help to damp the internal mechanism and should only be removed when the indicator is connected to a thermocouple. This type of instrument is sometimes called a D'Arsonval meter.

4 In the circuit will be situated a calibrating resistor (or sometimes a dummy thermocouple). This resistor is temperature sensitive and is subject to ambient temperature. It has two functions:

It calibrates the system since the lengths of the wires from the sensors to the indicators is critical (see below)



It compensates for ambient air temperature.

5 The complete circuit resistance is critical, usually 8, 15 or 22 ohms and is measured between the thermocouple harness and the flight deck indicator. For this reason, all connections must be accurately torque loaded and all screw threads should be smeared with graphite grease. No alterations are allowed in the wiring of any part of the system.

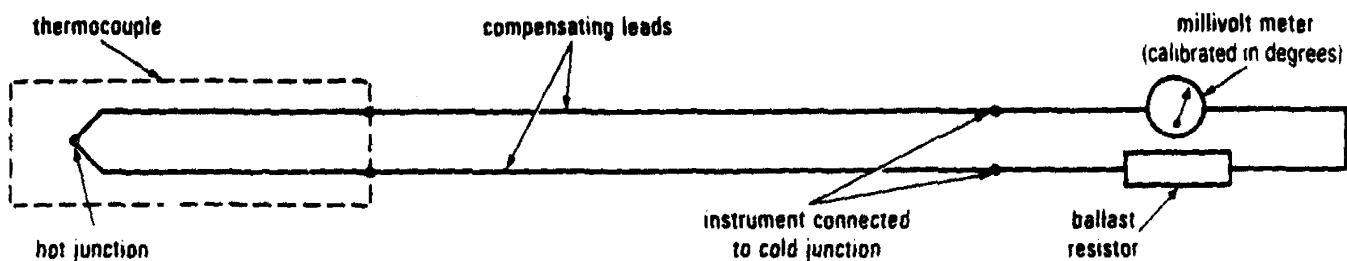


Figure 14.15: Thermocouple thermometer

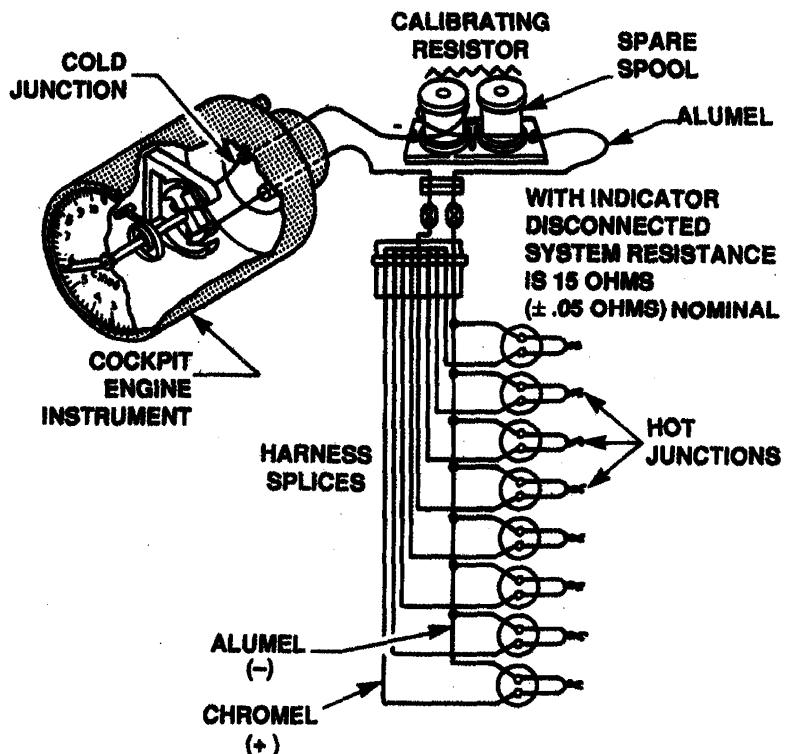


Figure 14.16: Simple aircraft thermocouple system



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Thermocouples are usually of the rapid response or stagnation type as shown opposite. Gas Turbine engines are usually of the stagnation type due to the rapid velocity of the jet efflux.

Thermocouples are inserted into the gas stream at a depth to obtain the most accurate reading. Many systems use double or triple element units (see below) to obtain an even more accurate indication. These multiple units are of differing lengths in order to obtain a temperature reading from different depths in the gas stream to provide a better average reading than can be obtained from a single probe.

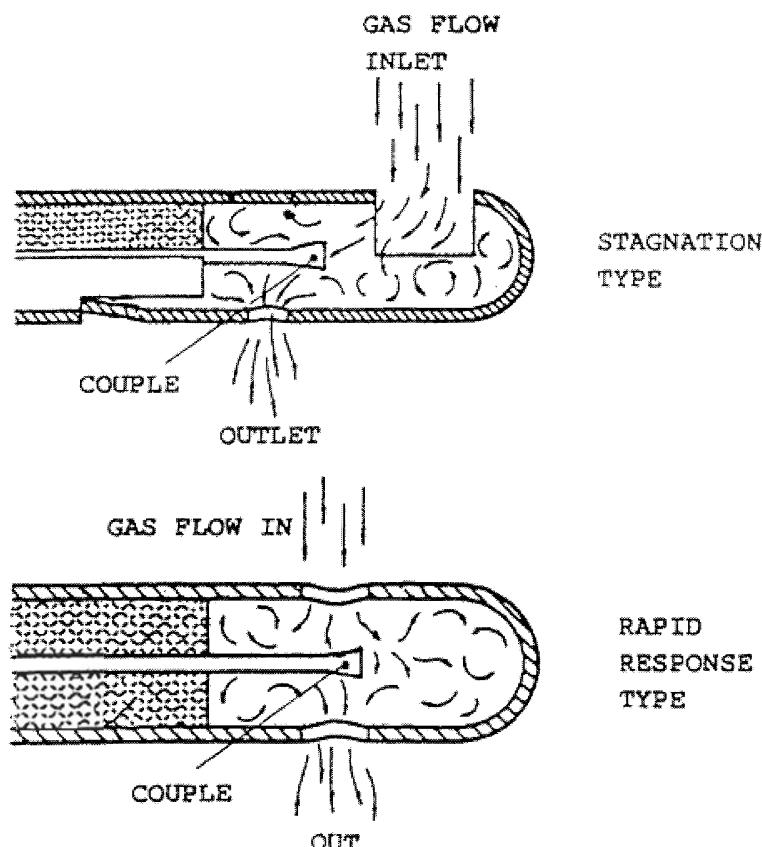


Figure 14.17: Stagnation Type and Rapid Response Type thermocouple probes

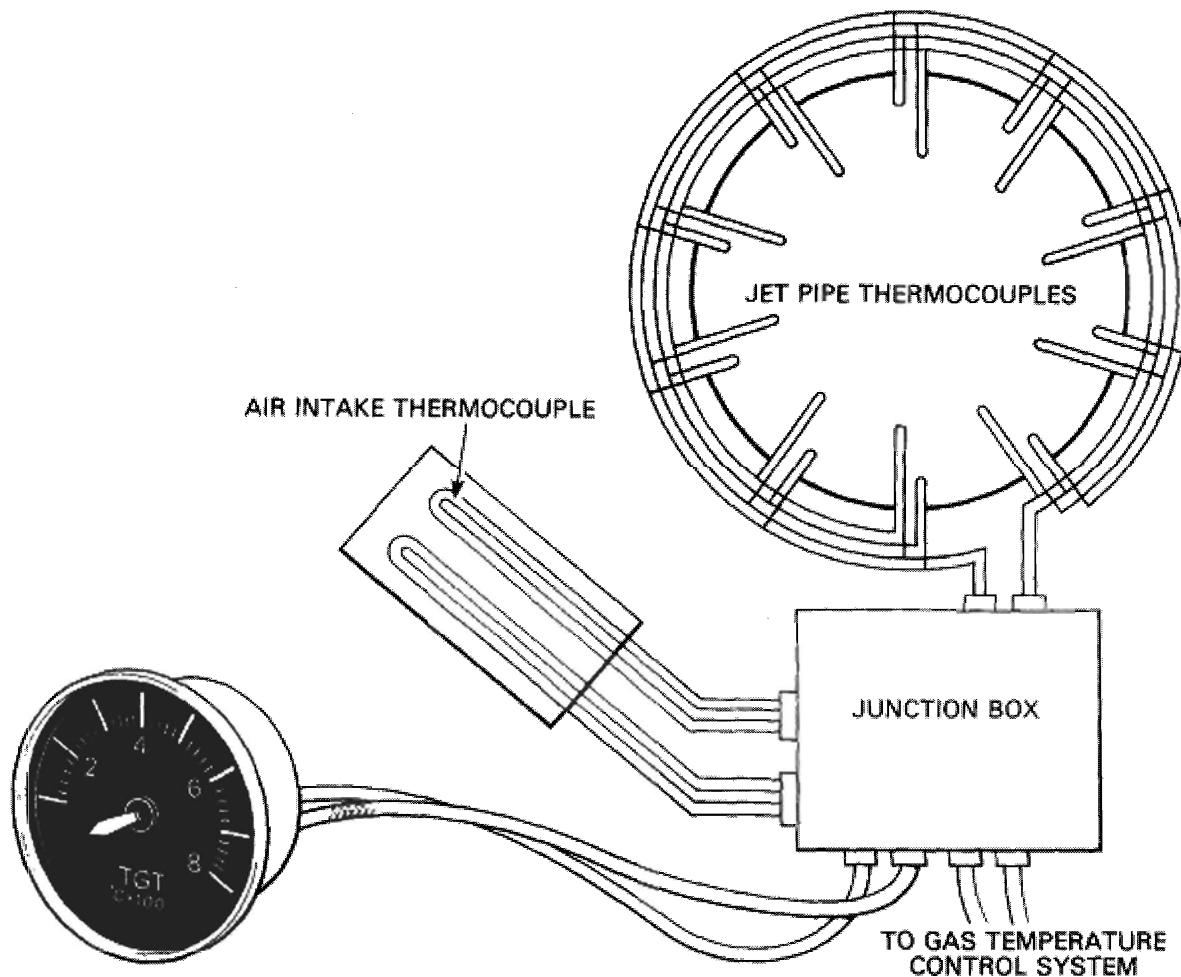


Figure 14.18: TGT thermocouple system



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A Modern Thermocouple System

Modern thermocouple systems do not use the simple moving coil instrument. If the engine uses an instrument, then it is likely to be a moving coil ratiometer, where the cold junction is in fact one leg of the ratiometer device.

In a FADEC engine the cold junction is within the FADEC EEC.

For Non FADEC engines with glass cockpit (Boeing 757) the cold junction will terminate at the EICAS computer. See below for the RB211/B757 EGT system

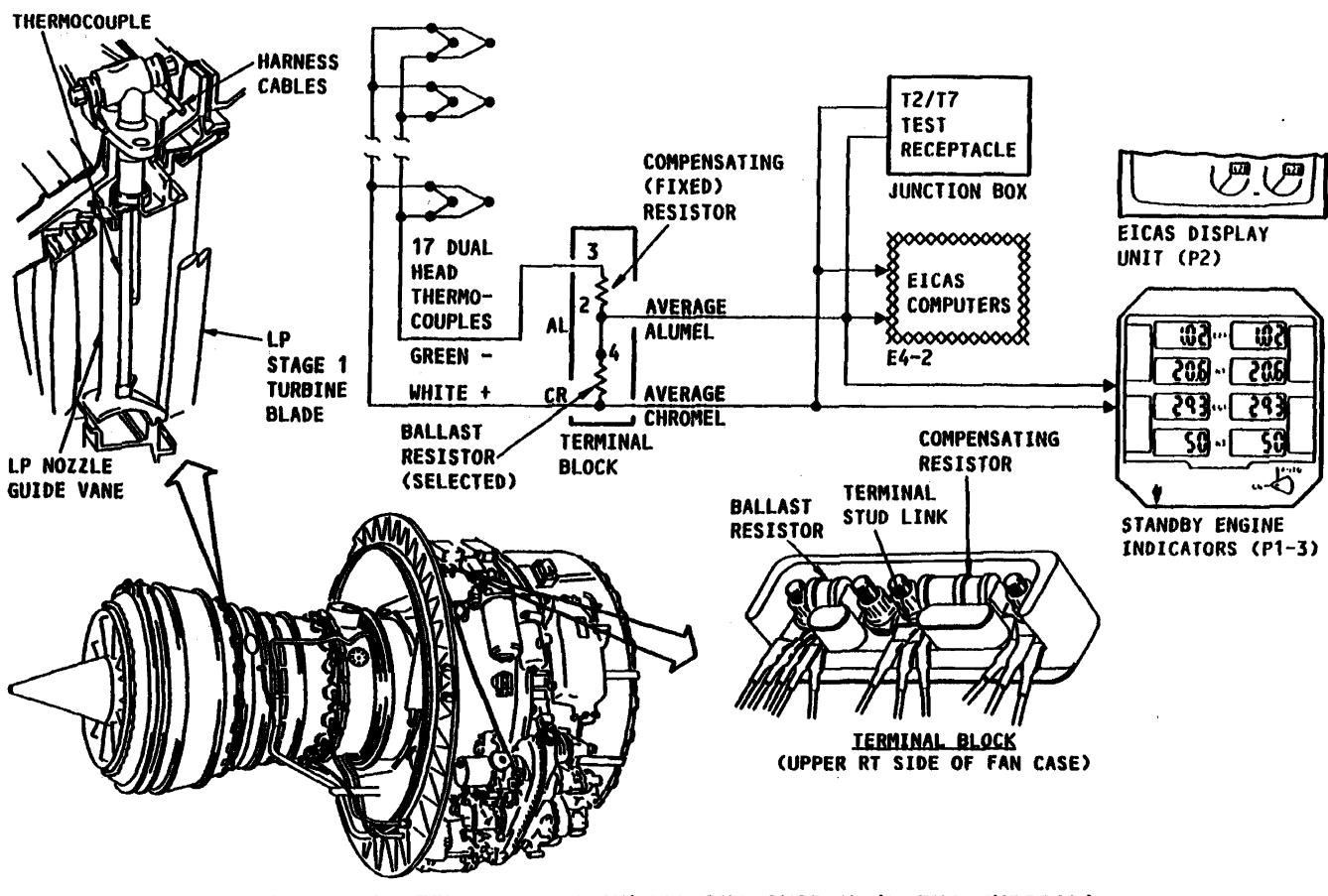


Figure 14.19: RB211/B757 EGT System

Note that the compensating resistor is fitted to adjust for variation in ambient temperature at the cold junction, whilst the ballast resistor standardizes EGT output to enable variation in individual engine performance to be eradicated in the interest of fleet commonality.



Thermocouple Maintenance

Maintenance of thermocouple EGT system consists of testing the circuit. This may be done in 2 ways.

The Jetcal Analyser

The Jetcal analyzer is a RPM and EGT test set. In the EGT mode it tests the following:

- Continuity Check of aircraft EGT circuit
- Functional Check of Aircraft EGT Circuit
- Resistance and Insulation Check
- EGT Indicator check

The first three above are carried out by heating a probe that fits over a thermocouple and the output is cross checked between the test set and the cockpit gauge. None of these tests require compensation for ambient temperature because the aircraft circuit and the test set are automatically corrected.

The EGT indicator test is carried out by removing the indicator from the aircraft and connecting to the test set. Correction for ambient temperature is not required.

Resistance and Continuity Checks

On modern engines you should confirm serviceability of the system by checking continuity and resistance of the system using Multimeter and Ohmmeter. Thermocouples are also checked individually by isolating them and checking resistance.

Fault diagnosis

For all power settings

False Low EGT	Circuit resistance is high	- Corroded terminals - leads too long after repair
False High EGT	Circuit resistance low	- Loose terminals - Gauge Fault



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Pressure Measurement

Oil pressure is electrically transmitted to an indicator on the instrument panel. Some installations use a flag-type indicator, which indicates if the pressure is high, normal or low; others use a dial-type gauge calibrated in pounds per square inch (PSI). EICAS and ECAM display oil pressure and temperature on the appropriate engine page.

Electrical operation of each type is similar; oil pressure, acting on the transmitter, causes a change in the electric current supplied to the indicator. The amount of change is proportional to the pressure applied at the transmitter.

The transmitter may be of either the **direct** or the **differential pressure** type. The latter senses the difference between engine feed and return oil pressures. **The differential pressure type is normally used on modern engines as it will take into account changes of altitude, which in a direct reading gauge would affect the indication.**

In addition to the pressure gauge operated by a transmitter, an oil pressure switch may be provided to indicate absolute minimum allowable oil pressure.

Direct Reading Pressure Gauges

Bourdon Tube Principle

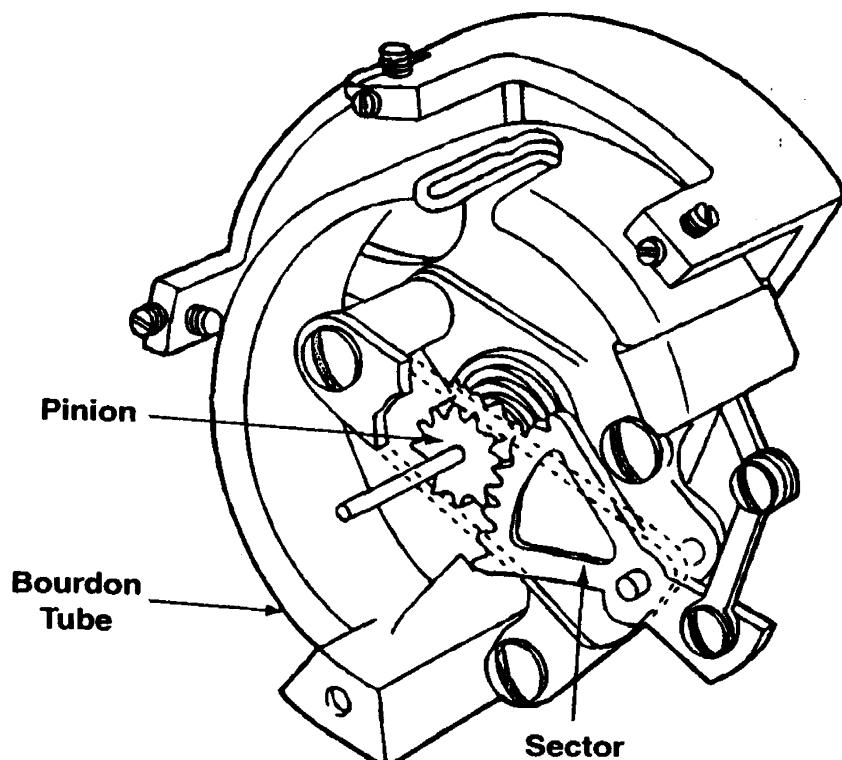


Figure 14.20: Bourdon tube principles



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Pressure Capsule

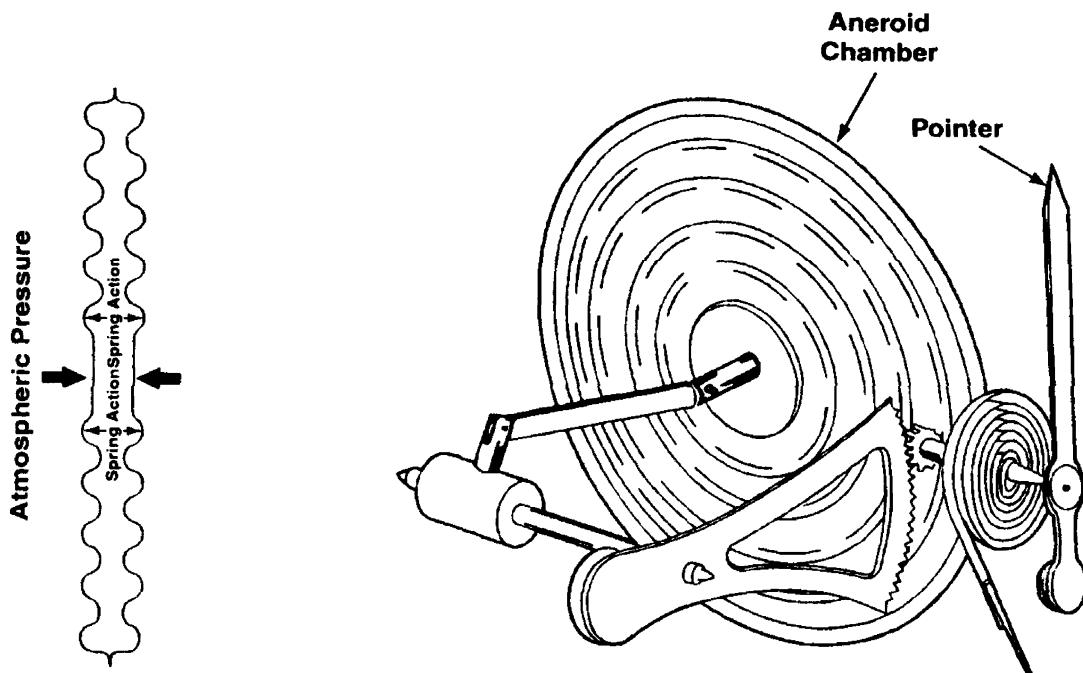


Figure 14.21: Aneroid pressure capsule

Pressure Bellows

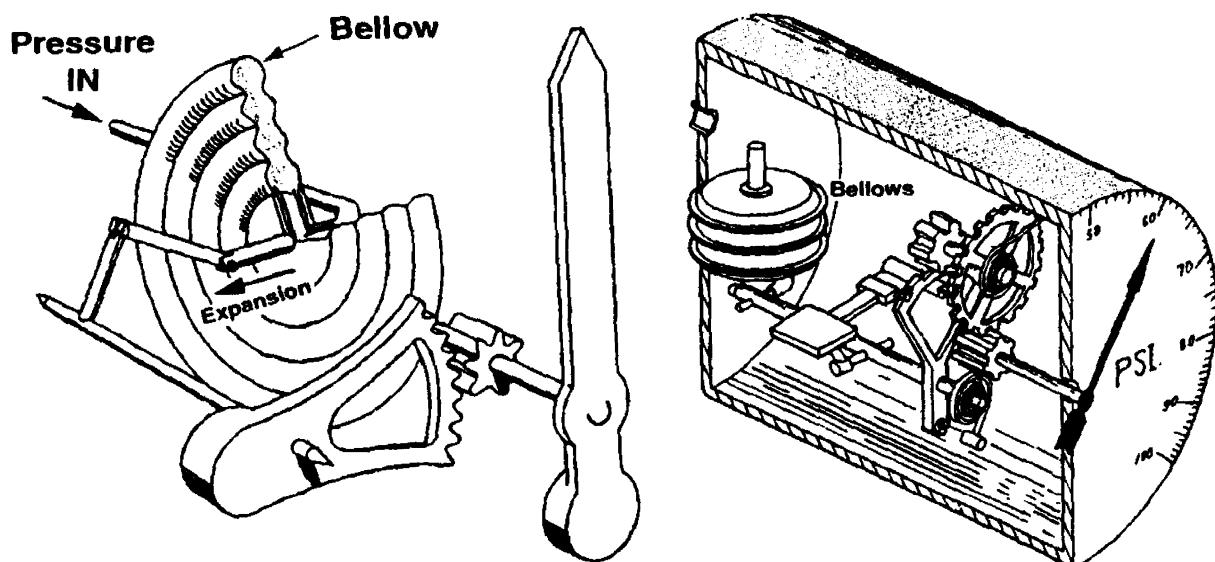


Figure 14.22: Bellows Mechanism and Instrument



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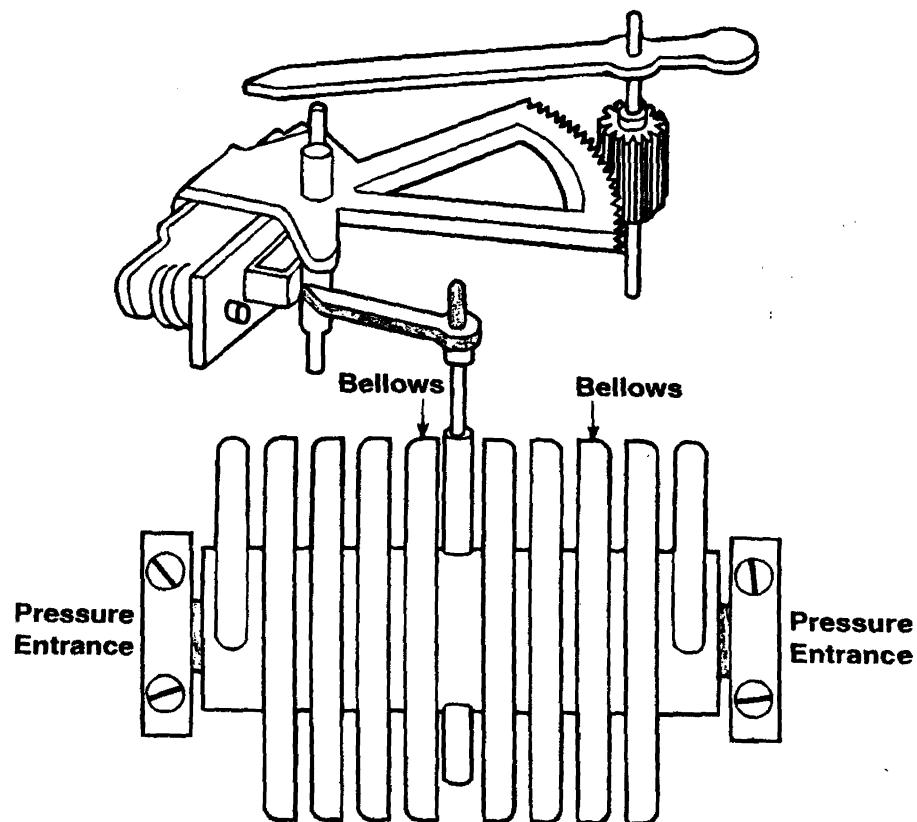


Figure 14.23: Differential Bellows with Indication Mechanism



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Remote Reading Pressure Instruments

Strain Gauges

These electric passive devices are used to detect forces. The resistance of strain-gauges varies with the force applied to it. The metallic wire consists of a chrome-nickel alloy. The length and the diameter of the conductor changes as a function of the force. Expanding force increases, shortening force decreases the resistance.

These sensors are used for different applications. Structure monitoring, force sensors, pressure transducers and weight measuring. Inside pressure sensors, the pressure affects is changed into force.

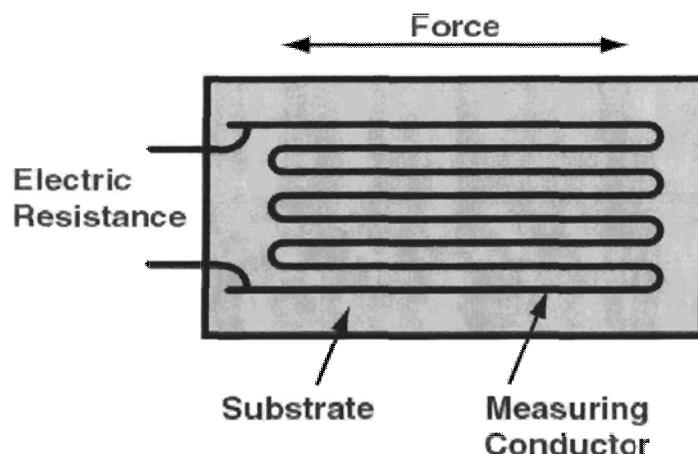


Figure 14.24: Strain Gauge

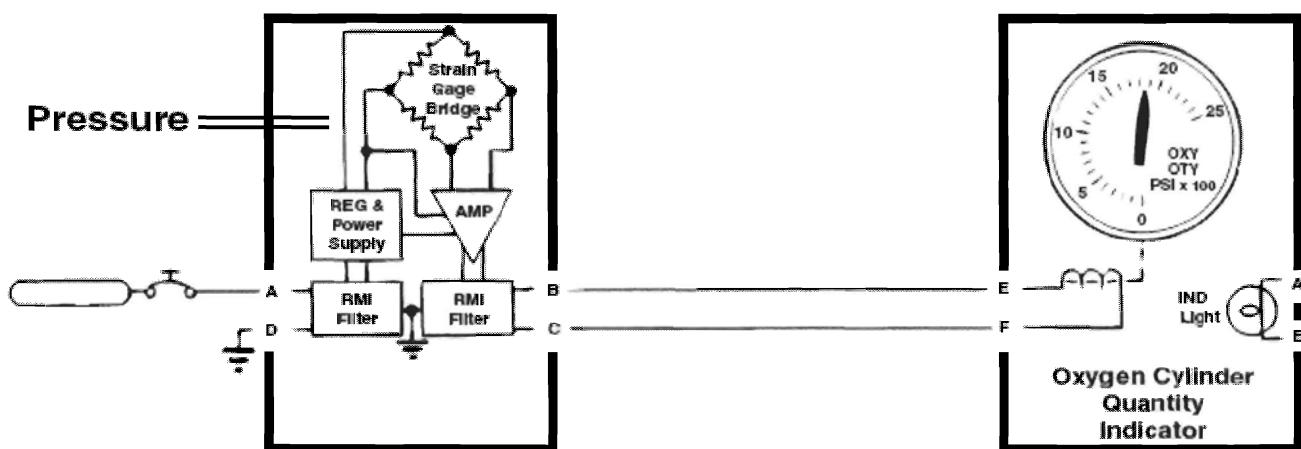


Figure 14.25: Pressure Indication using Strain Gauge Bridge



Piezo-Resistive Sensors

P- or N- conducting elements are diffused into a pure silicon substrate. This so called piezo-resistive effect changes the resistance with a much higher sensitivity than what a metallic strain gauge does.

Semiconductor based sensors are in many different forms. The substrate of the pressure sensor shown in figure 14.26 has a dimension of 3.5 x 3.5 mm. Inside there is a bridge with 4 elements.

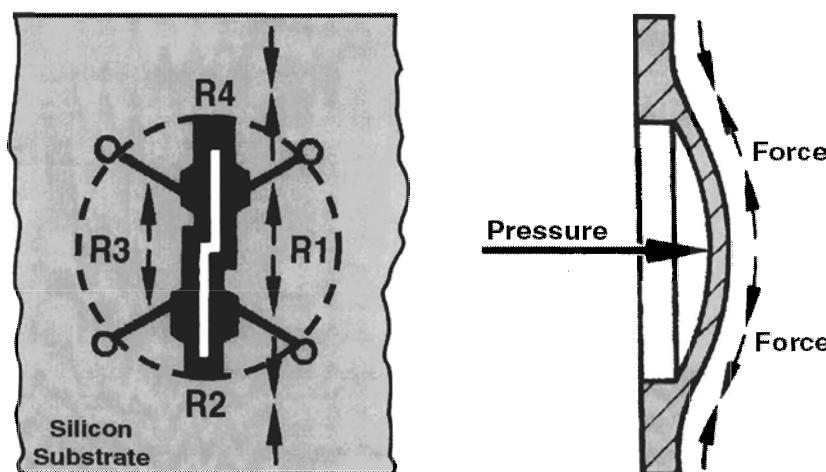


Figure 14.26: Piezo Resistive Element

Variable Frequency Signals

A variable frequency signal has a frequency which is controlled by a certain parameter. A device with a variable output frequency makes such a signal. The frequency varies, under control of the parameter, between a high and a low frequency. These limit frequencies are different from device to device and depend on the design of the device.

A control voltage, a variable capacitor, and a variable resistor are, for example, parameters that control the frequency.

Frequency counters, microprocessor system and special moving coil meters are all devices that work with variable frequency signals.



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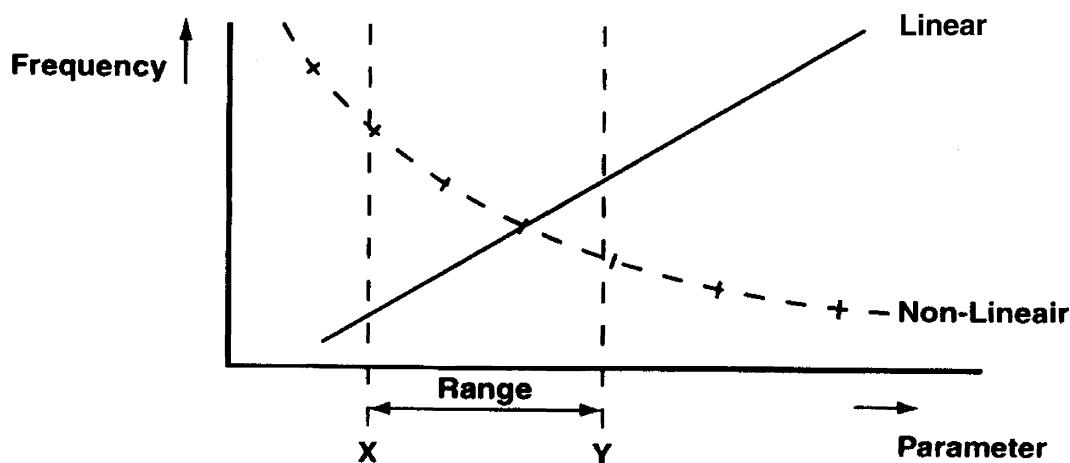


Figure 14.27: Linear Parameter Output after Conversion

Figure 14.28 shows a very sensitive and accurate pressure transducer used inside airdata computers. The oscillator coil assembly oscillates the diaphragm. Its resonant frequency increases with the applied pressure against the vacuum reference inside the transducer.

The output frequency, proportional to the pressure, is easily changed inside the computer, into a digital signal. The temperature sensing resistor compensates for influences of the ambient temperature.

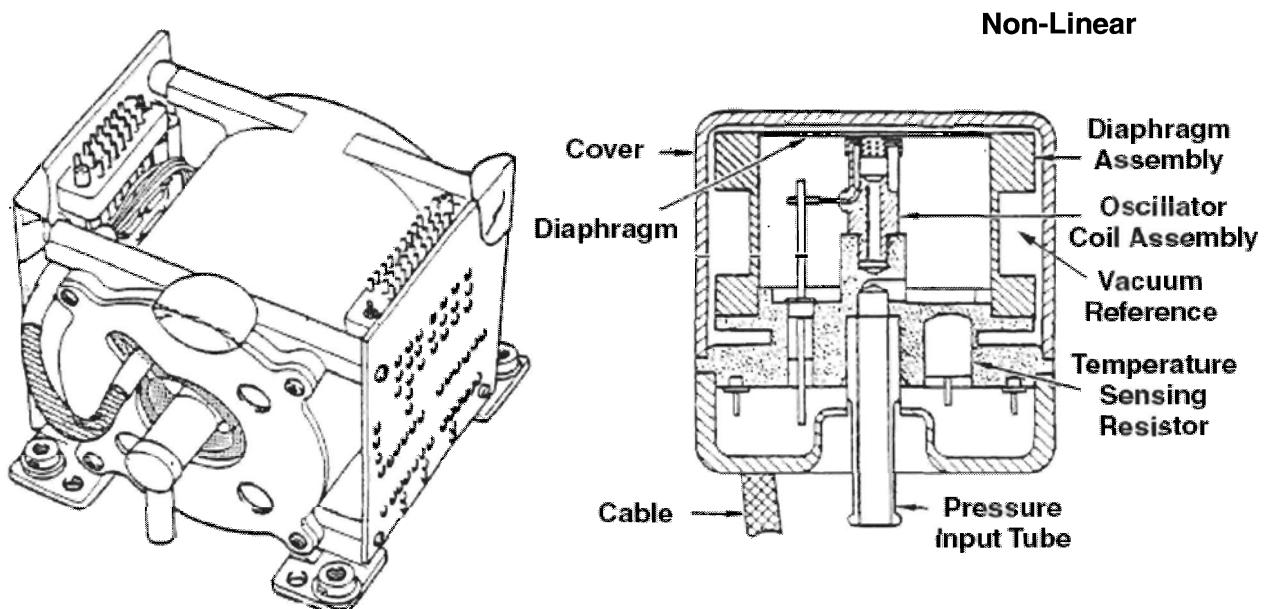


Figure 14.28: Vibrating Diaphragm Transducer

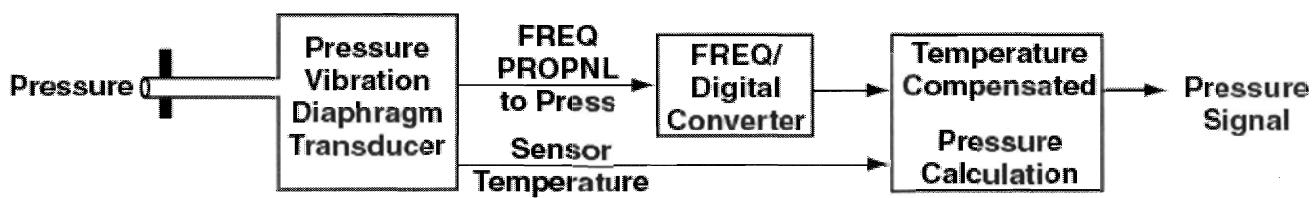


Figure 14.29: Pressure to Digital Conversion



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Engine Thrust Indication

Thrust can only be measured in an engine static test cell. Reference to the fundamental section of these notes should remind you why this is! Engines are rated by Static or Gross thrust, this figure is always quoted on the engine data plate.

Because of the above the indication of thrust, in the cockpit is always going to be an analogy, that is some other indication that can be used to indicate the thrust performance of the engine. The examples discussed below are:

- Engine Pressure Ratio
- Engine turbine discharge/Jet pipe pressure system
- High Bypass fan RPM (N1)

Engine Pressure Ratio

The engine pressure ratio (EPR) is a widely used thrust indicating system and is becoming more popular than the RPM as an indication of thrust. The pressures sensed are usually **compressor inlet pressure (P1)** and **turbine outlet pressure (P6)**, by a series of pitot pressure probes. A ratio of the two pressures are converted into an electrical signal by the **pressure ratio transmitter** for transmittal to the flight deck indicator.

Although an EPR of say, 1.6 (typical for cruise) is not a direct indication of the thrust itself, since other factors are involved (such as nozzle area), the ratio does vary linearly with thrust and can therefore be used as a thrust "indicator".

The Pressure Ratio Transmitter consists of a series of bellows sensitive to the air pressure tappings, which when processed into a ratio by mechanical means, is converted into an electrical signal for indication in the flight deck by a voltmeter, or, a Desynn or an Autosyn position indicator is used. Whichever system is used, it requires an electrical input.

Engine pressure ratio does vary with increased forward speed due to Ram Effect. Increased P1 will affect the P6/P1 ratio so that the ratio will decrease.

Note that High Bypass Fan engines variously define EPR as Fan Outlet Pressure to Fan Inlet Pressure or Turbine Integrated Pressure plus Fan Outlet Pressure to Fan Inlet Pressure.

Engine Turbine Discharge/Jet Pipe Pressure

This indication of thrust utilizes a pitot probe to measure the dynamic pressure of the jet stream aft of the turbine. The output will be in to a gauge that is calibrated in either:

- Lb/in²
- Inches of mercury (in Hg)
- Percentage of the maximum thrust



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Pressure Sensors

The exact position of sensors varies from engine to engine

- For a Turbo Jet $P_6:P_1 = EPR$
- For a High Bypass Engine a variety of pressure sensors are used

E.g. :

- RB 211 –535 Pf (Fan outlet pressure) : P_1 (Fan inlet pressure)
- CFM 56 $P_6 + Pf : P_1$ (known as Integrated EPR)

Note: With increased forward speed EPR indication decreases due to the rise in P_1 . The engine will normally have been set up to maintain a certain EPR (Cruise, climb, MaxT/O) and as a result will increase fuel flow to provide extra RPM which will produce the extra thrust to maintain the EPR value.

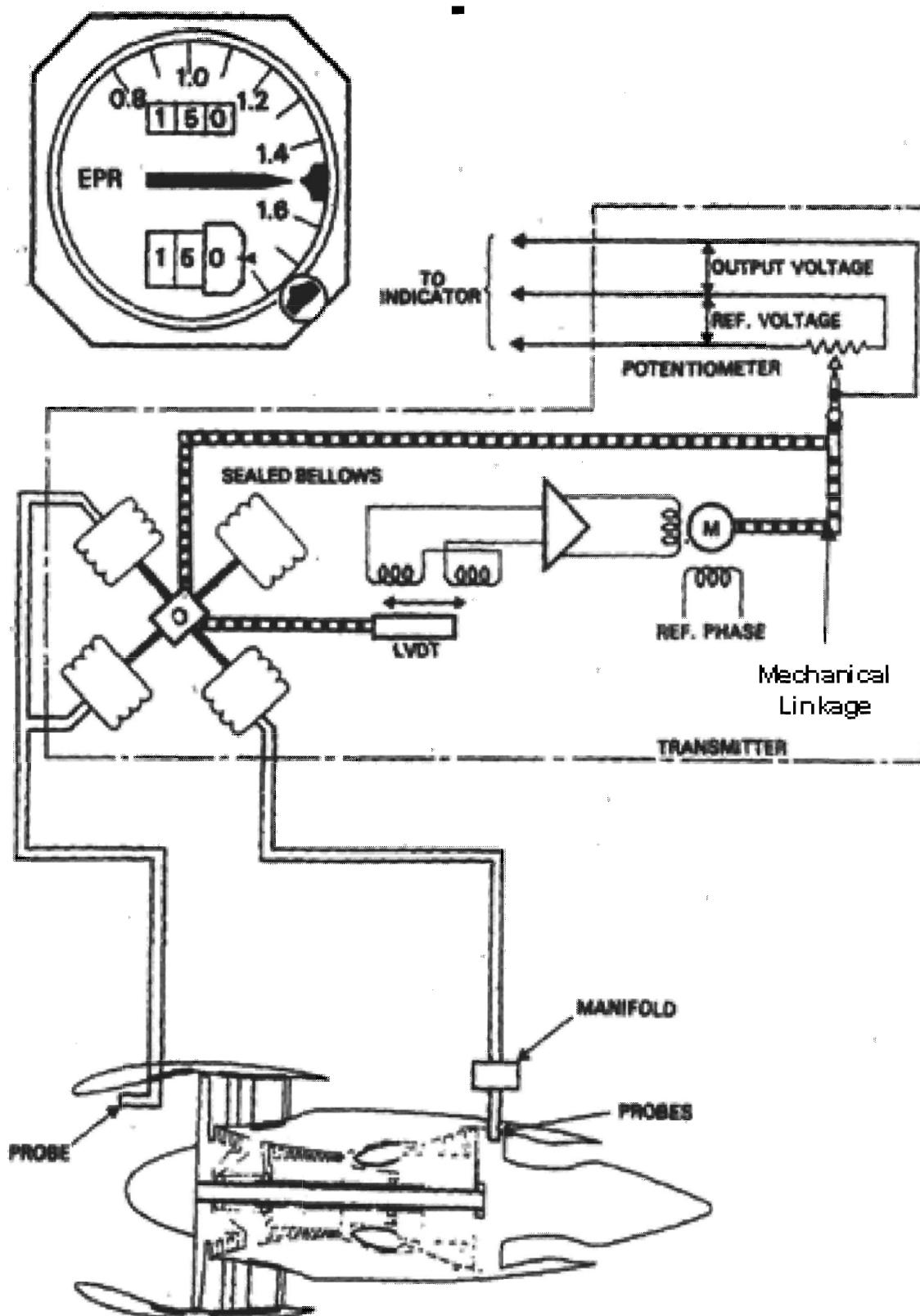


Figure 14.30: EPR system



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RPM

Older engines simply used compressor RPM as the indication of thrust. The higher the RPM the greater the thrust

High Bypass Fan RPM

In a high bypass engine the fan produces 80% of the thrust therefore it is reasonable to use N1 RPM as an analogy of thrust. The GE CF6 series engines are a good example of this. The RR Trent uses EPR, but has N1 available as a back up.



Oil Quantity Measurement

Systems

Modern oil tank indicating systems utilise a sliding magnet around a series of reed switches. As the oil level varies the magnet floats up and down the probe causing the reed switches to open and close. Current to the indicator varies as a function of the resistances in the probe circuit

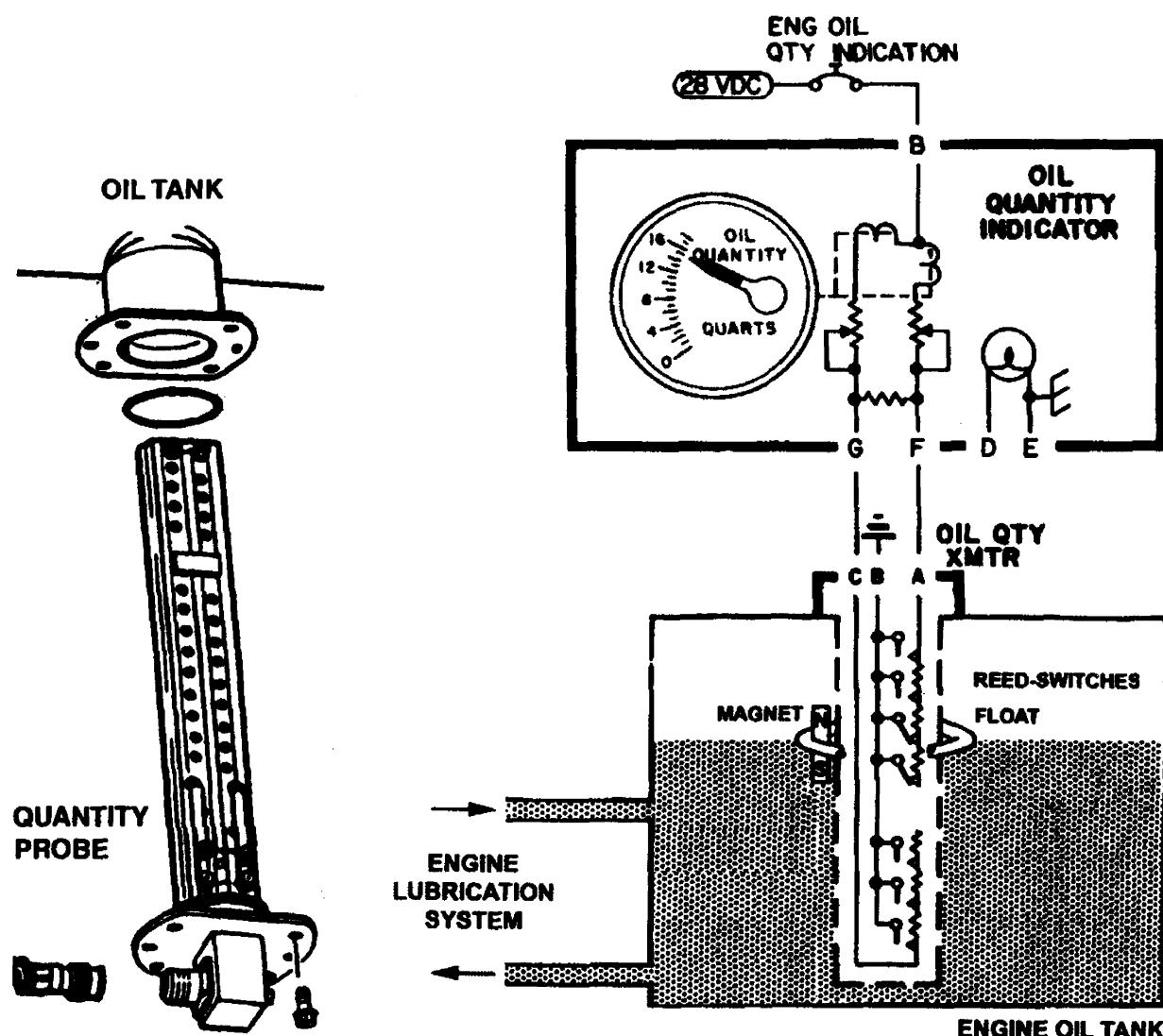


Figure 14.31: Oil quantity sensing system



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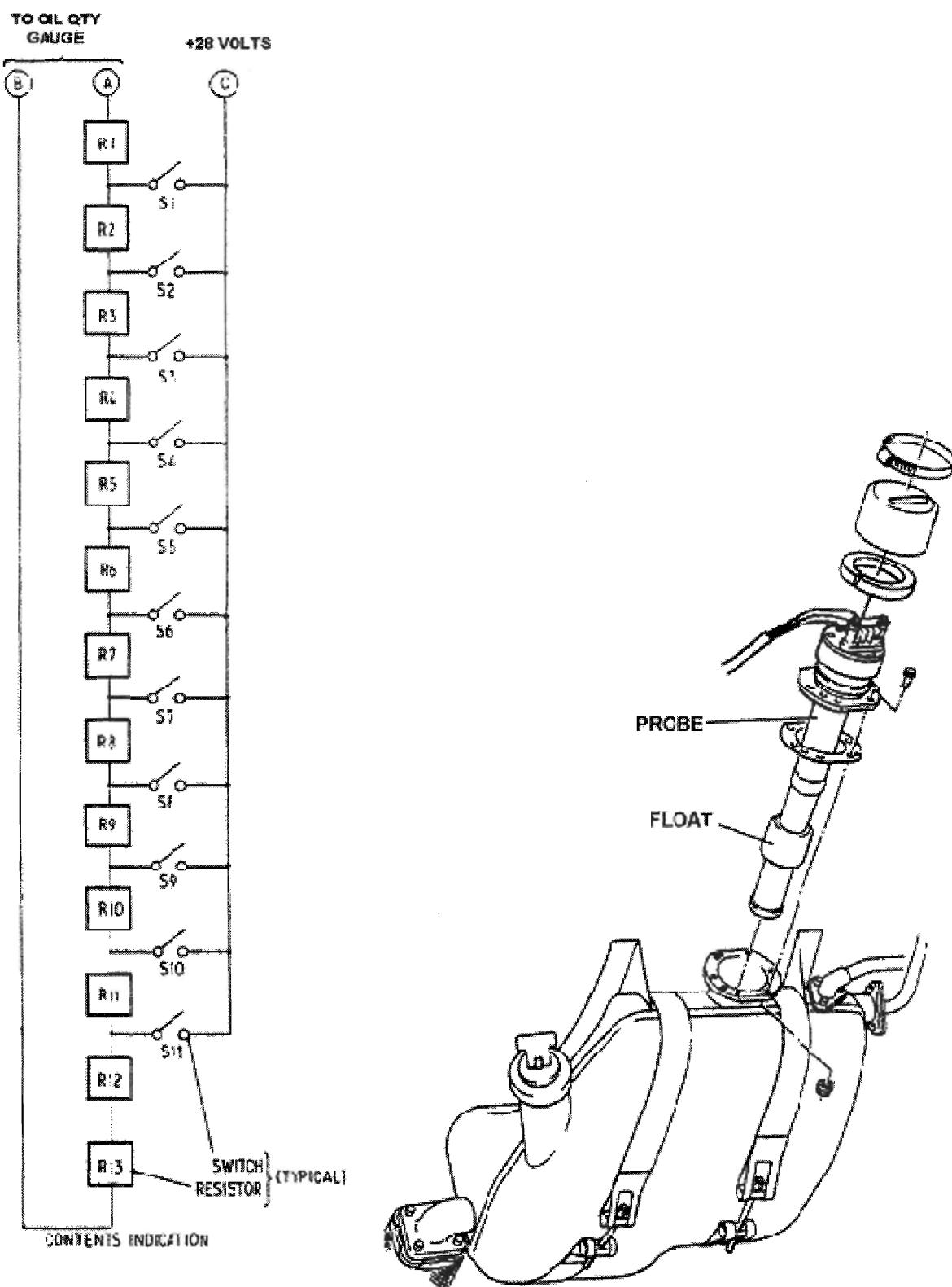


Figure 14.32: Oil quantity sensing system



Oil pressure warning light

Oil pressure is also monitored by an oil pressure switch (figure 14.21) that puts a light on when the oil pressure reaches a low level. The light is usually red and will be incorporated into the aircraft warning systems to alert the pilot. On later aircraft the pressure switch may have two pressure switched within it. A speed comparator will decide which switch to monitor. The idea being that a low oil pressure of say 20 psi is fine at low engine speed, however at higher engine speeds the engine could be sustaining damage due to insufficient oil pressure even though it is above 20 psi. The second pressure element would be activated when the engine speed was greater than say 80% and the oil pressure less than 50 psi.

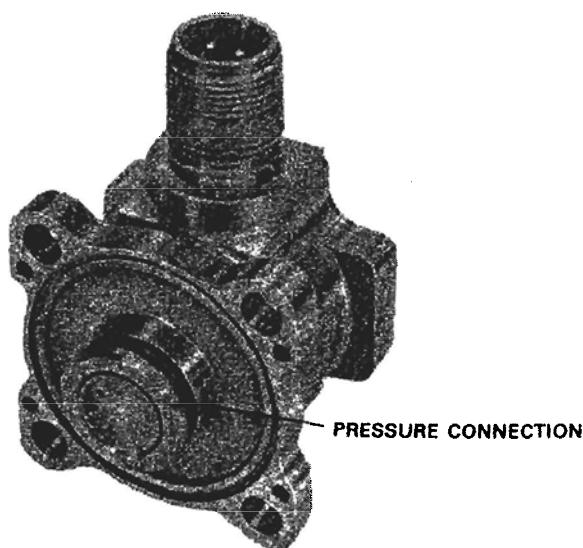
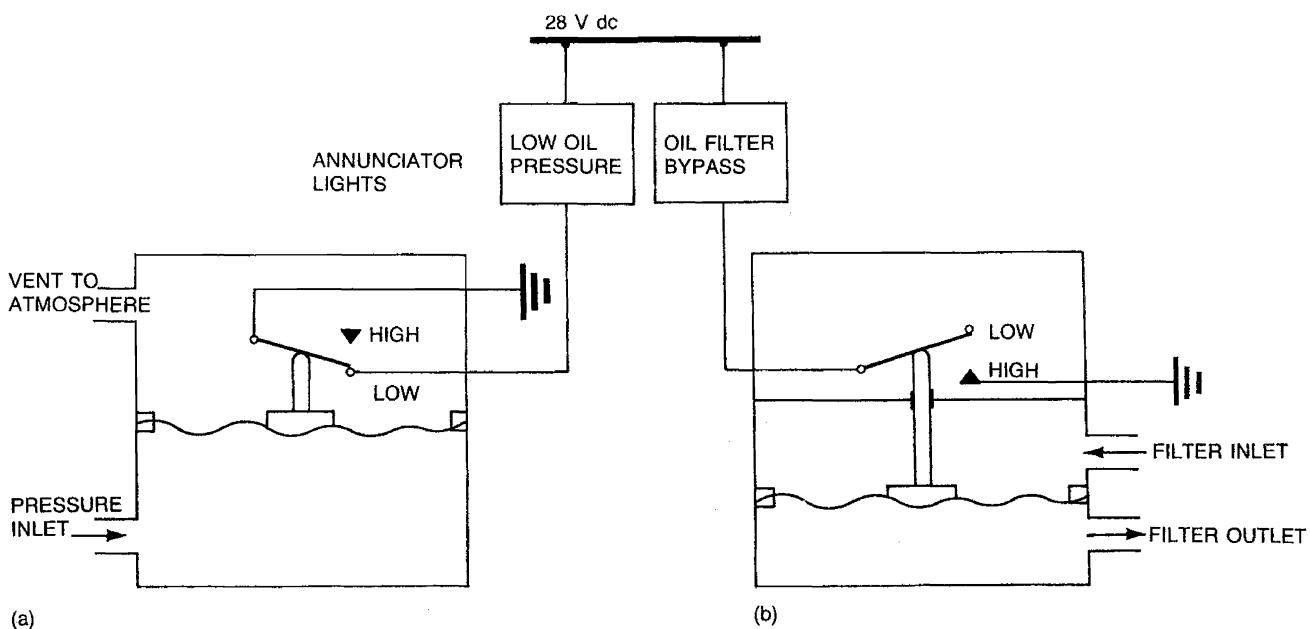


Figure 14.33: Low Oil Pressure warning



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Fuel Flow Indication

Although the amount of fuel consumed during a given flight may vary slightly between engines of the same type, fuel flow does provide a useful indication of the satisfactory operation of the engine.

Vane Type Fuel Flowmeter

A typical system consists of a fuel flow transmitter, which is fitted in the low pressure fuel system the simplest being of the vane type, its position is determined by the speed of flow. This position is then transmitted to the flight deck by either a Desynn or an Autosyn position indicator. Whatever system is used, it required external power.

It will indicate in lbs/hr or kg/hr. It may also indicate the amount of fuel used since the start of the flight, which is a better measure of the fuel usage over a period of time.

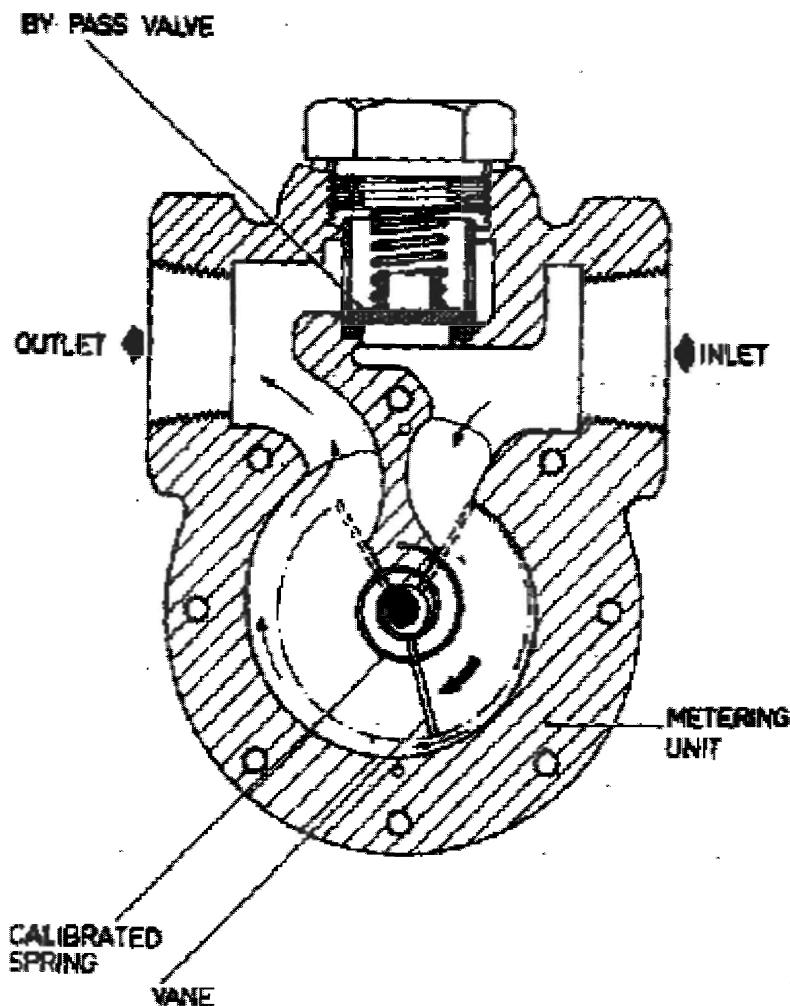


Figure 14.34: Vane type fuel flowmeter



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The vane type flowmeter shown above is generally fitted in the low pressure fuel system downstream of the LP Fuel Pump. Also note that the Bypass valve operates when the differential pressure across the valve increases above a set value, due to the vane seizing.

Synchronous Fuel Flowmeter (Motor driven)

Also known as an Autosyn Fuel Flowmeter

This system, more recently developed than the vane type, is said to have greater accuracy in that it measures mass flow rather than volume. In this way, it compensates for fuel temperature in its read-out.

The system measures in kilograms or pounds per hour. Fuel enters the transmitter impeller, which is rotated at a constant 60 revolutions per minute by the synchronous impeller motor. The temperature of the fuel will determine its volume and the amount of force to be created by the action of the impeller.

The turbine is twisted against its restraining spring by the mass flow force created by impeller movement. The mass flow electrical transmitter arrangement is similar to the vane type system.

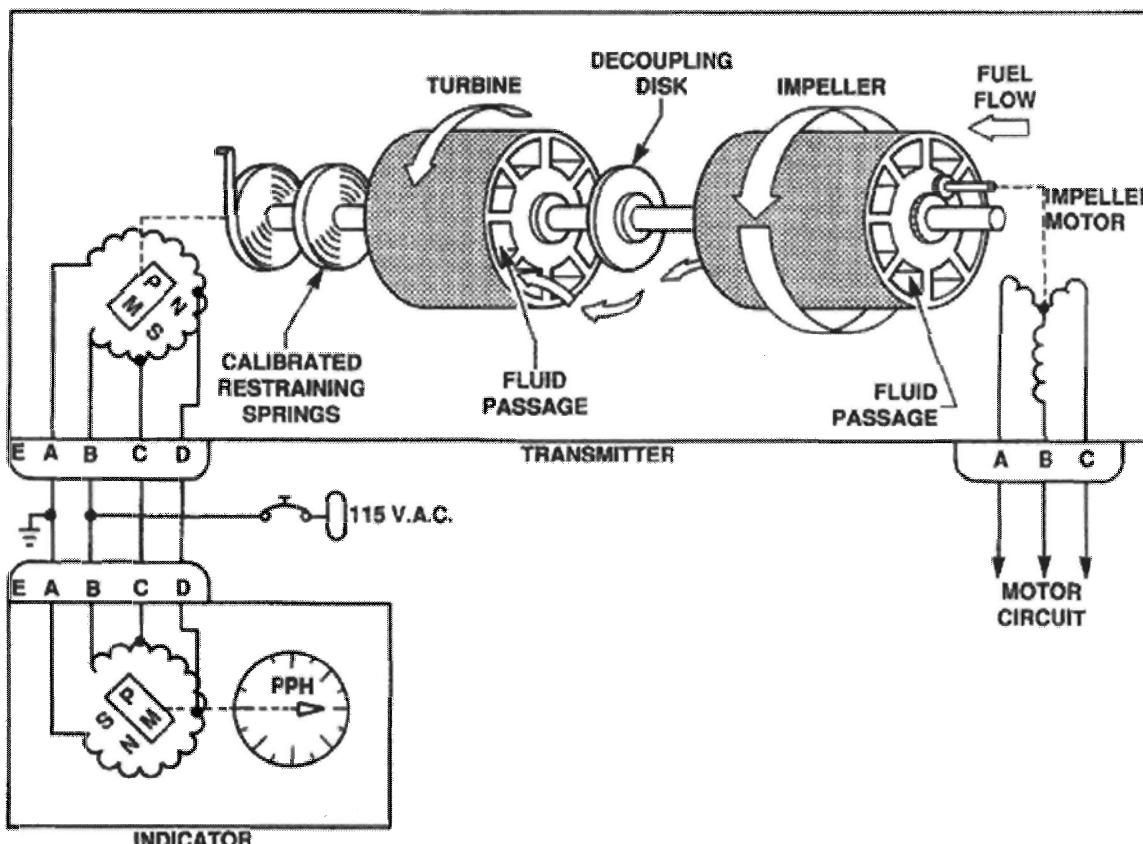


Figure 14.35: A mass-flow type flowmeter system



The Motorless Integrated Fuel Flow Transmitter

This type of fuel flow transmitter consists of a housing containing a swirl generator, a free-spinning rotor and a turbine, which is restrained by a spring attached to the housing.

Two permanent magnets are fixed, 180 degrees apart, at the forward and aft end of the rotor. With each complete revolution of the rotor, the forward end magnet induces an electrical pulse in a small coil mounted on the outer wall of the housing. This is known as the 'start' pulse. The aft end magnet aligns with a signal blade fixed on the turbine. As the magnet passes the signal blade, another pulse is induced into a second, larger coil, which is also on the outer wall of the housing. This is known as the 'stop' pulse.

One 'start' pulse and one 'stop' pulse are generated through the coils at each revolution of the rotor. If the rotor could spin without fuel flow, the start and stop pulses would occur simultaneously.

When the fuel starts flowing, the rotor spins at a speed that is proportional to the fuel flow and the signal blade on the turbine, restrained by the spring, begins to deflect along the path of rotation. The stop pulses now begin to occur after the start pulses.

As the mass flow (weight) of fuel through the transmitter increases, the turbine deflects further and further, and the time difference between the start and stop pulses increases proportionally. It is this time difference which is measured by the ECU, and converted to Fuel Flow and Fuel Used values, which are then made available to the A/C for cockpit indication. The operating range of the fuel flow transmitter output is from 0 to 170 milliseconds, which corresponds to a fuel flow range of 0 to 27000 lbs/hr.

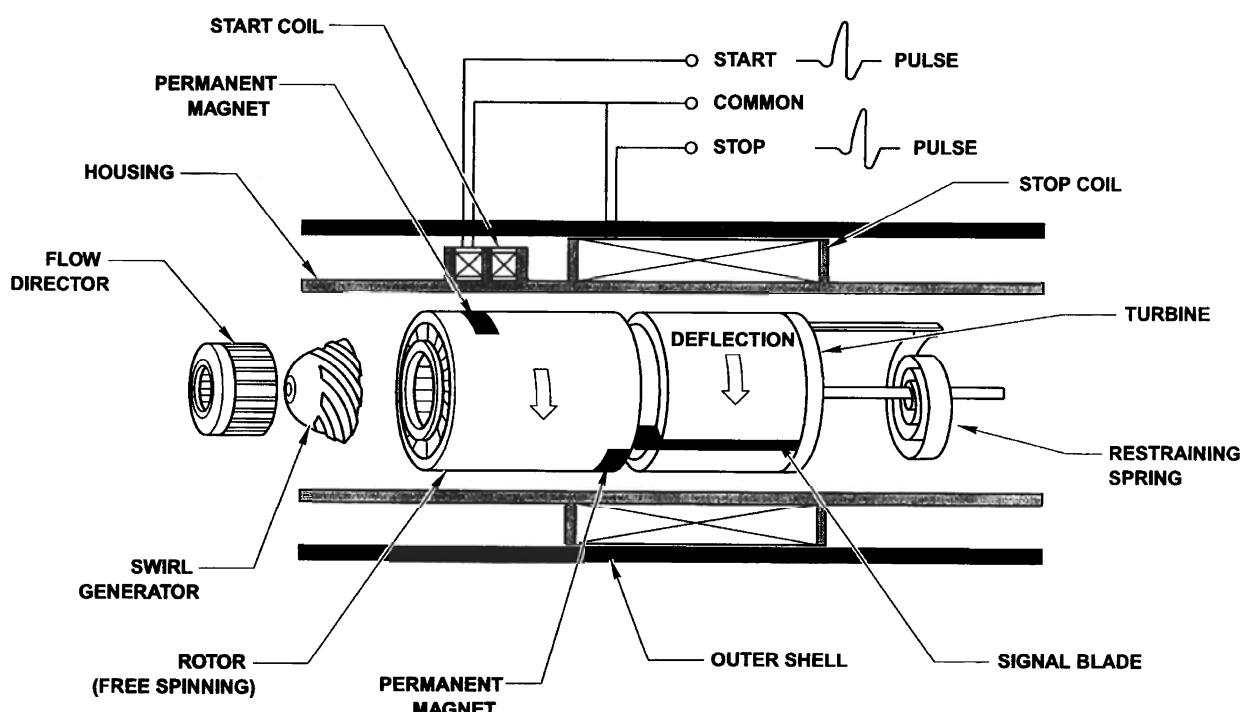


Figure 14.36: Motorless integrated fuel flow transmitter



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The Synchronous Integrated Fuel Flowmeter

This is an integrated Fuel Flowmeter that uses a 60V AC synchronous motor to impart swirl to the device. It still uses the pulse difference method to produce a signal. This was developed as an interim between the synchronous motor type and the motor less integrated type.

An integrator is essential if total fuel used is to be measured as the Kg/hr figure must be integrated to produce Kg alone.

Maintenance Practices

Fuel flow transmitters that are not installed within 24 hours must be treated to prevent corrosion. Fill the transmitter with engine oil to coat all internal parts, then drain. Install protective covers on the open ports.



Engine Speed

Because no two engines and no two compressors N1 and N2 operate at the same speed, percent revolutions per minute is used to simplify the flight deck indications.

There are two systems in common use, often both systems are used on the same engine.

- Tacho-generator
- Phonic wheel and pulse probe

Tacho-generator

The tachometer is an independent electrical system, consisting of an engine driven **three phase** AC generator and a synchronous motor driven indicator. The frequency of the generated current is dependent upon the speed of the engine. The tacho-generator is connected to the main gearbox, which is driven by the high pressure spool, and therefore is most commonly used to indicate the HP spool speed.

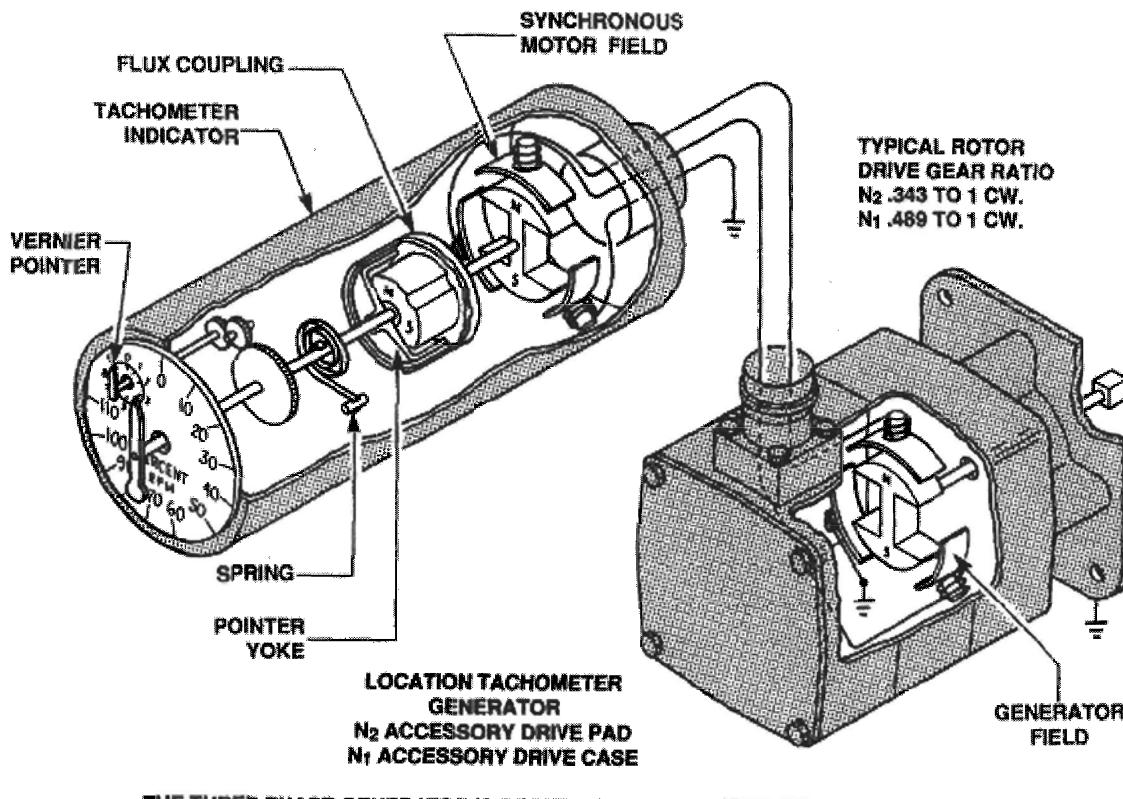


Figure 14.37: Tacho Generator



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Phonic Wheel and Pulse Probe

Often called a "Variable Reluctance" system. It consists of either one or two permanent magnets in close proximity to a toothed wheel on the engine shaft called a "phonic wheel". However, no contact is made with the wheel. A pickup coil is situated in the magnetic field, which is greatest when the teeth of the wheel are in-line with the pole pieces as shown, since the magnetism does not have such a great air gap to travel through. The resulting fluctuating induced current in the coil has a frequency proportional to the speed of the engine shaft. This can then be indicated in a similar way to the tacho-generator indicator.

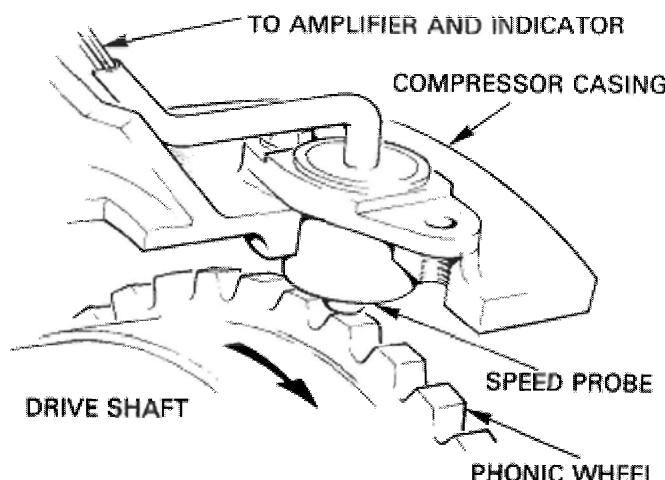


Figure 14.38: Pulse probe tachometer



Vibration Indication Systems

A turbine engine has an extremely low vibration level and a change in vibration, due to an impending or partial failure, may go unnoticed. Many engines are therefore fitted with vibration indicators that continually monitor the vibration level of the engine.

Early vibration transducers were of the moving coil type and up to three could be located at strategic locations around the engine (HP Compressor case, LP Turbine case etc). The units of vibration for these systems were in terms of Relative Amplitude

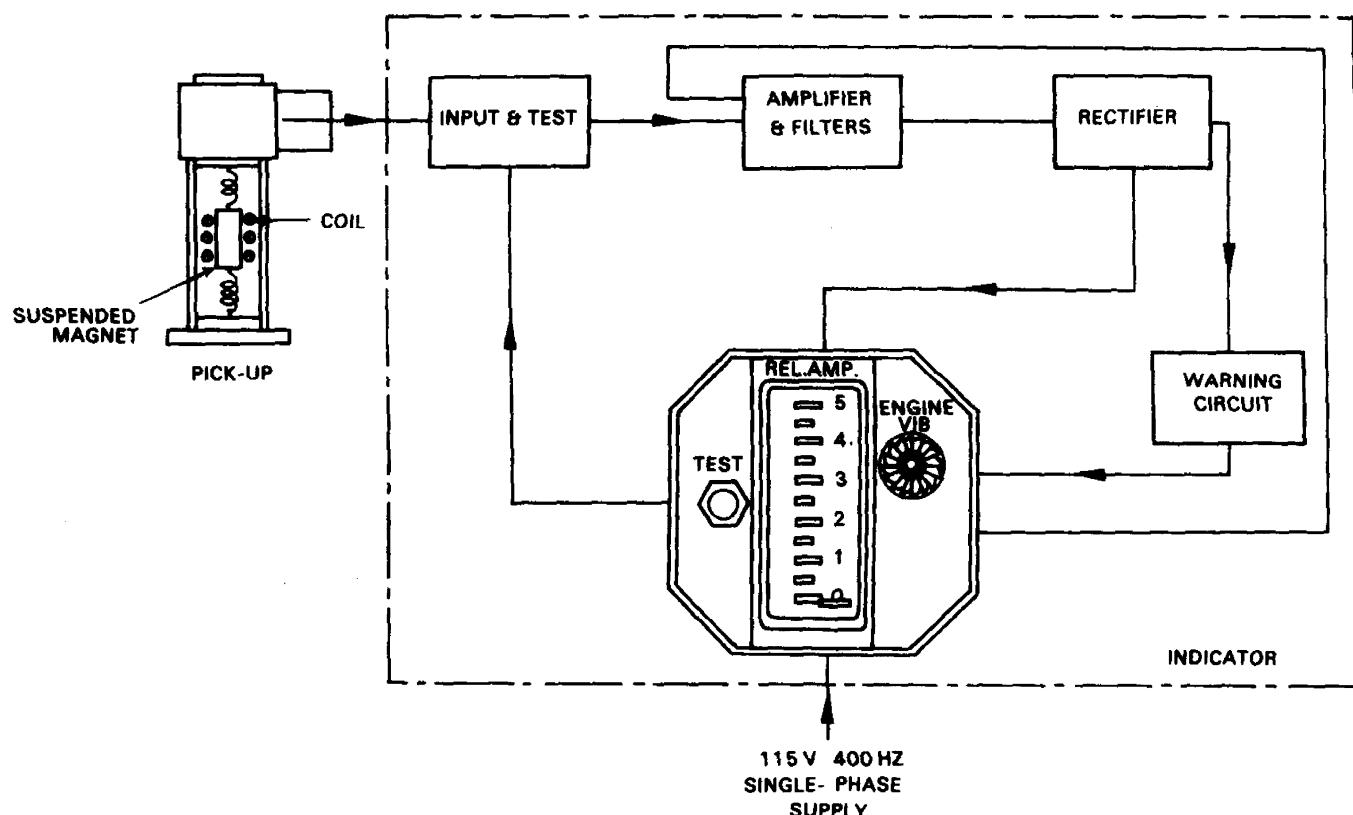


Figure 14.39: Vibration indicating system

An alternative system consists of a piezo-electric crystal and a mass inside a casing. As the engine vibrates, the mass will exert a force upon the crystal which will emit a small alternating current of a frequency equal to the frequency of vibration. This is then amplified and displayed in the flight deck via an ammeter.



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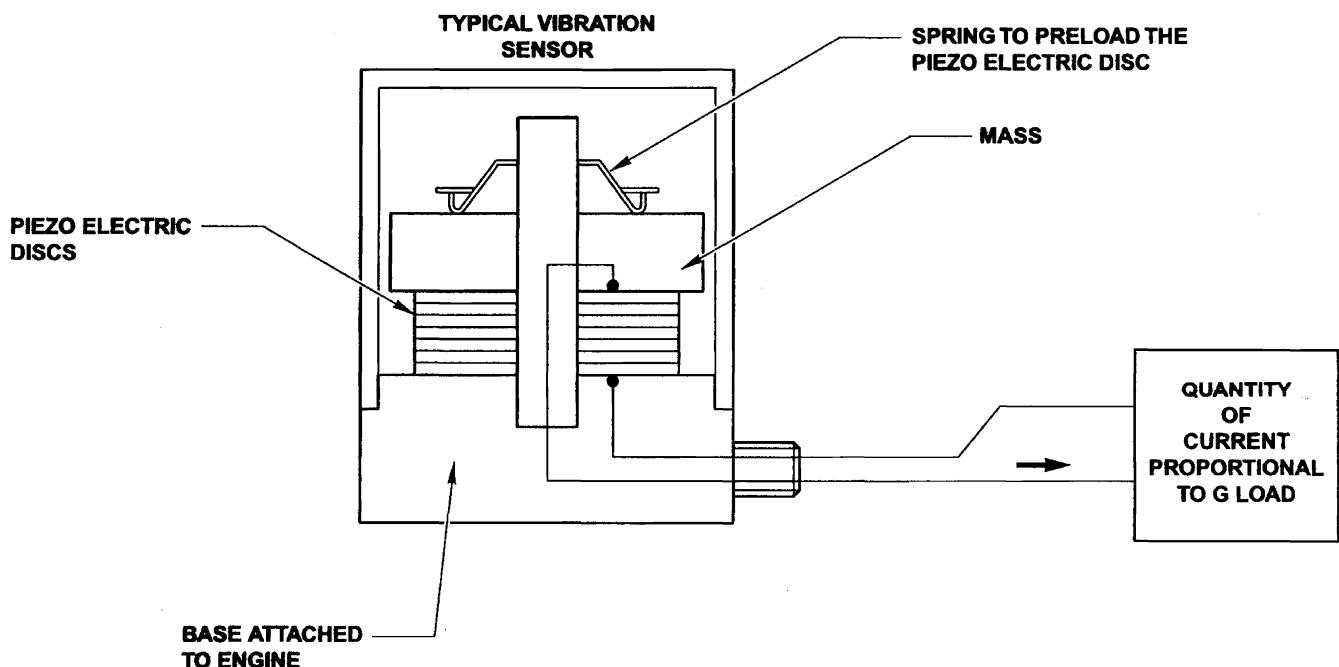


Figure 14.40: Piezo Electric Vibration Transducer

More modern systems have a pair of piezoelectric crystals contained within the same housing. This provides for dual channel redundancy. Each transducer detects a **broadband** vibration signal that reflects all the vibrations in the engine. This broadband signal is processed by a micro-processor and the frequency of the rotating spools (N1, N2 and for RR engines N3) so that the amplitude of vibration of these major assemblies can be displayed, usually on EICAS or ECAM.



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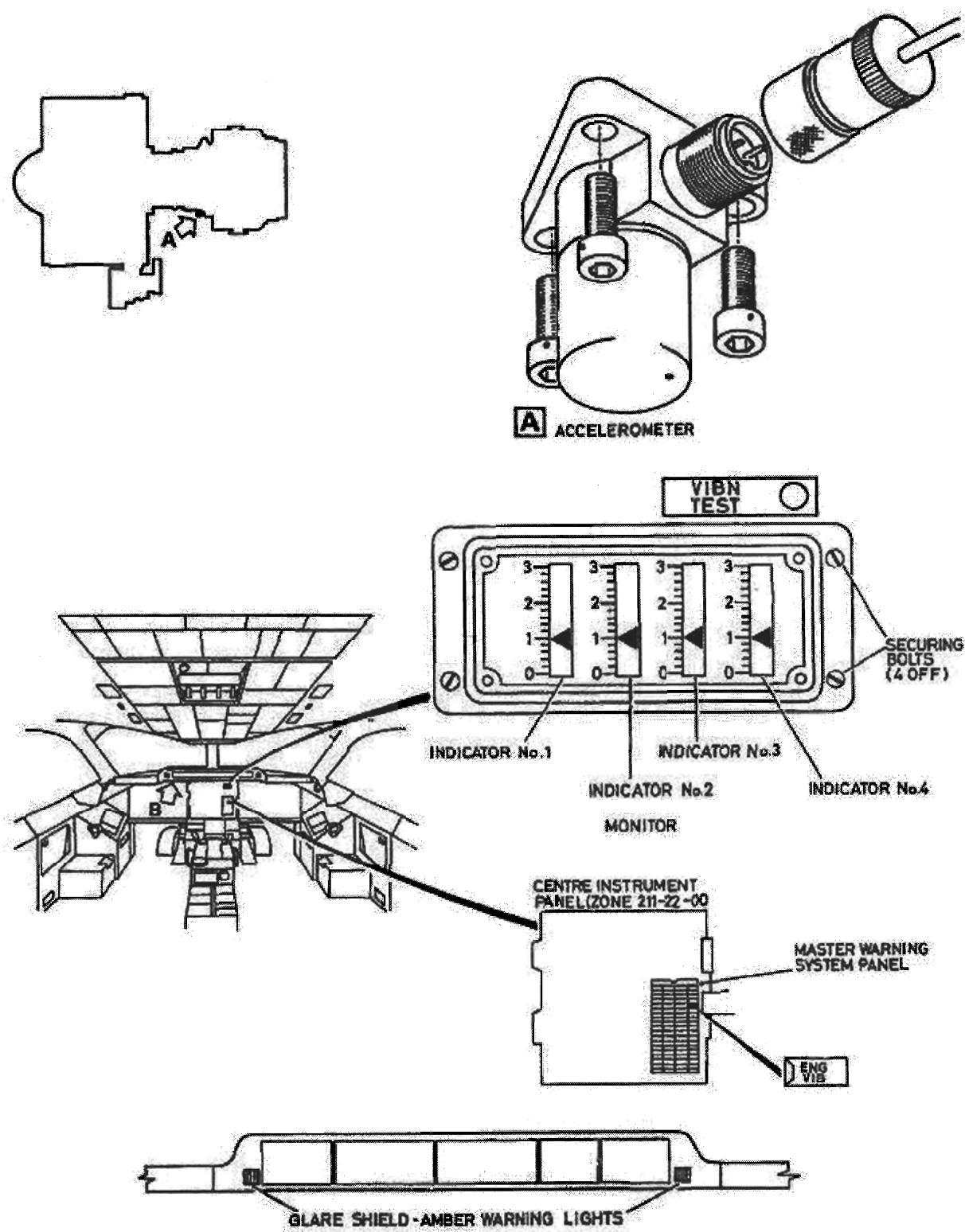
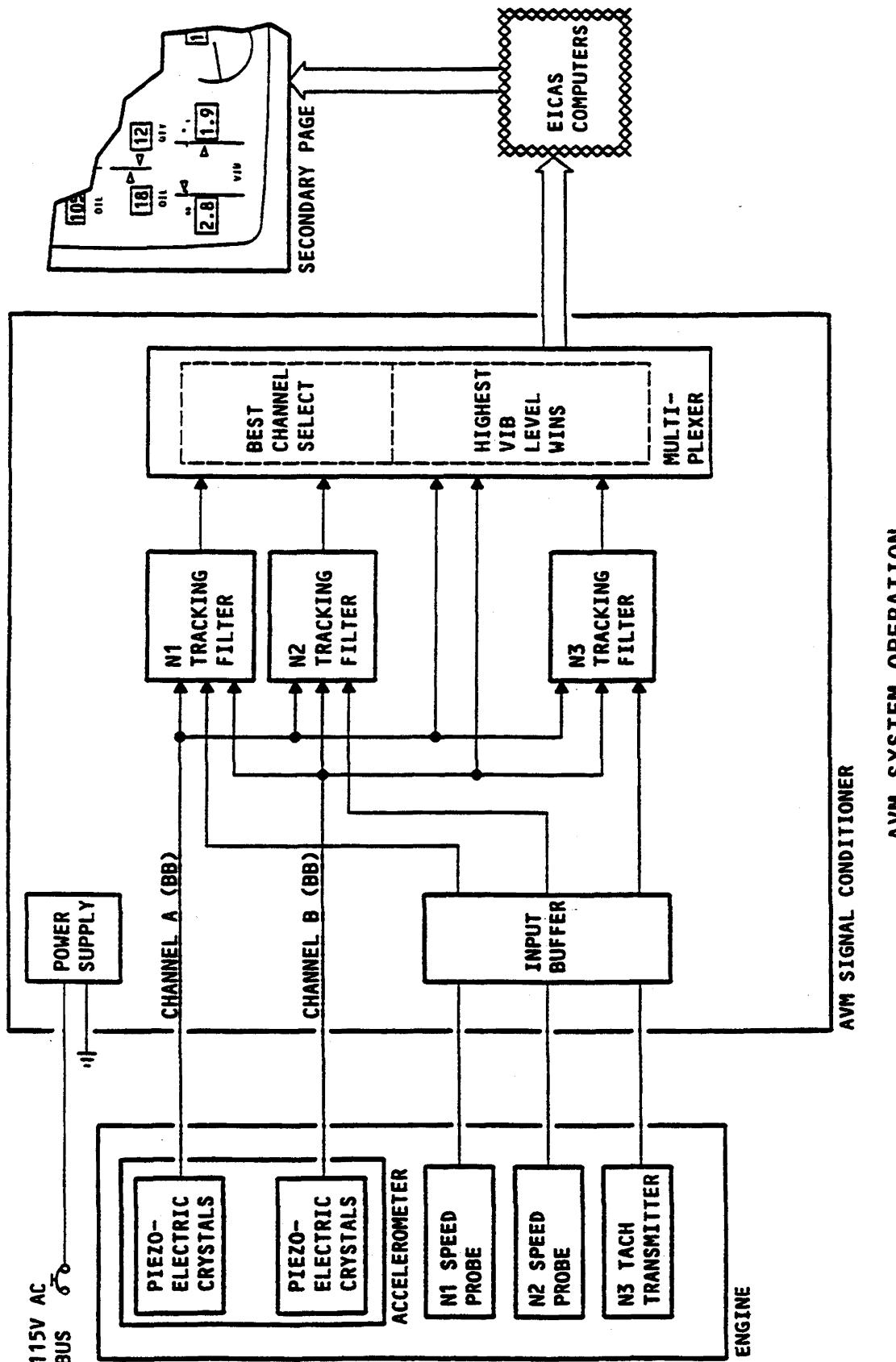


Figure 14.41: Vibration indicating system



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AVM SYSTEM OPERATION

Figure 14.42: Vibration indicating system



Torque Indicating System

A torque indicating system is essential on all torque producing engines, such as turboprops and turbo shafts. It is the primary performance instrument in the flight deck.

Torque may be presented in a number of ways, such as torque oil pressure (PSI), direct torque (ft-lb), torque percent or a direct horsepower reading.

Most systems work on one or the other of the following principles;

- 1 The fact that as torque increases, the output shaft twists slightly with a magnitude which is directly proportional to the torque being transmitted through it. This angle of twist can be measured by a number of ways, e.g.
 - Hydro-Mechanical sensor
 - Electronic sensors
 - Strain Gauge sensors

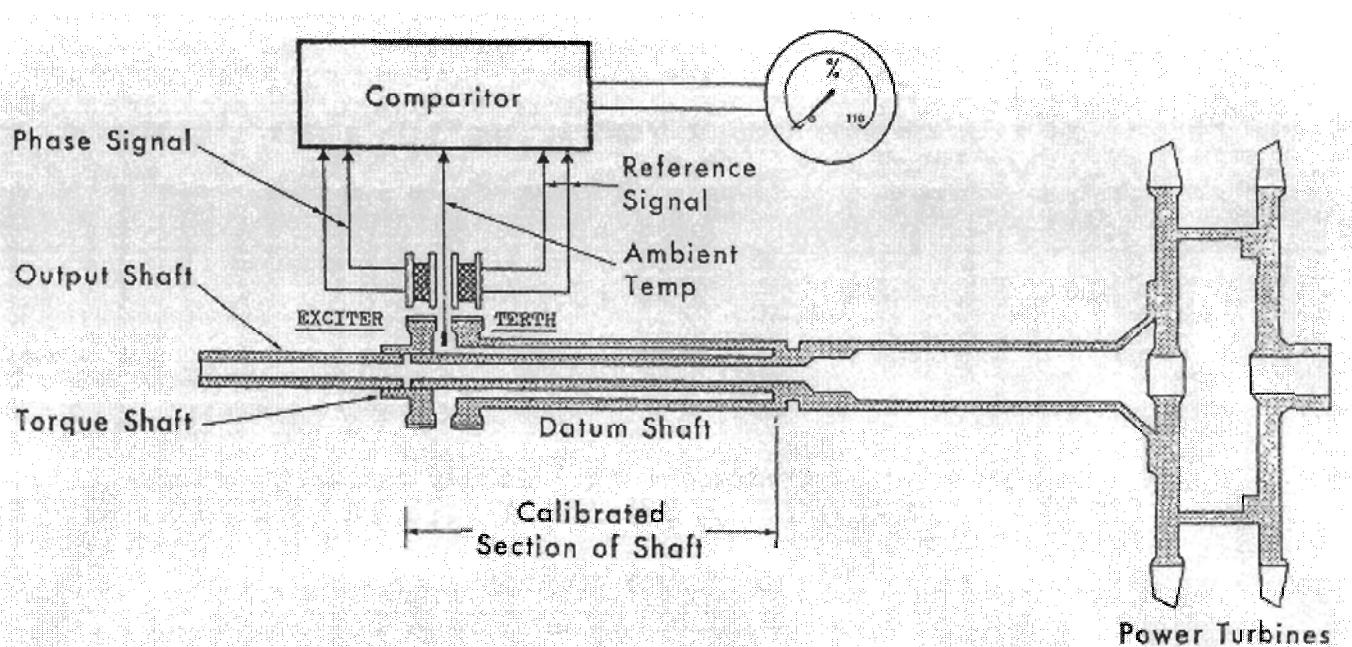


Figure 14.43: Phase comparison torque indicator

- 2 A series of helical gears inside the reduction gearbox will produce an axial thrust proportional to the torque that they transmit. This axial thrust can be used to pressurize oil and the oil pressure is indicated in the flight deck. The gauge is calibrated in PSI.



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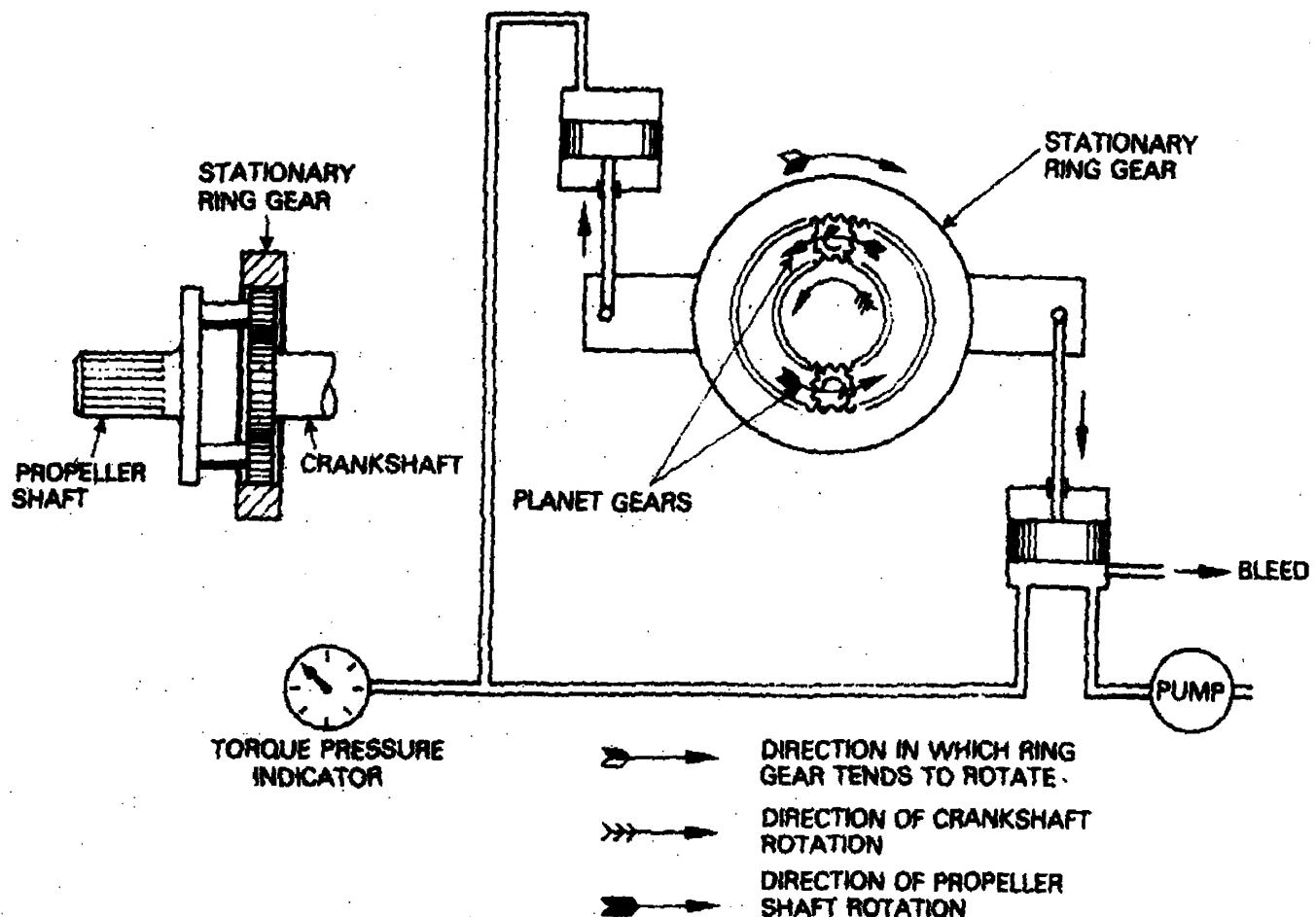


Figure 14.44: Torque pressure indicator



The torquemeter measures hydraulically the axial load produced by the helical gears when transmitting a driving torque to the propeller

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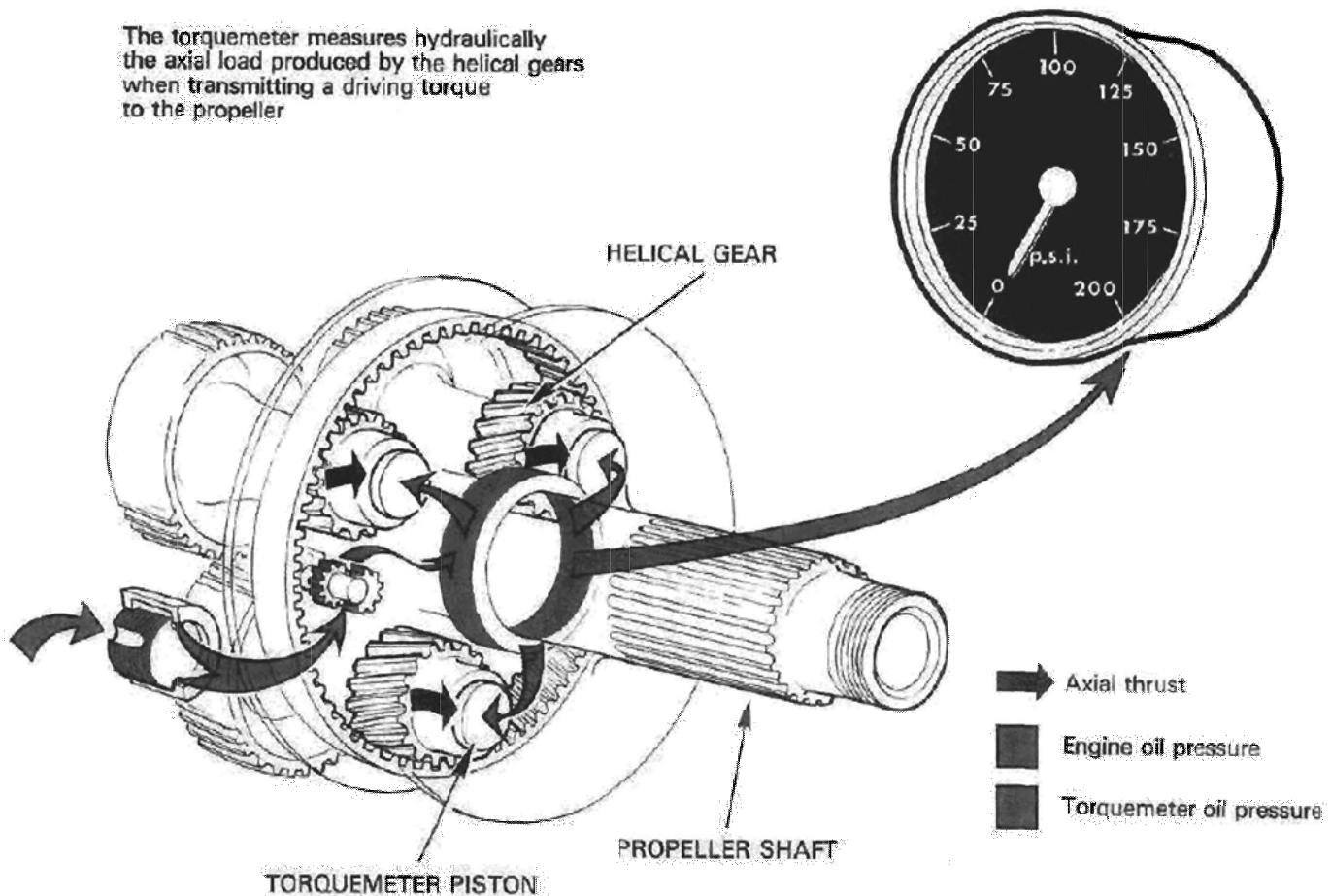


Figure 14.45: Helical Gear Torque Meter



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Module 15.14 Engine Indication Systems

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Module 15 Licence Category B1

Gas Turbine Engine

15.15 Power Augmentation Systems



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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.15 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module15.15 - Power Augmentation Systems

Introduction

The thrust produced by any gas turbine engine depends upon the following two things:-

- The mass of air drawn into the engine
- The increase in speed of that mass of air

If for any reason, any of the above are reduced, the thrust will be reduced.

Power Augmentation is the process of either;

- increasing the normal engine power at sea level (to take-off with heavier loads, or for military interception)

or

- restore the engine power output to standard sea level conditions, in situations of high atmospheric temperature, or high altitude airfields, or both.

Types of Thrust Augmentation

There are two methods of thrust augmentation, each working on a completely different principle, as the following pages describe.

- Reheat (or afterburning) system
- Water/Methanol Injection system



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Reheat System

This system is normally only used on turbo-jet or turbo-fan engines to augment the thrust of the engine for short periods, e.g. takeoff, climb, acceleration. Increases in thrust ranging from 5% to 100% are possible - but they are expensive in extra fuel.

The increased thrust is obtained by injecting and burning large quantities of fuel in the specially shaped engine exhaust system. The resulting combustion causes a large increase in gas temperature, giving a rapid expansion of the gases and thus an increase in the exhaust gas velocity. By Newton's third law, there is a reaction to this increase in speed called THRUST.

Note: Reheat system does not increase the mass of air entering the engine, nor does it affect the operation of the rest of the engine. It therefore works on the second of the two principles of THRUST as listed above under "Introduction" - that is increasing the speed of the air.

Reheat System Components

The following components are likely to be found in a typical reheat system:-

- Fuel flow control unit
- Engine driven fuel pump
- Reheat Jet Pipe - including fuel spray rings, flame stabilisers and Screech Liner
- Variable area final nozzle
- Nozzle control; system
- Ignition system



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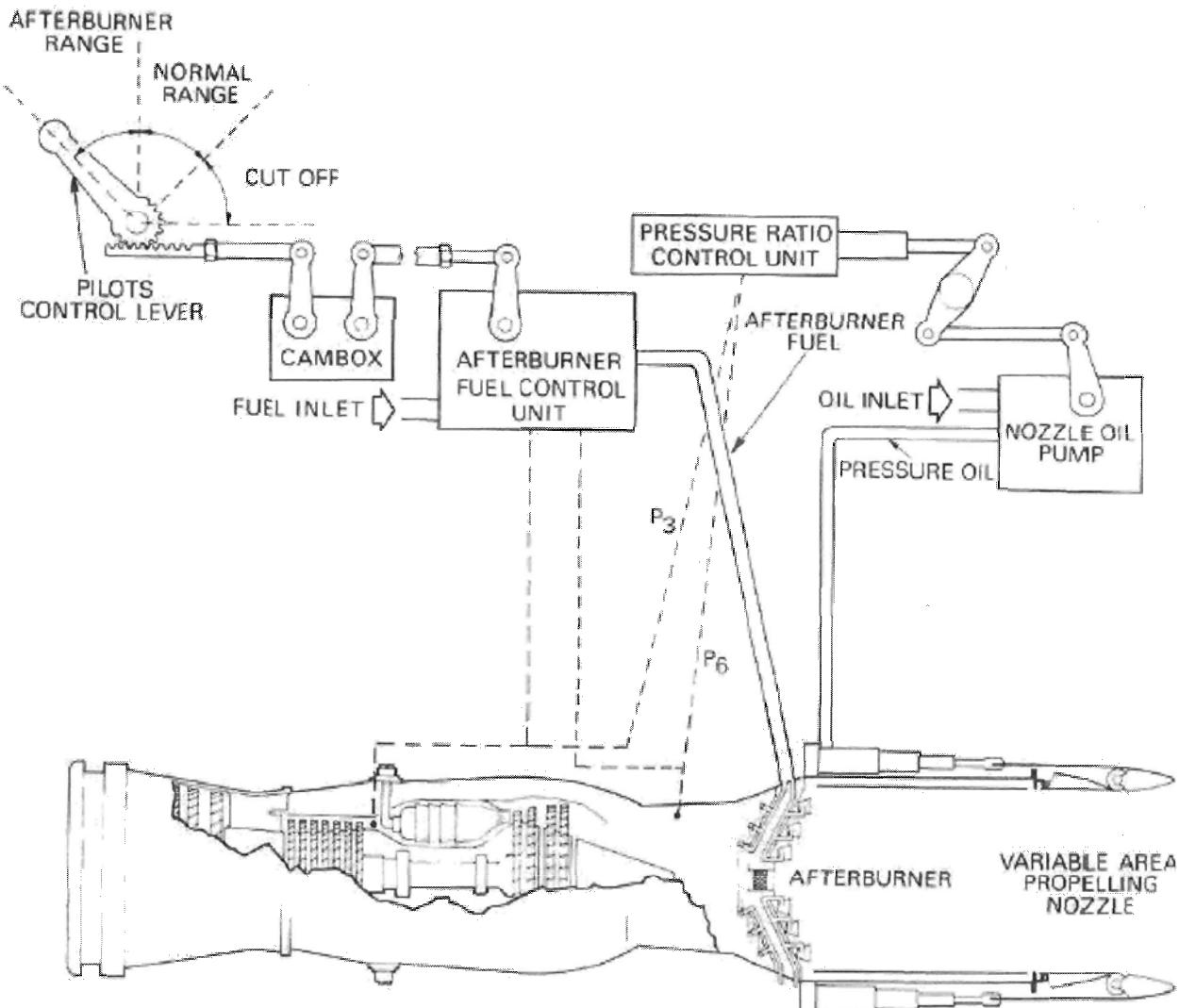


Figure 15.1: Simplified control system

Fuel Flow Control Unit - This unit receives a signal from the throttle lever only when it is in the reheat range (via a cam-box), and senses signals from the compressor outlet (P_3) and exhaust (P_6). It uses these values to determine and control the amount of fuel flow to the reheat burners to match the available airflow.

Engine driven fuel pump - The large quantities of fuel needed by the reheat system is supplied by this pump. It is not shown on the diagram but is situated before the afterburner fuel control unit.

Reheat Jet Pipe - The jet pipe on an engine with reheat is wider and constructed from stronger materials than a normal jet pipe. An internal shield (Screech Liner) is fitted to reduce the thermal and vibratory stresses that sometimes occur inside the jet pipe due to rapid fluctuations in pressure (called "Screech"). These vibrations can sometimes be severe and destructive so the Screech Liner is likely to be made of a strong and heavy material.



Several concentric fuel spray rings or spray "bars" and "V" shaped flame stabilisers are fitted at the front of the jet pipe. These provide the low velocity air circulation for good air/fuel mixing, good combustion and flame stability.

Variable area final nozzle - When combustion takes place in the reheat jet pipe, the rapid expansion of the gases results in an increase in velocity. If the exit area of the nozzle were not increased to allow the expanding gases to escape, the exit nozzle would cause a restriction and there would be a build up of pressure inside the jet pipe.

This increase in pressure is effectively a back pressure which is felt right back through the engine and could cause compressor stall or surge. To prevent this happening, a variable area final nozzle is fitted. The nozzle is normally closed (convergent) when reheat is not operating, and it is opened just sufficient to stop a "back pressure" developing (as sensed by the P_3 and P_6 sensors). In use the nozzle may be parallel or more likely slightly divergent. The nozzle is moved by a system of hydraulic rams (automatic nozzle control system).

Nozzle Control System - This consists of an automatic control unit and a series of rams to move the nozzle itself. The unit receives sensing signals of P_3 and P_6 and adjusts the nozzle area by the use of the rams to maintain the correct ratio.

Ignition System - injection of the fuel into the jet pipe will not normally cause combustion to take place. Also, the gases are travelling too fast for combustion to be self sustaining even after ignition has occurred. Therefore some form of continuous ignition is required.

There are three ways of providing this;

Spark Ignition functions in a similar way to normal combustion chamber igniters. Light-up is initiated by a pilot fuel supply, and an igniter plug. A tapping from the main fuel flow supplies fuel for the pilot burner. The burner sprays fuel into a region of low velocity inside a cone forming part of the reheat assembly. The igniter plug is of the spark gap type and projects into the cone adjacent to the pilot burner. When reheat is selected, the ignition system is energised via a time switch. The switch will cut out ignition after a pre-determined time.

Hot Shot Ignition

Is operated by two fuel injectors, one spraying fuel into one of the combustion chamber "cans", the other spraying fuel into the exhaust system. The streak of flame initiated in the combustion chamber ignites the fuel/air mixture in the reheat jet pipe. The turbine blades are not damaged by the hot streak because of its relatively low energy content and the fact that reheat is used only briefly.



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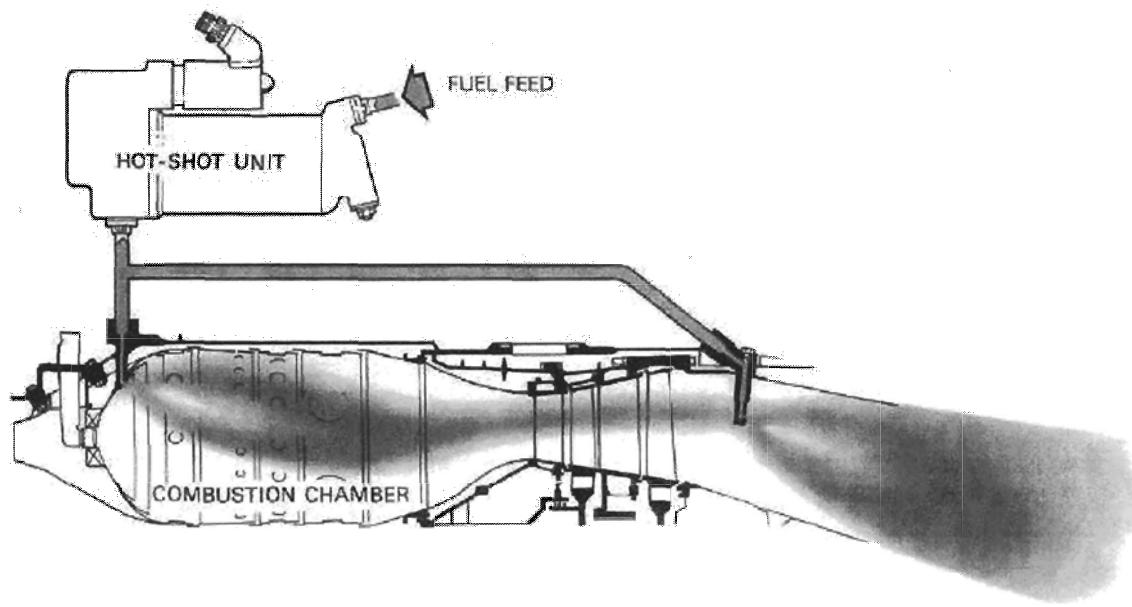


Figure 15.2: Hot-shot ignition system

Catalytic Ignition

Consists of a platinum/rhodium element in a case fitted into a housing secured to the burner hub. The housing contains a venturi tube, the mouth of which is open to the main gas stream from the turbines. Fuel is taken to the throat of the tube and the fuel/air mixture is sprayed on to the element of the igniter. A chemical reaction between the fuel/air mixture and the platinum/rhodium element lowers the flashpoint of the fuel to below the normal temperature of the exhaust gases (about 800°C).

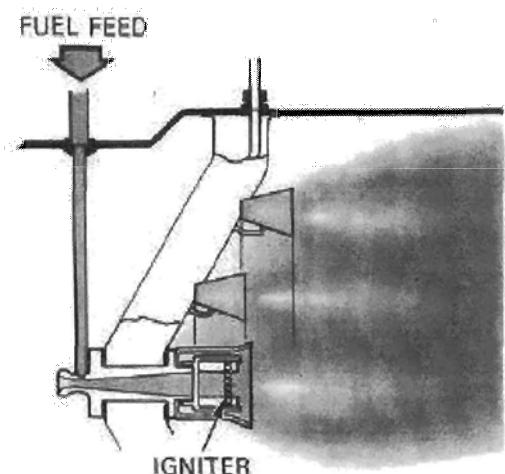


Figure 15.3: Catalytic ignition system



Operation and Control of a Reheat System

A master switch is placed in the "ON" position and the engine throttle lever is advanced beyond the normal engine maximum "dry" power position. This movement operates microswitches, completing electrical circuits, to open fuel valves, operate the fuel pump, and if required power the ignition system. The reheat will light up in the minimum reheat position and the rapid gas expansion will, via the nozzle control system, reposition the variable area final nozzle towards the OPEN position. Any further movement of the throttle forwards will increase fuel flow, increase gas expansion, which increases the thrust, and the nozzle will open further until "max" is reached.

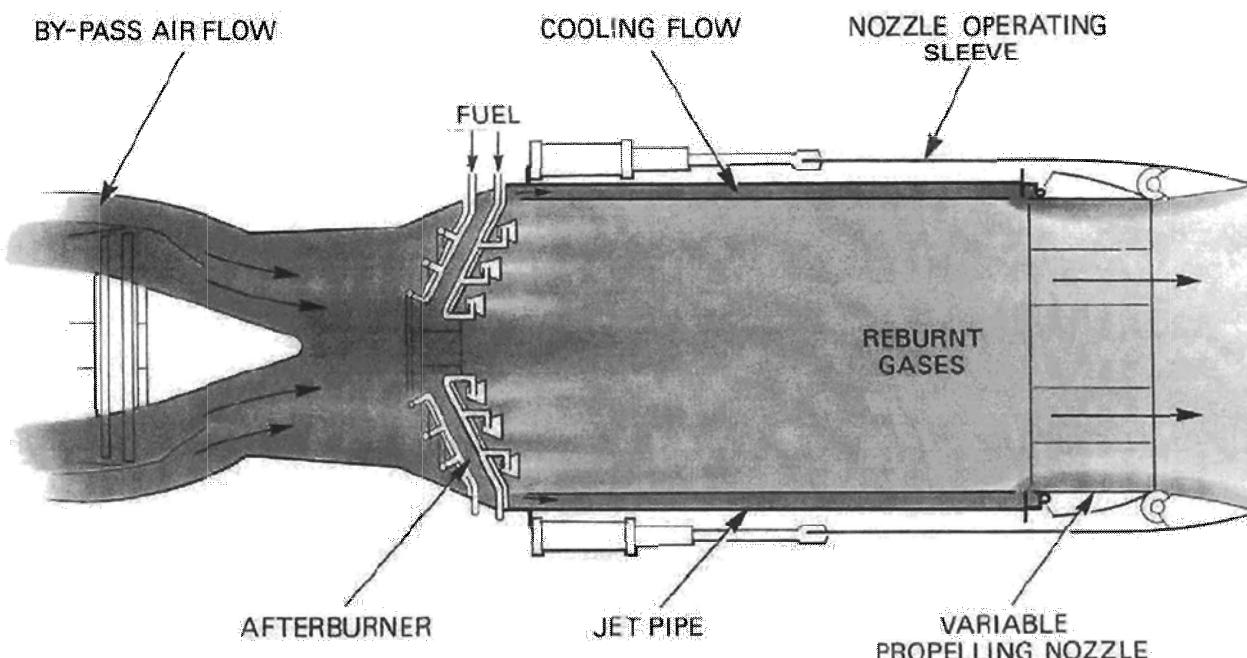


Figure 15.4: Principle of Reheat



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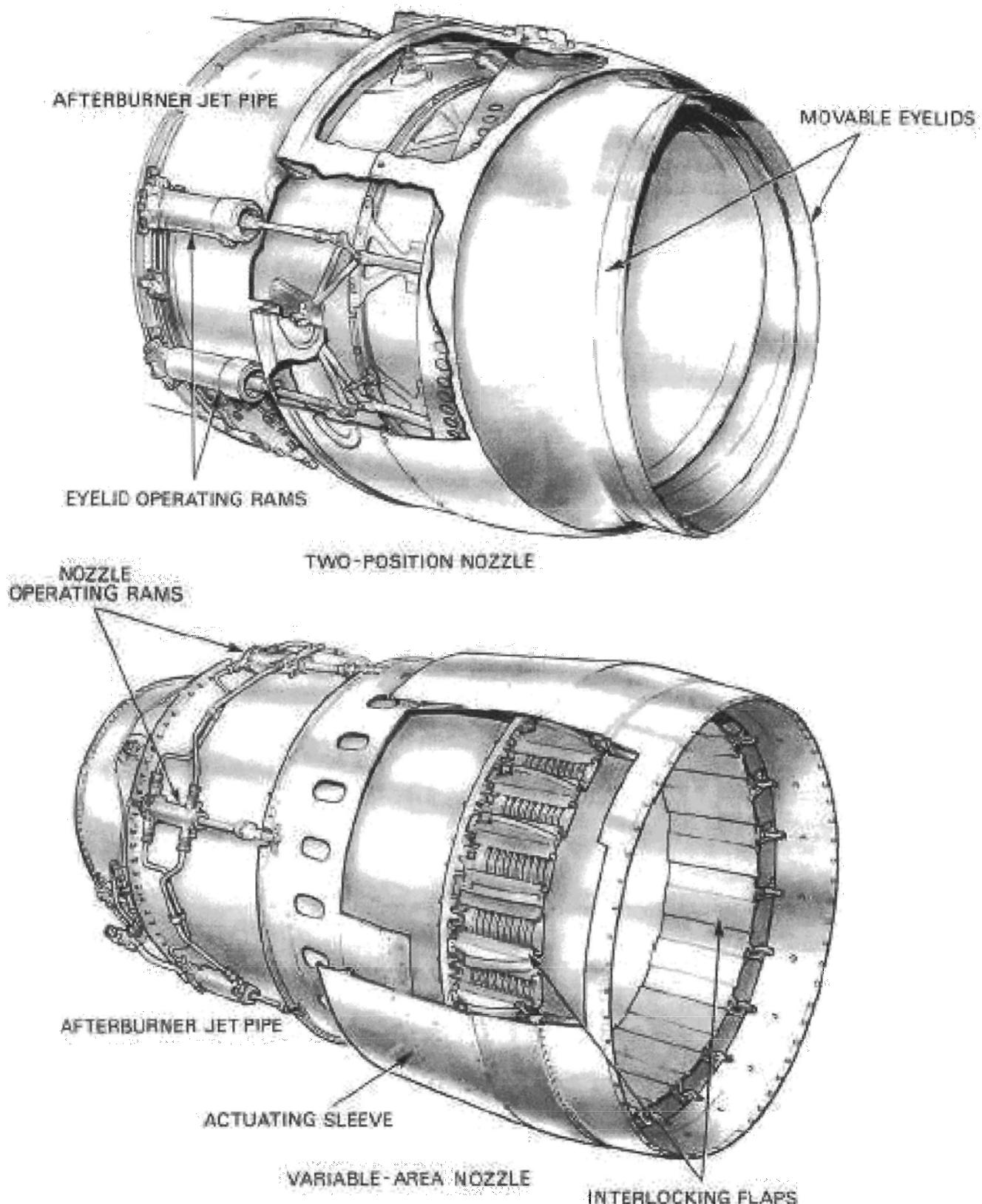


Figure 15.5: Variable Area Nozzle, and Typical Reheat Jet Pipe with Catylitic Ignitor



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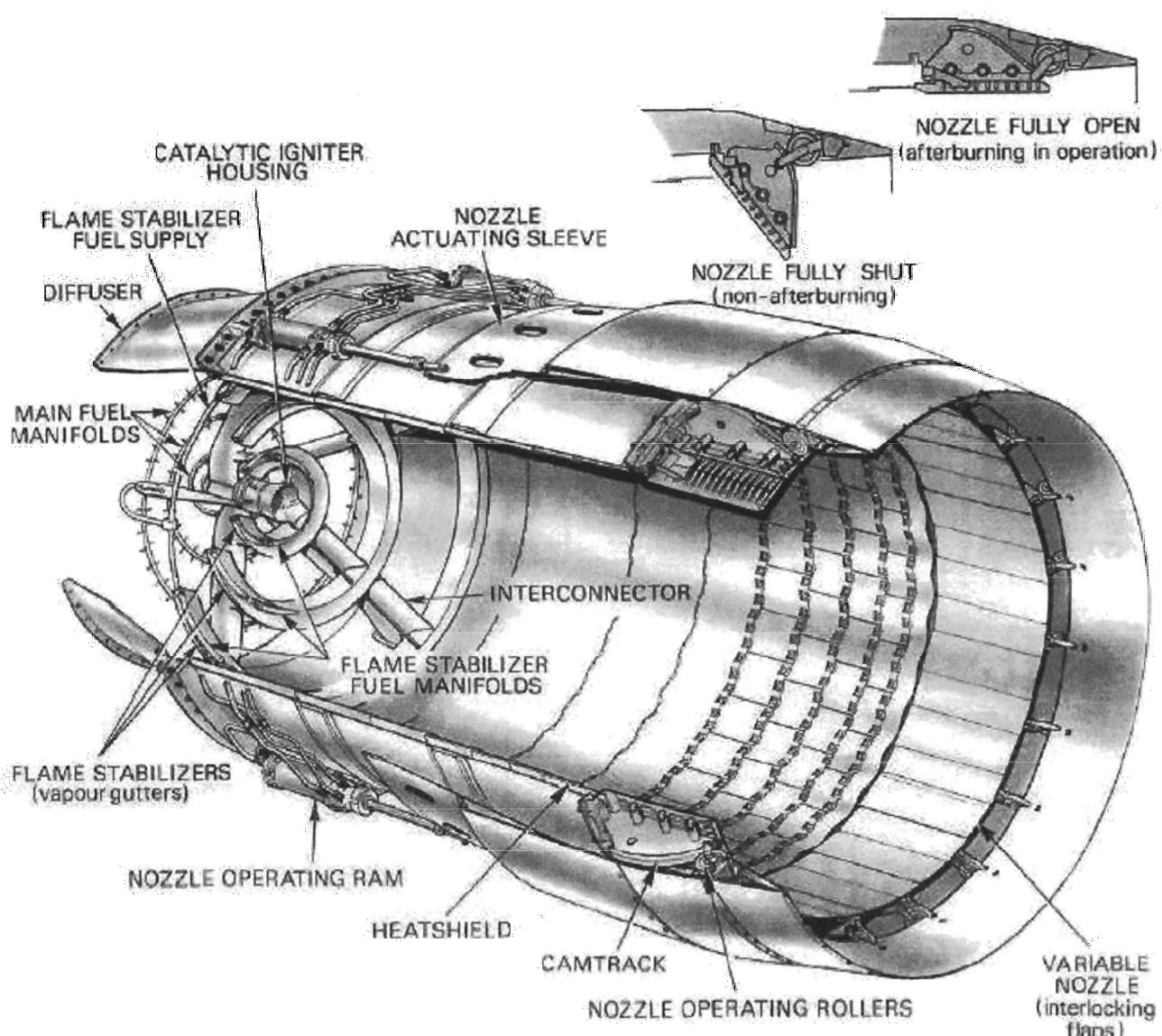


Figure 15.6: Complete reheat assembly



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Water/Methanol Injection

Engine Operation in Adverse Conditions

Adverse conditions, as far as the engine is concerned, is operation in high ambient temperature and/or high altitude. It may be possible for an aircraft to fly into a hot/high airfield with low fuel payload, but to take-off again with full payload of passengers and fuel requires maximum power. In such adverse conditions, the air density is very low hence the mass flow of air through the engine is low.

To compensate for this, the pilot must pump more fuel into the engine to increase the engine RPM. and hence restore the thrust. However, extra fuel means a higher turbine temperature, and this must be limited to protect the turbine components. It may be possible that the turbine temperature limit is reached before the aircraft has enough power to take off.

Water Injection Theory

Water injection increases the thrust by two different methods;

Injection of water into the engine inlet will cool the inlet air and hence its density will increase. The greater the density of air going through the engine, the greater the mass flow, the greater is the thrust of the engine.

When the water hits the turbine components, it will cool them to below the maximum allowable temperature. This will allow the fuel control system to schedule more fuel into the engine, and thus increase the engine RPM to a point where the turbine temperature again reaches its limit OR the maximum RPM is reached.

The water flow rate for the required turbine temperature reduction is set by the engine manufacturers. Generally, water/air ratios are 1-5:100 by weight. The quantity of water carried is usually sufficient for ONE "wet" take-off only.

Take off thrust can be increased by 10 to 30% by the use of water injection.

Water/Methanol Injection Theory

It can be seen that the fuel control system schedules more fuel into the engine to increase the engine RPM. If the fuel was mixed with the water then there would not need to be any adjustment to the fuel control system, as the fuel in the water would ignite and therefore turn the turbines with greater speed.



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Why methanol?

Methanol is used for two reasons; the first is that it acts as an anti-freeze for the water in the water tank, and secondly, it is the only fuel that will mix completely with water. As it is a fuel it will increase the power output if it is burnt in the combustion chamber, albeit not by a lot as methanol has a low calorific value.

Note that the prime purpose of Methanol is anti-freeze not increase in fuel for burning.

Types of System

The water or water/methanol may be injected either into the compressor inlet, or the combustion chamber inlet. The latter is more suitable for engines with an axial flow compressor. This is because a more even distribution can be obtained and a greater quantity of coolant can be satisfactorily injected. Also, the greatest advantage of the water injection system is the cooling of the turbine components. The gain due to reduction of inlet air temperature can usually be neglected.

In the combustion chamber inlet injection system, a non return valve must be fitted in the water delivery pipe to prevent Compressor Delivery Pressure entering the water injection system components.

Note: Demineralised water is used to avoid fouling the compressor or turbine blades, etc. with the impurities normally found in household drinking water. The water should contain no more than 10 parts per million of solids or the life of the engine may be seriously reduced.

Note: Methyl/ethyl mixtures will generally be a blend of 35 to 50 percent alcohol in either demineralised or distilled water.

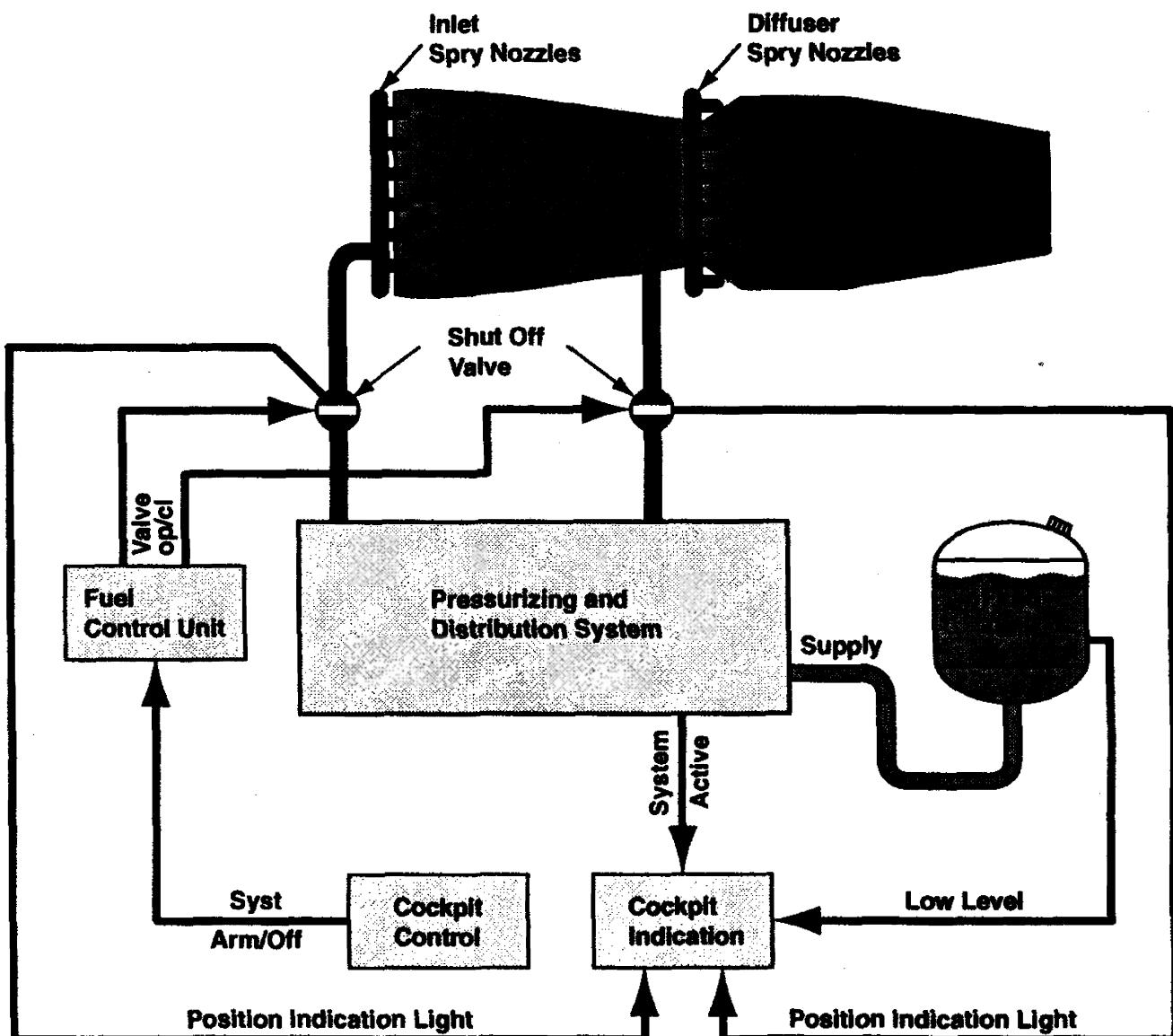


Figure 15.7: Simplified Water Injection System



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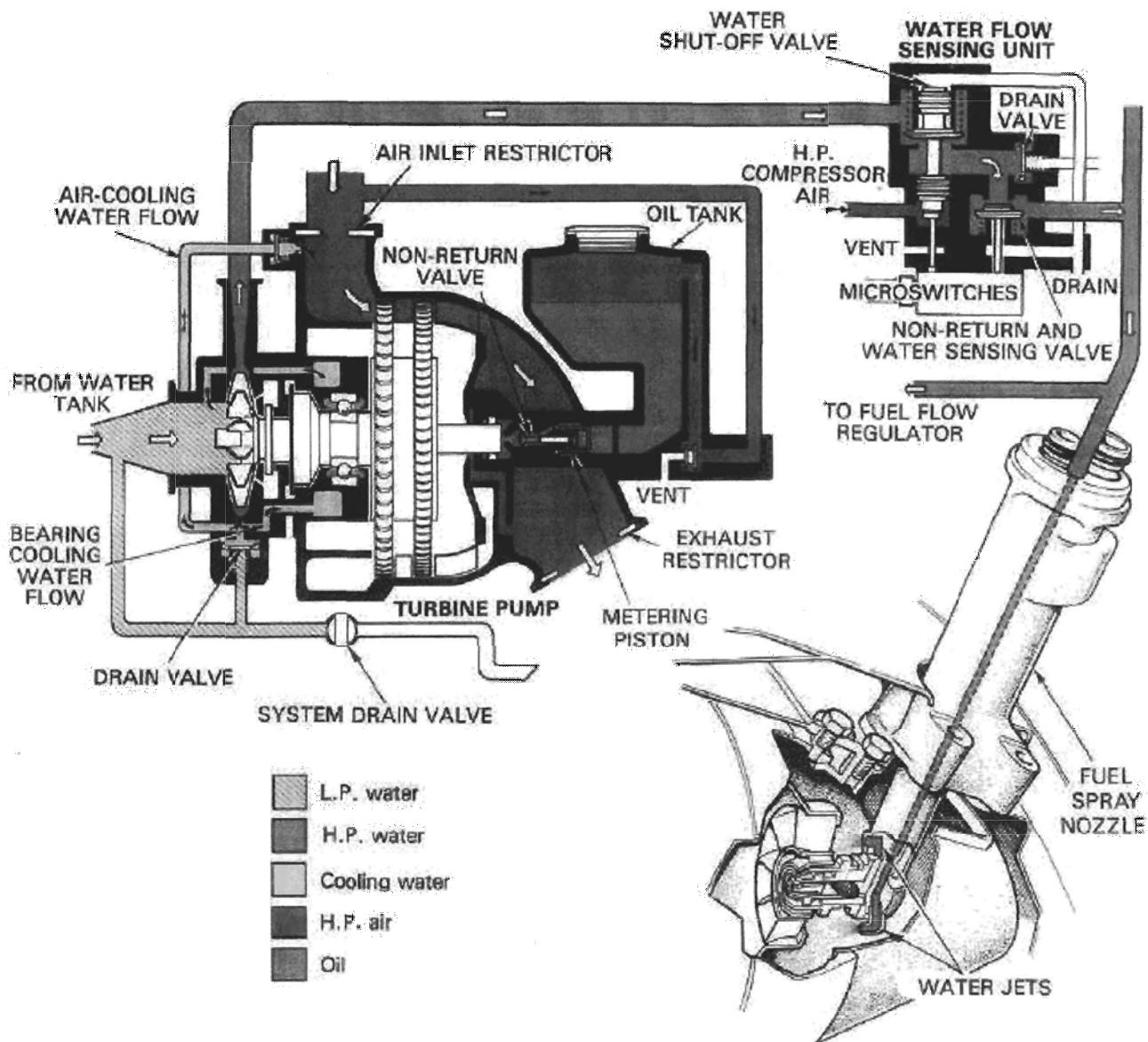


Figure 15.8: Water injection schematic

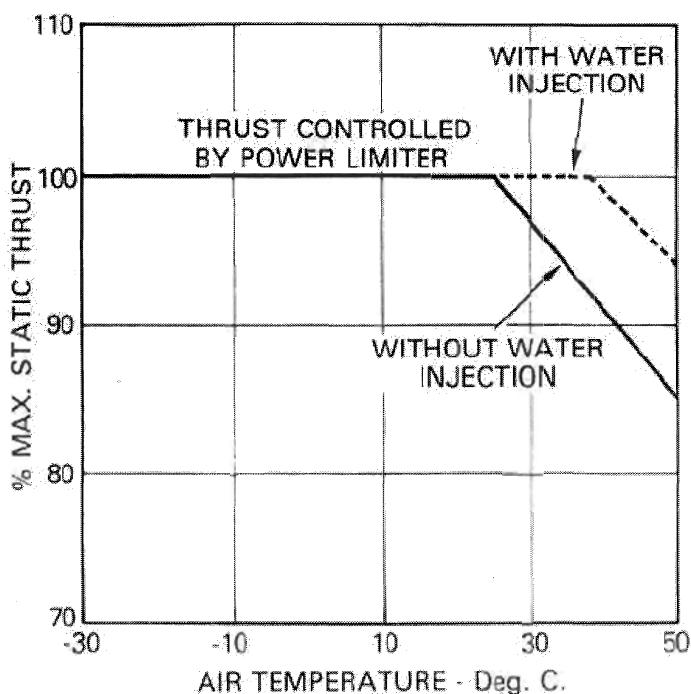


Figure 15.9: Turbojet thrust restoration

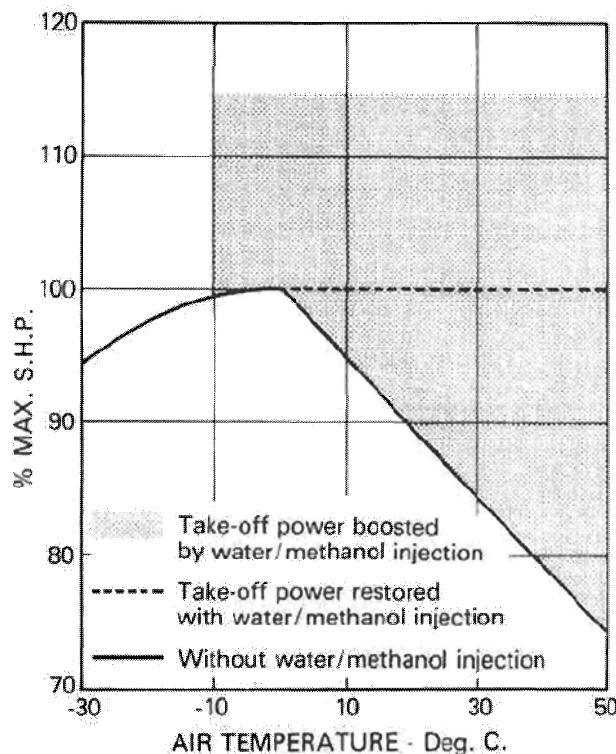


Figure 15.10: Turbo-propeller power boost



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TTS Integrated Training System

Module 15 Licence Category B1

Gas Turbine Engine

15.16 Turbo-prop Engines

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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.16 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:

Objective	EASA 66	Level
	Reference	B1
Turbo-prop Engines	15.16	2
Gas coupled/free turbine and gear coupled	turbines;	
Reduction gears;		
Integrated engine and propeller controls;		
Overspeed safety devices.		
	</	



Module 15.16 - Turbo-prop Engines

Introduction

A turbine engine can drive a propeller by extracting some of the energy that remains in the exhaust gases after they have driven the compressor. This can be done by connecting the propeller to the compressor through a set of reduction gears. But the propeller can be more efficiently driven through appropriate reduction gears by a turbine separate from the core engine, the portion of the engine that drives the compressor. An engine that uses a separate turbine to drive the propeller is called a free-turbine engine.

There are two basic types of turboprop engines: single-shaft and free-turbine.

The single-shaft engine drives the reduction gears from the same shaft that contains the compressors and the turbines. The free-turbine engine drives its propeller reduction gears with a free turbine that is independent of the gas generator turbine.

Single Shaft / Gear Coupled / Direct Coupled Turbine

The single shaft engine is a turboprop engine in which the propeller reduction gears are driven by the same shaft which drives the compressor for the gas generator.

The TPE331 engine has an additional turbine stage on the same shaft as the compressor and the gas generator turbines. This shaft, which is coupled to a 26:1 reduction gear system that reduces the low-torque 41,730 RPM turbine speed to a high-torque 1,591 RPM at the propeller shaft, has excess energy beyond that needed to drive the compressor

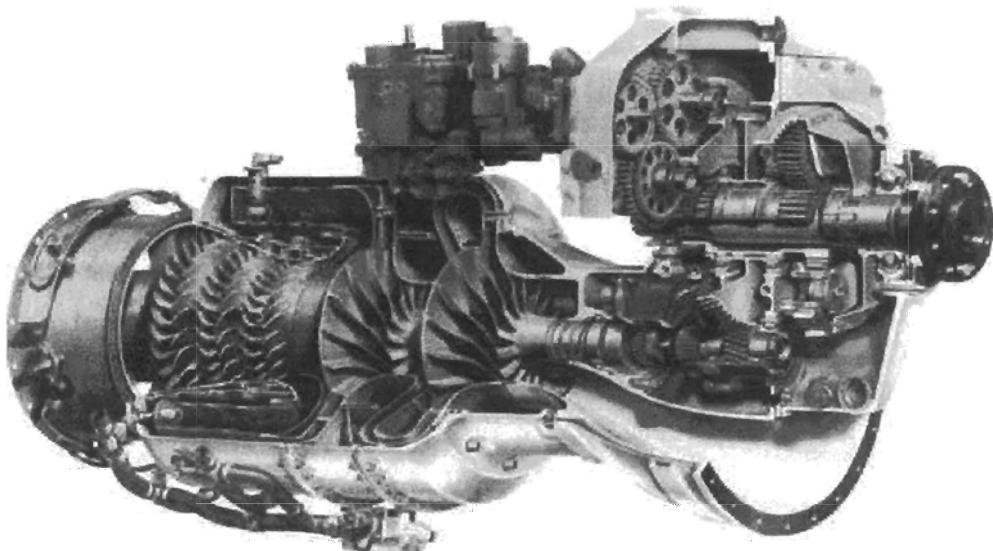


Figure 16.1: TPE 331 Gear Coupled Turbo-Prop



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Free Turbine / Power Turbine

A Free or Power turbine engine is defined as a gas turbine engine with a turbine stage on a shaft independent of the shaft used to drive the compressor. Generally, about 80% of the energy produced in the gas generator section is absorbed by the gas generator's turbine to drive the compressor, leaving 20% to drive the free turbine, which turns the propeller or helicopter rotor.

The Pratt & Whitney of Canada PT6 is a free-turbine turboprop engine in the 750 to 1,000 horsepower range and is popular for commuter airliners and business aircraft. For the gas generator, 100% RPM is approximately 38,000 RPM and at this speed, the propeller turns at about 2,000 RPM. Air enters near the accessory end and flows forward through three stages of axial compression and one stage of centrifugal compression. It then flows through an annular reverse-flow combustor where fuel is added and burned. The hot gases reverse direction again and flow forward through a single stage of compressor turbine and a single stage of free, or power, turbine, and exit through pipes at the forward end of the engine.

One of the operational differences between the PT6 free-turbine engine and the TPE331 single-shaft engine is that the TPE331 is shut down with the propeller blades held against low pitch stops to minimize the load on the starter when the engine is being started.

The propeller on the PT6 is allowed to go to its feather position when the engine is shut down because the starter rotates only the gas generator turbine and is not loaded by the propeller and power turbine during an engine start.

The turbine that drives the propeller is turned by the hot exhaust from the gas generator.



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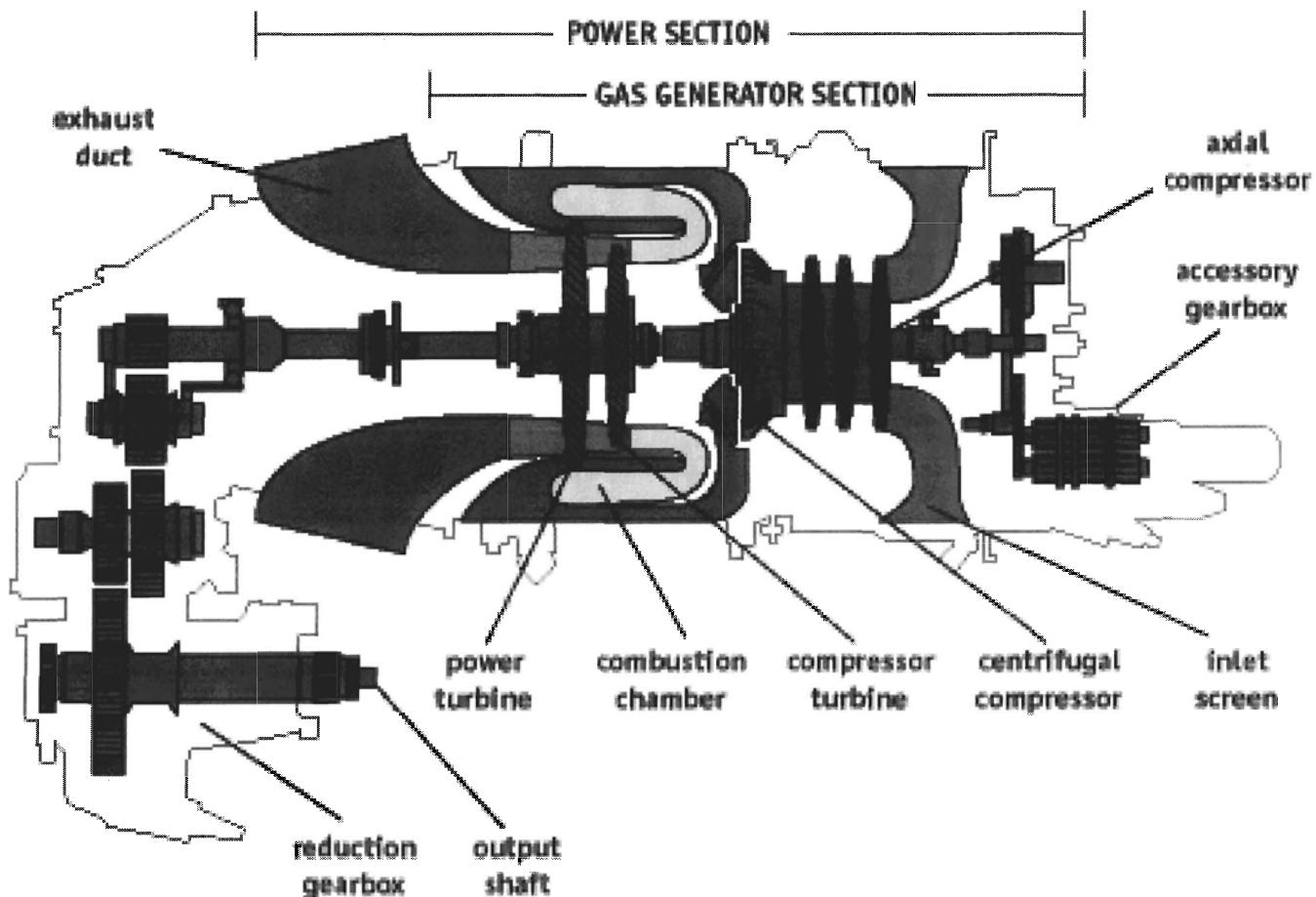


Figure 16.2: PT6 Free (Power) Turbine Engine



Reduction Gears

Power turbines run at speeds, which suit the design characteristics of the rest of the engine. This does not have anything in common with the speed of the propeller, which is set by its own characteristics, chiefly blade diameter.

This, as has already been seen, compromises the design and operation of the coupled turbine engine but is much less problematic in a free turbine design.

As power turbines can be spinning at up to 38,500 RPM and anything much over 2,000 RPM is considered quite fast for a propeller, it is obvious that a means of reducing this speed difference must be found. A suitable gear train will carry out this function.

Types of Reduction Gear

There are two main types available to the designer.

The parallel spur gear type

The epicyclic type.

Parallel Spur Gears

This type of gear train has the advantage of being mechanically simple and therefore relatively cheap to manufacture.

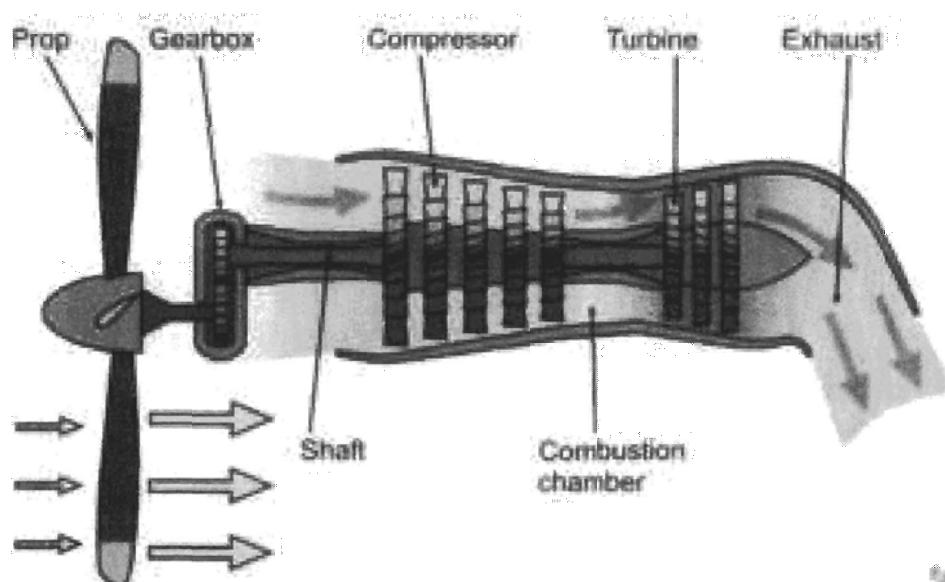


Figure 16.3: Parallel Spur gears in use



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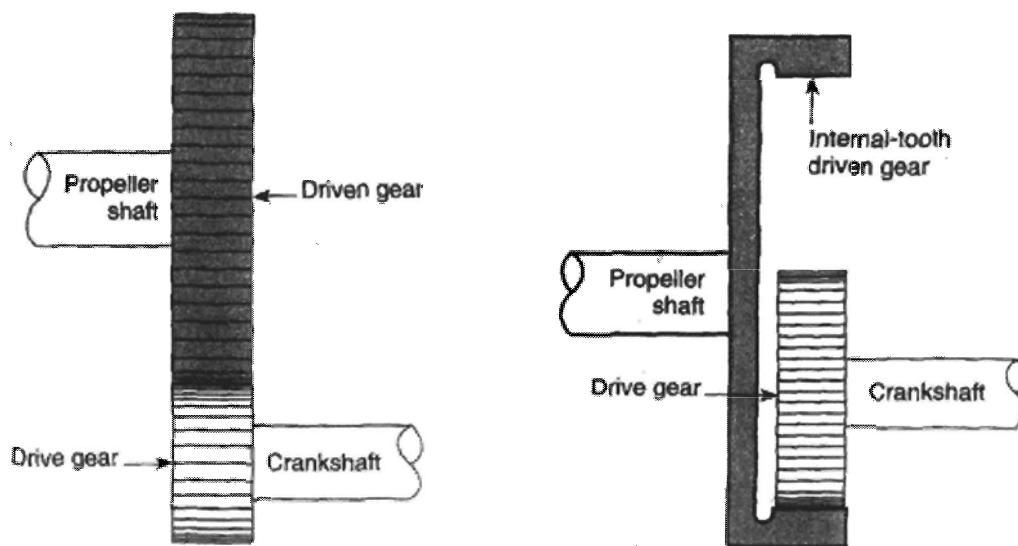


Figure 16.4: Parallel Spur Gears – External and Internal



Epicyclic Reduction Gears

A gear train consisting of a sun (driving) gear meshing with and driving three or more equi-spaced gears known as 'Planet Pinions'. These pinions are mounted on a carrier and rotate independently on their own axles. Surrounding the gear train is an internally toothed 'Annulus Gear' in mesh with the Planet Pinions.

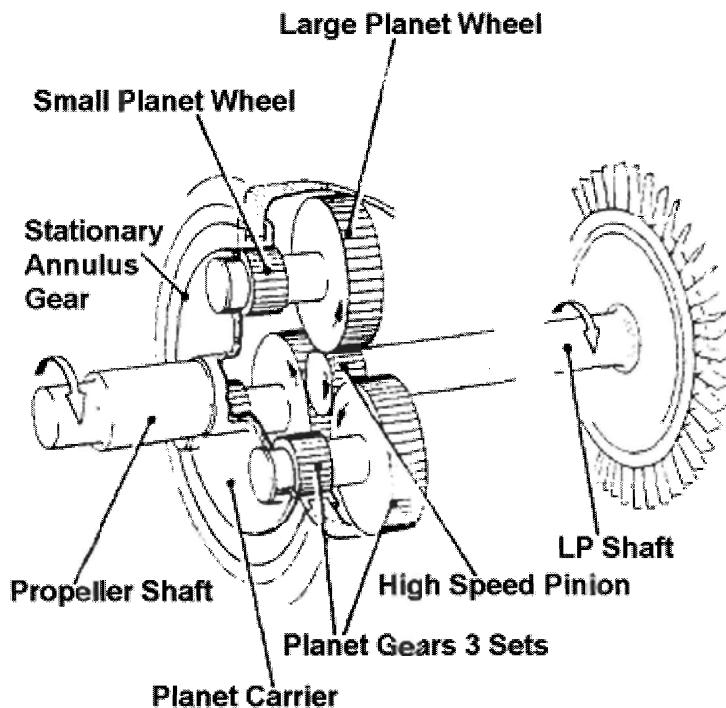


Figure 16.5: An epicyclic gear

If the annulus is fixed, rotation of the sun wheel causes the planet pinions to rotate about their axes within the annulus gear, this causes the planet carrier to rotate in the same direction as sun wheel but at a lower speed. With the propeller shaft secured to the planet pinion carrier, a speed reduction is obtained with the turbine shaft (input shaft) and propeller shaft (output shaft) in the same axis and rotating in the same direction. (Fig.16.6.)



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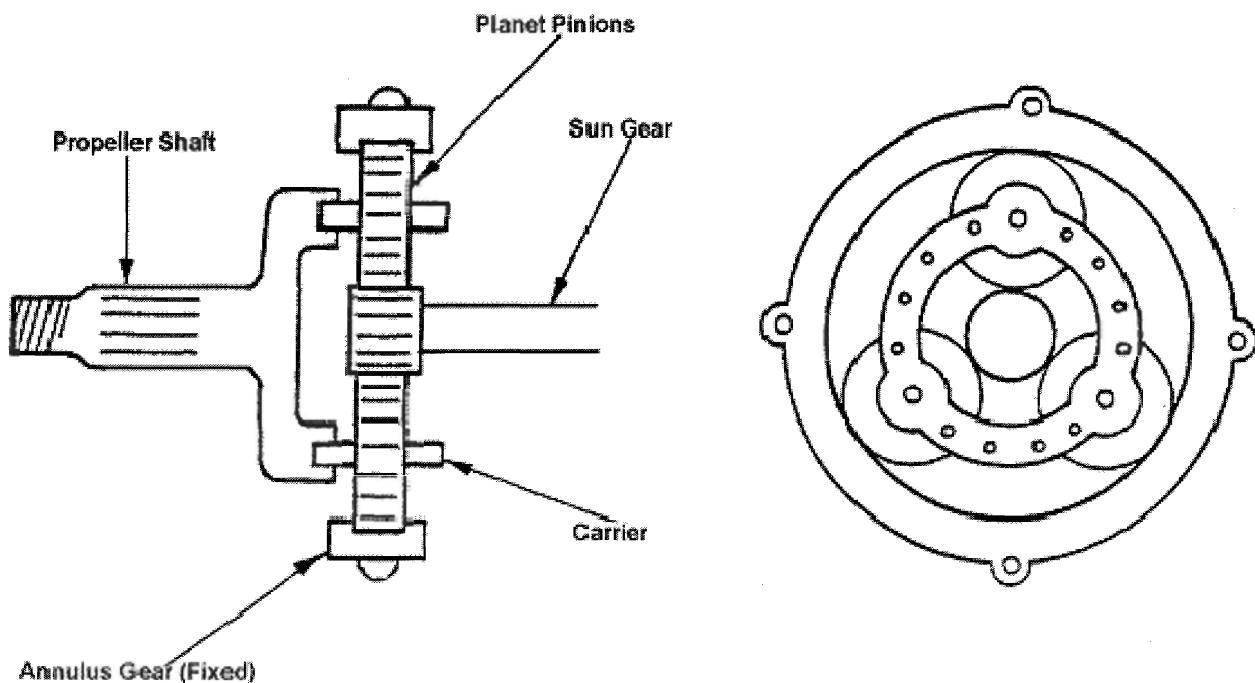


Figure 16.6: Epicyclic Gear train with Fixed Annulus Ring Rear

If the annulus is free, rotation of the sun wheel causes the planet pinions to rotate about their axles within the annulus gear. With the planet pinion carrier fixed and the propeller shaft attached to the annulus gear, rotation of the planet pinions causes the annulus gear and propeller to rotate in the opposite direction to the sun wheel and at a reduced speed. (Fig.16.7.)

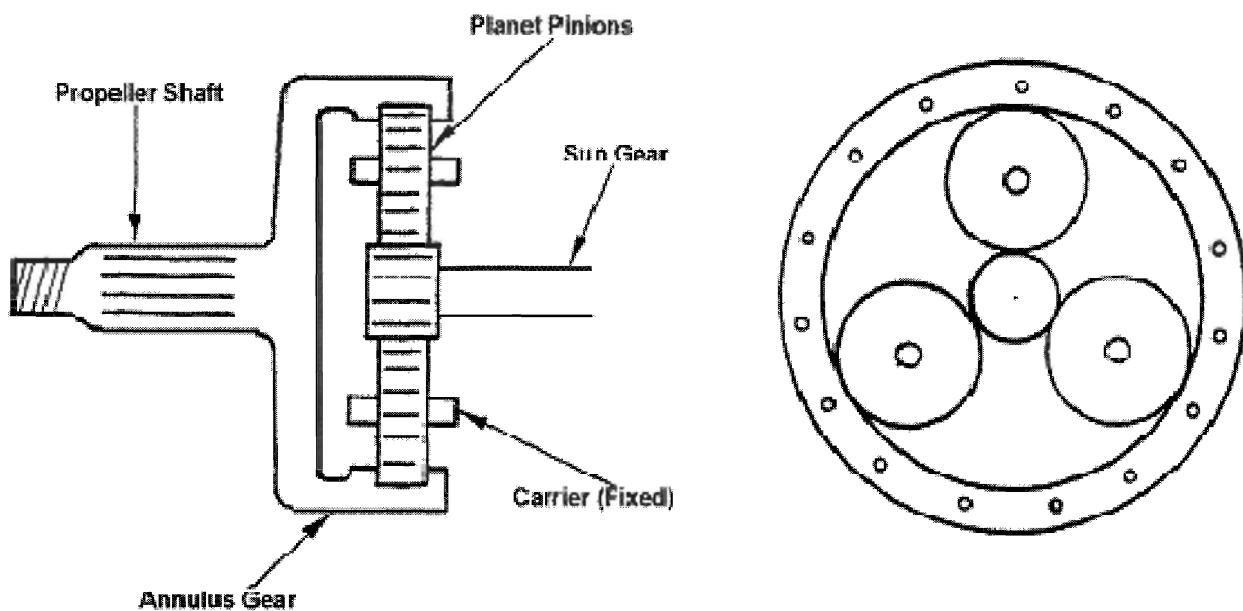


Figure 16.7: Epicyclic Gear Train with Fixed Planet gear Carrier



Compound Spur Epicyclic

Compound epicyclic reduction gears enable a greater reduction in speed to be obtained without resorting to larger components. They may be of either the fixed or free annulus type.

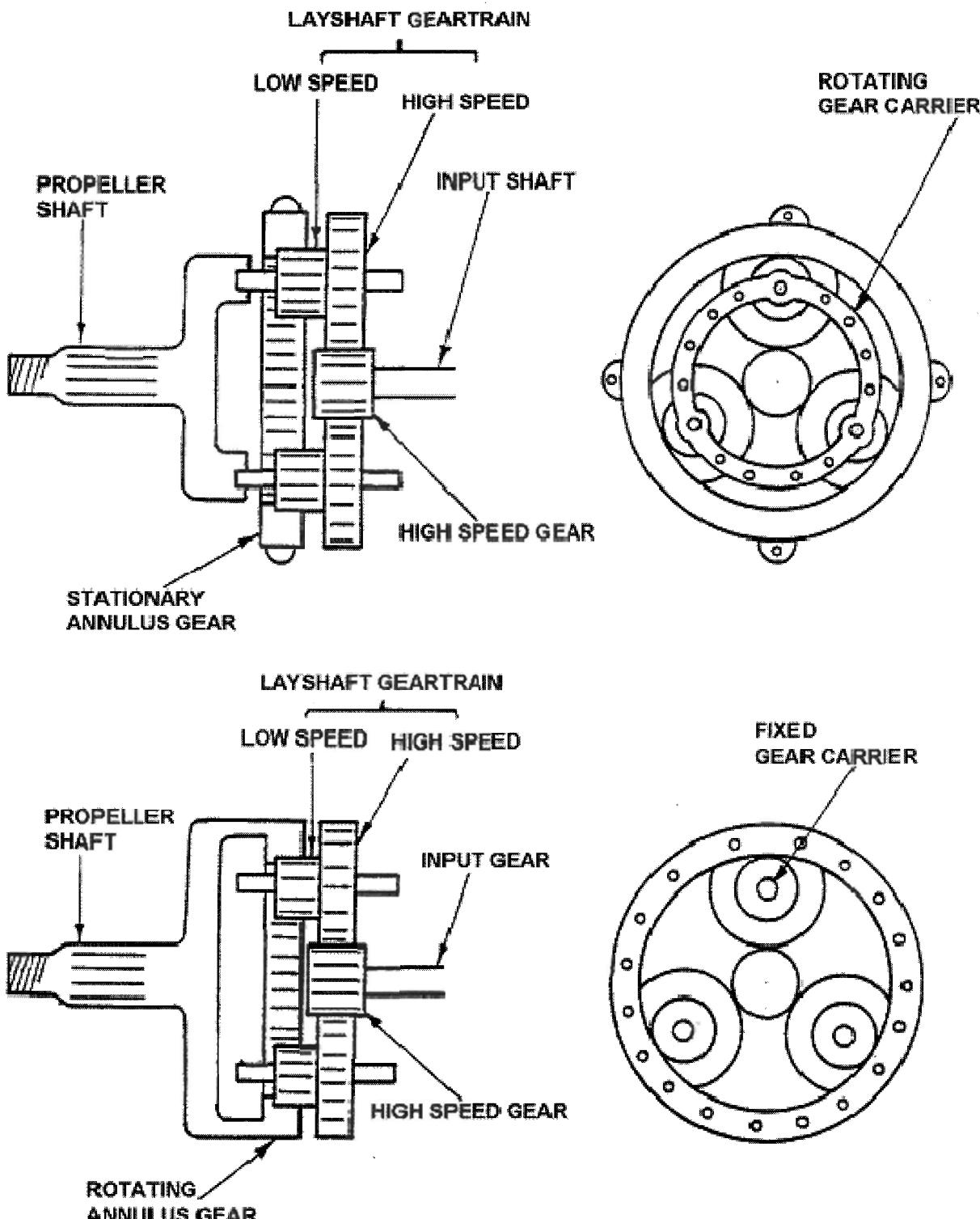


Figure 16.8: Compound spur epicyclic gears



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Gear Train / Epicyclic

Some turbo-props will use a gear train or a combination of gear train and epicyclic.

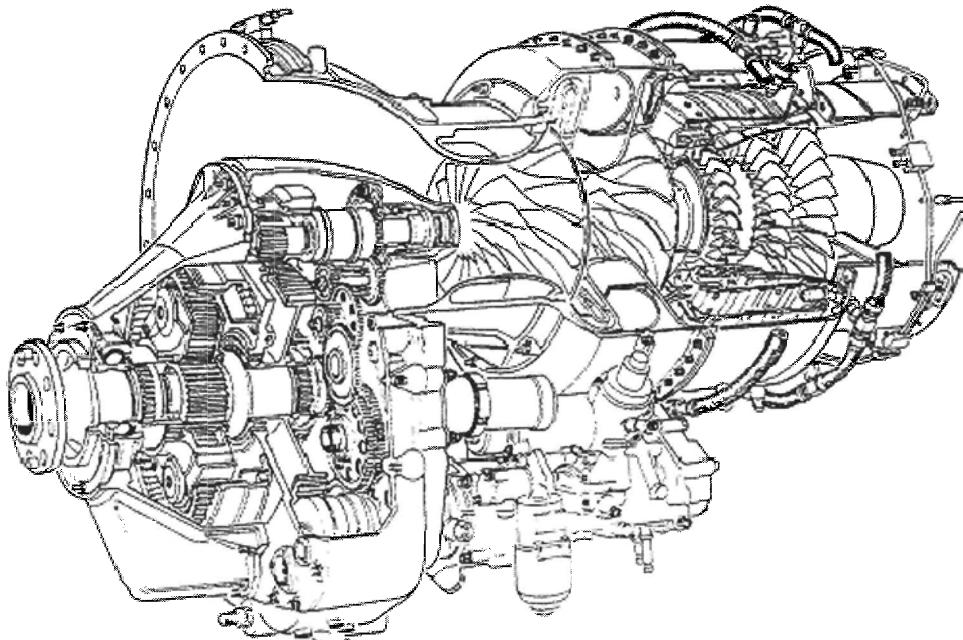


Figure 16.9: Cut-away showing combined compound epicyclic and gear train

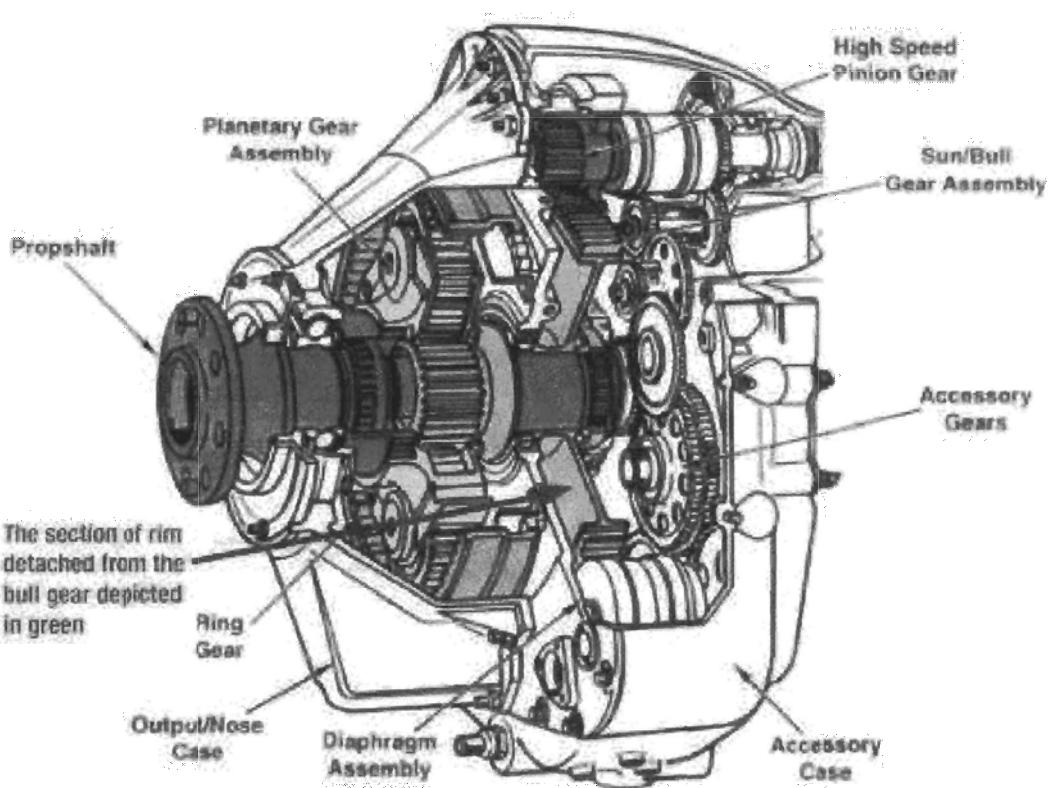


Figure 16.10: A typical epicyclic gear box



Engine Controls

Because the engine and propeller must work together to produce the required thrust for a turbo-prop installation, there are a few unique relationships. The turboprop fuel control and the propeller governor are connected and operate in coordination with each other. The power lever directs a signal from the cockpit to the fuel control for a specific amount of power from the engine.

The fuel control and the propeller governor together establish the correct combination of RPM, fuel flow, and propeller blade angle to provide the desired power.

Alpha Range

The propeller control system is divided into two types of control: one for flight and one for ground operation. For flight, the propeller blade angle and fuel flow for any given power setting are governed automatically according to a predetermined schedule. This is known as the alpha range.

Beta Range

Below the “flight idle” power lever position, the coordinated RPM blade angle schedule becomes incapable of handling the engine efficiently. Here the ground handling range, referred to as the beta range, is encountered. In the beta range of the throttle quadrant, the propeller blade angle is not governed by the propeller governor, but is controlled by the power lever position. When the power lever is moved below the start position, the propeller pitch is reversed to provide reverse thrust for rapid deceleration of the aircraft after landing.

Engine Operation

Turboprops are constant-speed engines, because they operate throughout the operational cycle at near 100% RPM. To hold the RPM constant, the fuel control adjusts the fuel flow in relation to the engine load.

When idling, the RPM remains high, but the propeller pitch is reduced until almost flat, so it produces very little thrust and requires a minimum fuel flow.

Considering the engine type there will be two groups of engines:

- Hydro-Mechanical Fuel Control (older generations)
- FADEC (Full Authority Digital Engine Control)



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Hydro Mechanical Fuel Control System

Power Lever

The power lever operates in a quadrant slot labelled "POWER" with positions (from rear to front) labelled "MAX REV", "DISC", "FLT IDLE" and "MAX". The power lever is connected by cables, pushrods and bellcranks to the control system and PCU of the associated powerplant. The power lever quadrant slot has a lockout gate at the FLT IDLE position, which is controlled by a finger latch below the power lever knob. Raising the latch permits aft movement into the ground range.

The power lever controls power in the forward thrust range and blade angle in the flight Beta and ground Beta ranges. The flight Beta range extends from a blade angle of 26° to 19° (minimum in-flight blade angle). The power lever controls blade angle from aft of FLT IDLE to MAX REV.

The spring-loaded, detented DISC position produces at 0° blade angle or flat discing; further aft movement increases blade angle in a negative direction until at MAX REV the blade angle is -11.5° . Both of these positions will assist in slowing the aircraft during landing.

While operating in the Beta range, the HP fuel control regulates engine power, providing N_p underspeed governing between FLT IDLE and DISC and both engine power and blade angle control in the reverse thrust range.

When the flight control gust lock lever, labelled "CONT LOCK" is at the on position, the power lever cannot be moved to the MAX position. This lever will also lock the aircraft flight controls.

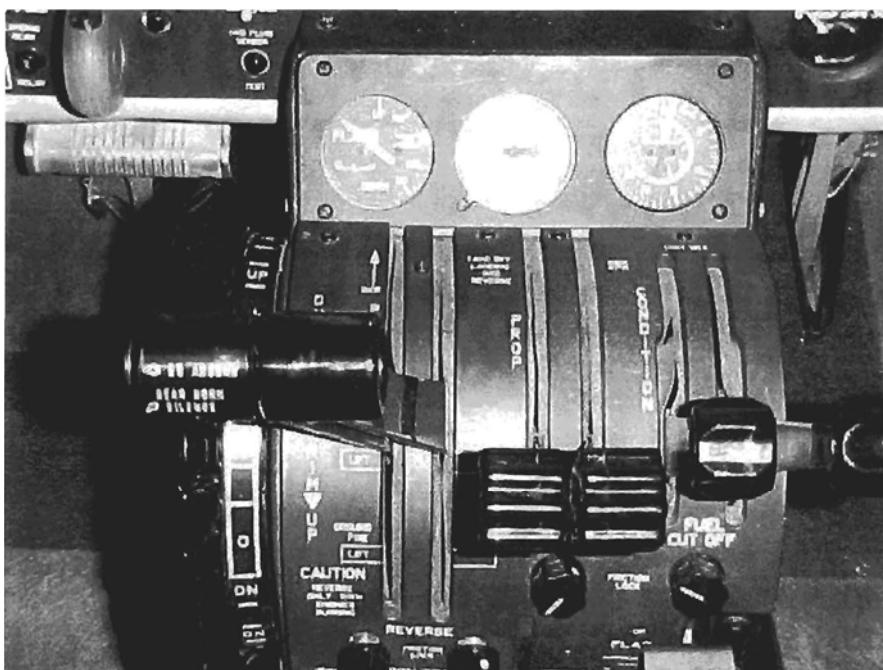


Figure 16.11: Turbo-prop engine controls



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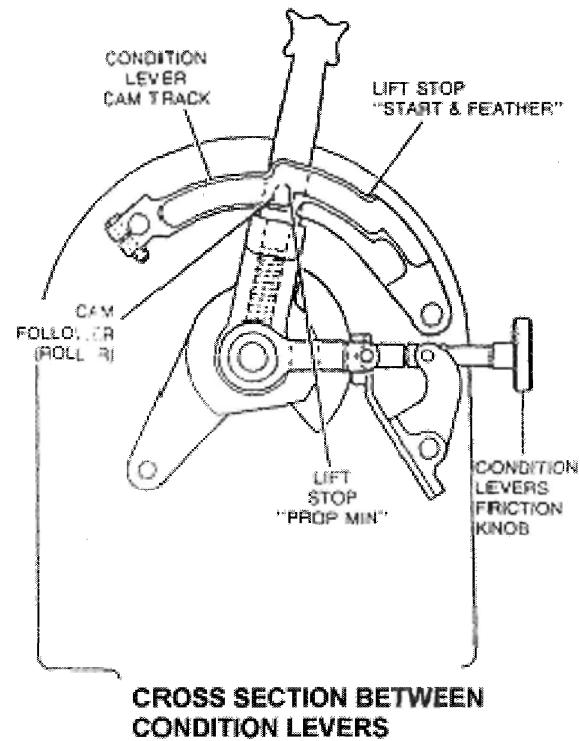
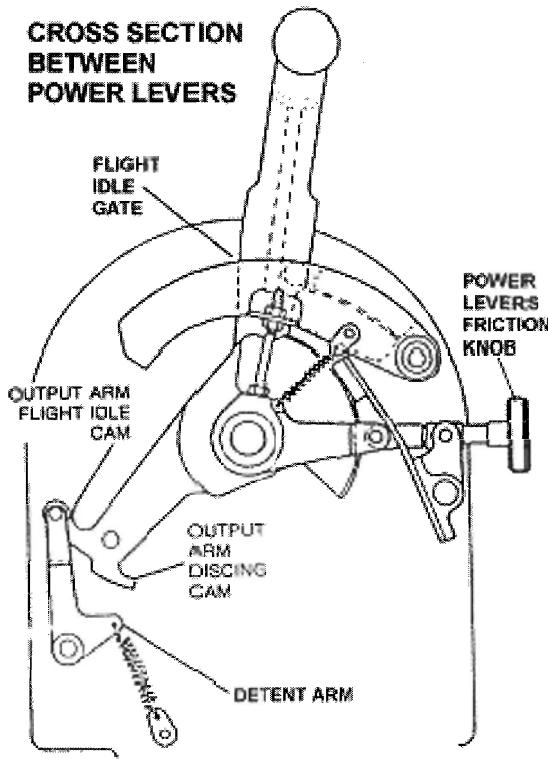


Figure 16.12: Power and Condition levers

Condition Lever (RPM Control)

The condition lever is connected to the PCU and HP fuel control by cables, pushrods and bellcranks and operates in a quadrant slot labelled "PROP" on the centre console. The condition lever positions are labelled (rear to front) "FUEL OFF", "START & FEATHER", "MIN" and "MAX". The range between START & FEATHER and MIN is labelled "UN-FEATHER". Inadvertent selections below MIN and START & FEATHER are prevented by detents. The lever must be pulled out for aft movement past these positions.

Moving the condition lever from MIN to START & FEATHER feathers the propeller through the PCU and signals the HP fuel system to establish a fuel flow to sustain ground idle rpm. Moving the lever forward of START & FEATHER unfeathers the propeller when the engine is running. When the condition lever is moved from START & FEATHER to FUEL OFF, it mechanically closes the fuel shut-off valve on the HP fuel system and shuts down the engine. The condition lever range between MIN and MAX sets propeller rpm for in-flight constant speed operation.

Constant Speed Range

The constant speed range is defined as propeller operation from a fully fine setting (condition lever at MAX RPM) to an increased blade angle pre-selected by a condition lever angle (CLA) setting of a speed-sensitive, flyweight governor in the PCU. The governor operates to obtain and maintain constant speed settings between 900 and 1,200 propeller rpm (Np). Ground range lights indicate at 16.5° and the discing is between 1.5 and 3.0°.



Beta Range

The term “Beta Range” is used to define propeller operation from a maximum Beta setting (propeller blade angle 26°) to a full reverse setting (propeller blade angle – 11.5°). The Beta range is divided operationally into two ranges by a gate on the associated power lever which controls blade angle from 16 to 19° above the gate and below the gate to full reverse.

Propeller blade angle at full feather is 86 +/- 5°.



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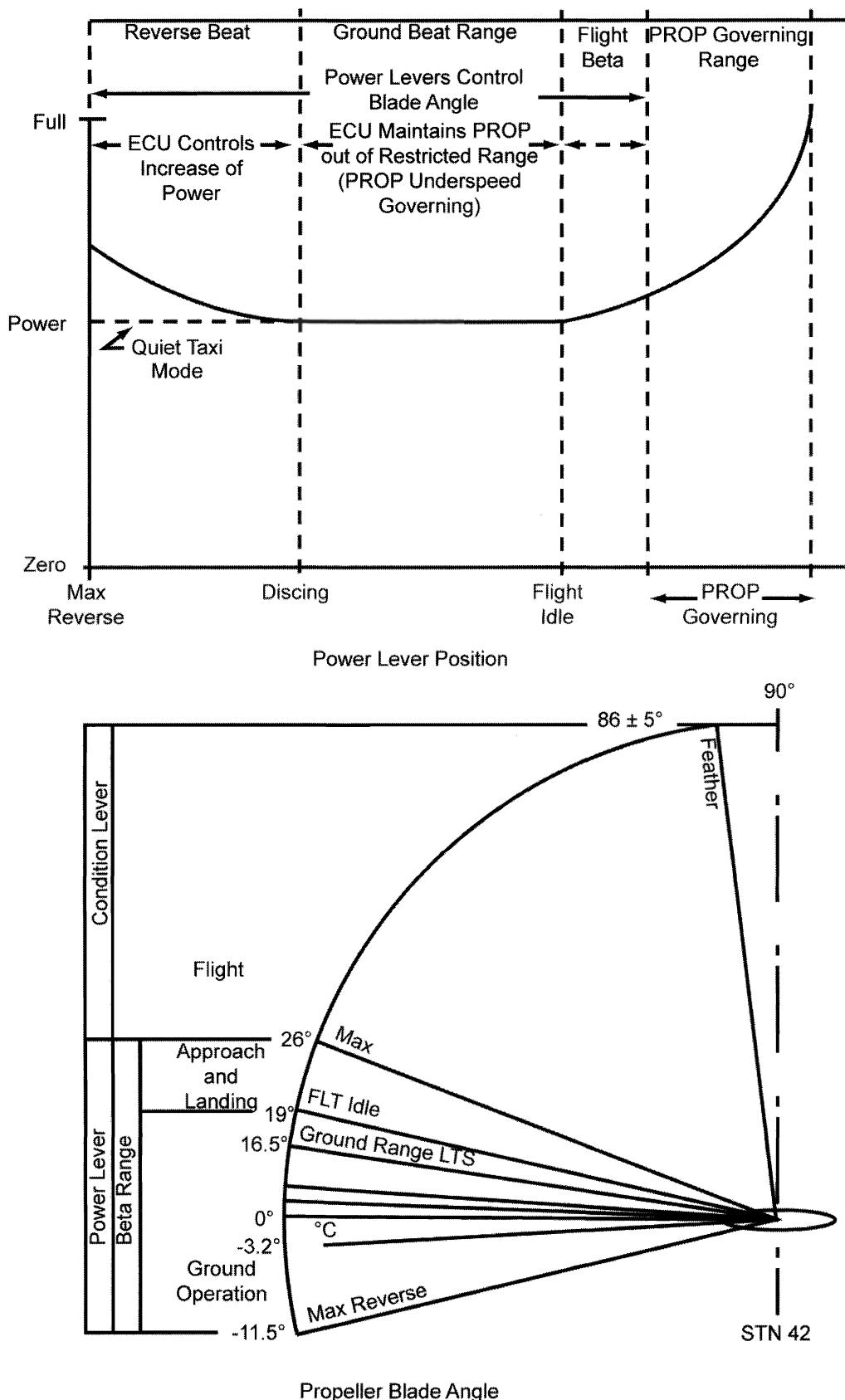


Figure 16.13: Power Lever and Propeller ranges

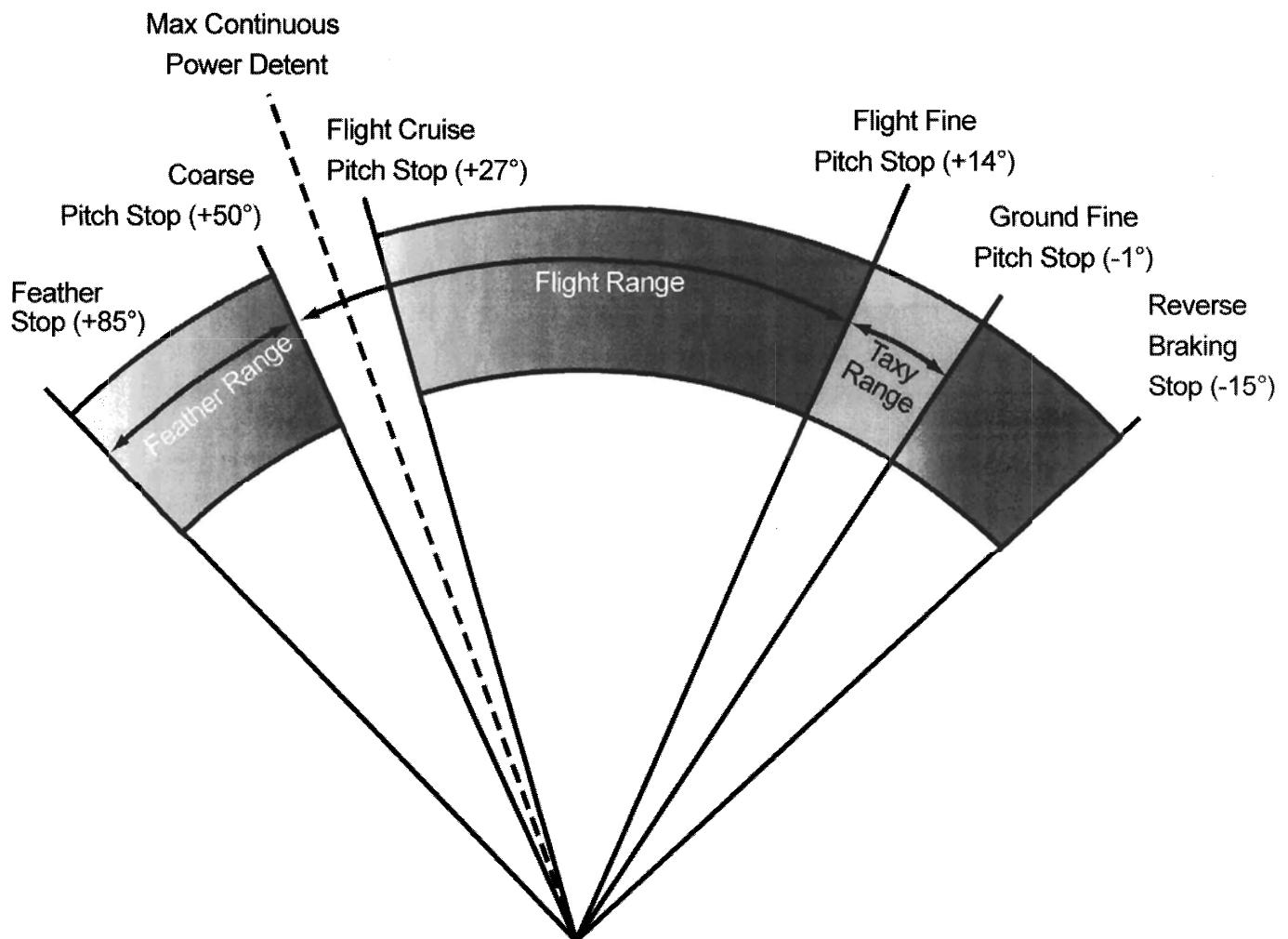


Figure 16.14: Power Lever Quadrant and associated typical blade angles



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Fixed and Removable Stops

A number of stops or latches can be incorporated in the propeller control system; their purpose is to confine the angular movement of the blades within limits appropriate to the phase of flight or ground handling. The most common stops are described below and typical values are given for the corresponding blade angles.

- **Feather and Reverse Braking Stops.** These two fixed stops define the full range within which the propeller angle may be varied (+85° to -15°).
- **Ground Fine Pitch Stop.** This is a removable stop (-1°) which is provided for starting the engine and maintaining minimum constant rpm; the stop also prevents the propeller from entering the reverse pitch range.
- **Flight Fine Pitch Stop.** This is a removable stop (+14°) which prevents the blade angle from fineing off below its preset value. Its purpose is to prevent propeller overspeeding after a CSU failure. It also limits the amount of windmilling drag on the final approach. The stop is usually engaged automatically as the pitch is increased above its setting; removal of the stop is, however, usually by switch selection.
- **Flight Cruise Pitch Stop.** This is a removable stop (+27°) which is fitted to prevent excessive drag or overspeeding in the event of a PCU failure. The stop engages automatically as the pitch is increased above its setting and is also withdrawn automatically as the pitch is decreased towards flight idle provided that two or more of the propellers fine off at the same time. Variations on this type of stop include automatic drag limiters (ADL) and a Beta follow-up system. In the first of these, the stop is in the form of a variable pitch datum which is sensitive to torque pressure. If the propeller torque falls below the datum value, the pitch of the propeller is automatically increased. The pitch value at which the ADL is set is varied by the position of the power lever. Thus, as the power is reduced, the ADL torque datum value is also reduced so that the necessary approach and landing drag may be attained, while simultaneously limiting the drag to a safe maximum value. The Beta follow-up stop uses the Beta control (i.e. direct selection of blade angle for ground handling) to select a blade angle just below the value controlled by the PCU. In the event of a PCU failure, the propeller can only fine off by a few degrees before it is prevented from further movement in that direction by the Beta follow-up stop. In the flight range, the position of this stop always remains below the minimum normal blade angle and so does not interfere with the PCU governing.
- **Coarse Pitch Stop.** This stop (+50°) limits the maximum coarse pitch obtainable in the normal flight range. A feathering selection normally over-rides this stop.



Example - PT6 Power Turbine

The PT6 (typical free turbine engine) is controlled by engine and propeller control systems that are operated by three levers: a power control lever, a propeller control lever, and a start control lever.

The power control lever - is connected to the fuel control and is used to control the engine power (Torque) from full reverse thrust, through idle, to takeoff.

The propeller speed lever - is connected to the propeller governor to request blade angle and maintain the desired propeller RPM. When moved to the extreme aft position, it causes the propeller to feather.

The start lever - attaches to the fuel control and it has three positions: Cutoff, Idle, and Run.

The emergency power lever - used to directly control engine power if the pneumatic side of the fuel control unit fails.

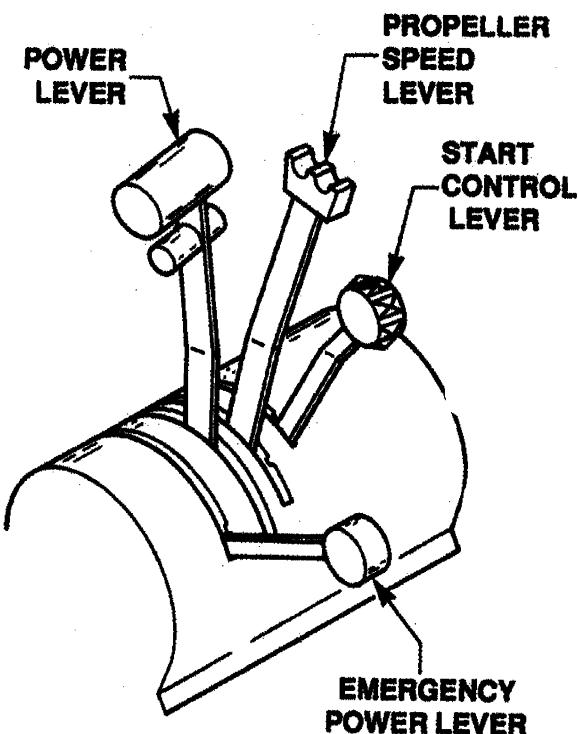


Figure 16.15: PT6 Engine Control



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Example - TPE331 Fixed Turbine Turbo-Prop

The TFE 331 uses two engine controls on the cockpit quadrant:

The power lever and
the speed, or condition, lever.

The power lever relates to the throttle of a reciprocating engine, but it also gives the pilot control over the propeller during ground operation. It affects the fuel flow, torque, and EGT, and has four positions:

- REVERSE (REV)
- GROUND IDLE (GI)
- FLIGHT IDLE (FI)
- MAXIMUM (MAX)

The speed or condition lever -primarily controls the propeller at higher speeds in the alpha range and in some installations it acts as a manual feather and emergency cutoff lever. The condition lever has three positions:

- EMERGENCY SHUTOFF
- LOW RPM
- HIGH RPM

The condition lever sets engine speed by changing the propeller blade angle. During flight this lever remains at its set position with the engine running at a constant speed.

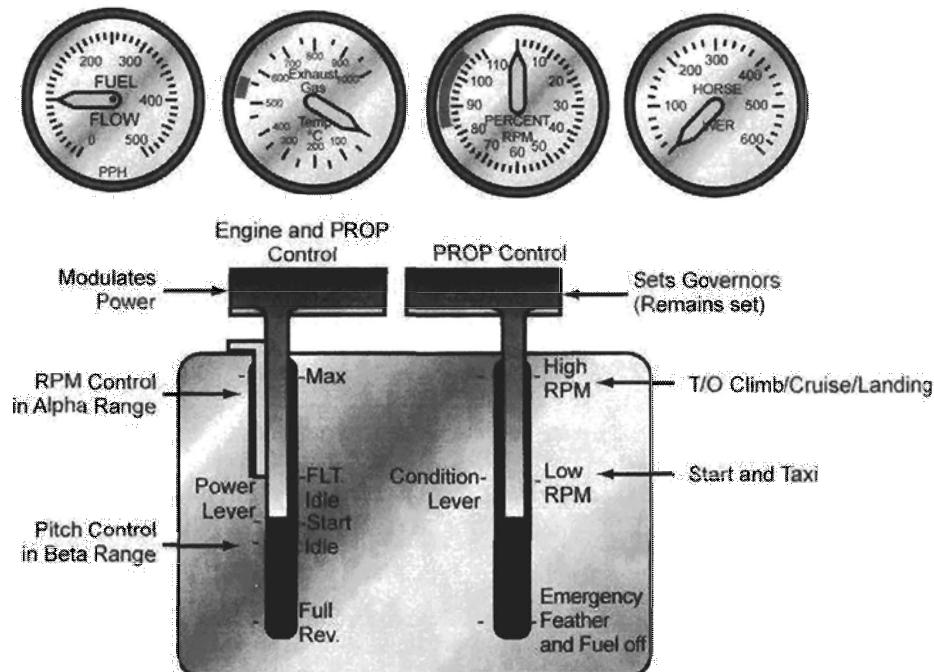


Figure 16.16: TPE 331 propeller controls



FADEC Control System

The primary function of the cockpit engine controls is to give the inputs to control the operation of the power plants. The engine controls are divided as follows:

- The power control
- The emergency shutdown.

The power control system changes the manual inputs from the two pilots, into an electrical or an electronic output signal. The electrical and the electronic output signals give the input data (in relation to the position of the engine controls) to the full-authority digital engine-control (FADEC) and the other applicable systems of the aircraft. The emergency shutdown procedure: safely stops the operation of the power plant and automatically closes the fuel, the hydraulic and the pneumatic connections between the airframe and the power plant.

Considering a newer version (FADEC controlled) of the Allison 250 engine, there is a handling difference to look at. The condition lever no longer controls the propeller governor, this task is calculated by the FADEC system depending on the position of the power lever, other aircraft system inputs and flight phase.

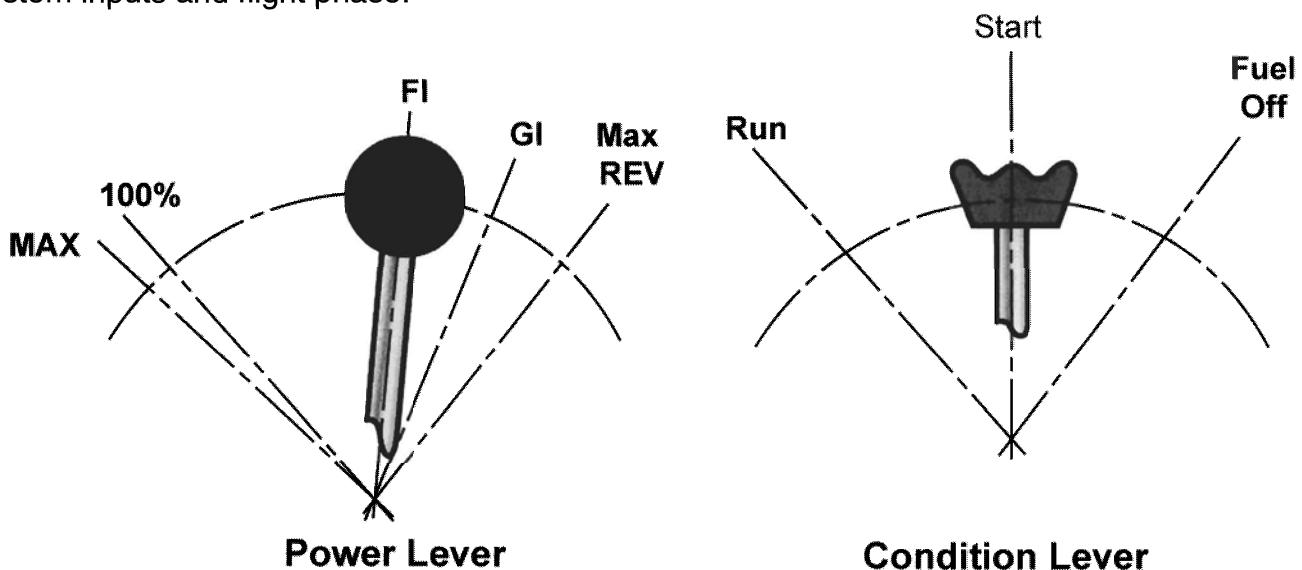


Figure 16.17: FADEC control



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Turbo Prop Instrumentation

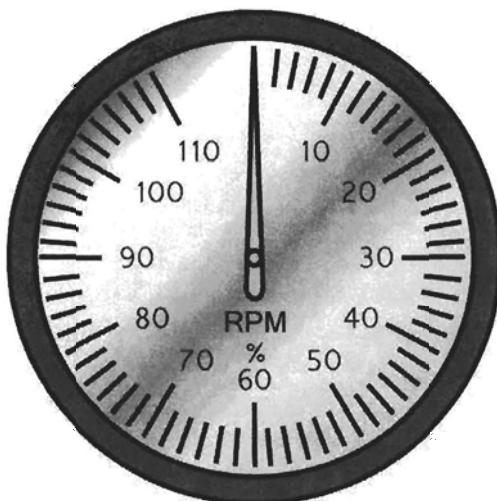
Usually four instruments are used to monitor the performance of a turboprop engine:

Tachometer: Shows the RPM of the compressor in percentage of its rated speed

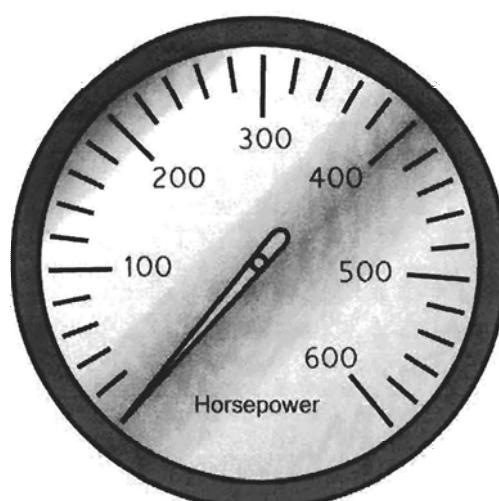
Torquemeter: Shows the torque or shaft horsepower being developed

Fuel Flowmeter Shows the number of pounds of fuel per hour being delivered to the engine

EGT Indicator: Shows the temperature of the exhaust gases as they leave the turbine



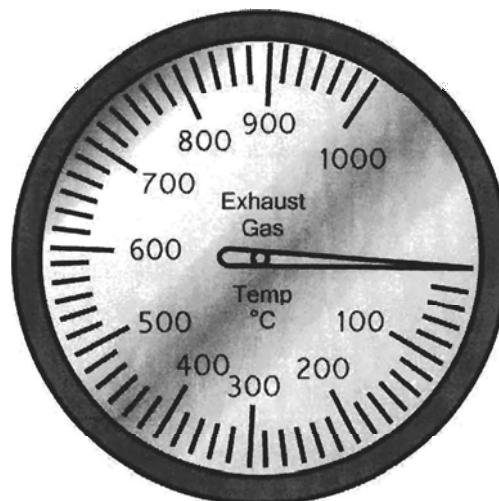
Tachometer



Torquemeter



Fuel Flowmeter



Exhaust Gas Temperature Indicator

Figure 16.18: Engine power monitoring instruments

When the engine is operating with a given propeller load, and the power lever is moved forward to increase the fuel flow, the RPM will try to increase. To prevent this, the propeller governor



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increases the blade angle, which causes the RPM to remain constant and the power produced by the engine to increase. When the power lever is moved back, the fuel flow is reduced, and the RPM begins to decrease. But the propeller governor decreases the blade angle, which causes the RPM to remain constant, and the power to decrease.

Starting

The pilot must monitor the compressor speed during engine start up, and upon reaching the prescribed speed for light off, advance the condition lever to maximum speed position to initiate fuel flow. The fuel control unit will automatically regulate fuel flow during the acceleration to idle. Propeller unfeathering will automatically occur with the propeller beta valve regulating the blade angle. A ground start is accomplished with the power lever placed into flight idle position.

On FADEC controlled engines the start-up sequence is accomplished automatically, when the condition lever is moved to the START position. When the engine reaches ground idle RPM, the operator moves the condition lever to the RUN position to conclude the start-up sequence.

Engine Run

For low power settings during the engine run the condition lever should be put in the MAXIMUM PROPELLER SPEED range. The power lever can then be moved freely to obtain the desired thrust.

For high power settings, i.e., takeoff power, the condition lever should be in the position for 100% propeller speed, allowing the propeller governor to maintain the compressor speed control. The power lever controls the power setting of the engine. The power lever must be controlled so as not to exceed the turbine outlet temperature and torque limits.

On FADEC controlled engines only the power lever is used to change power settings and propeller pitch, the FADEC system monitors and controls the power and propeller settings according to the position of the power lever, inputs from other systems and flight face. During normal engine operation the condition lever remains in its RUN position.

Stopping

Engine stopping is effected by shutting off the fuel supply by means of a fuel control cutoff valve. At the same time the propellers move to the feathered position. The condition lever controls both the fuel cutoff and propeller feathering. Make sure that before the engine is shut down, the power lever is first put in the Ground Idle position, and allow the turbine outlet temperature to stabilize for two minutes.

The condition lever is then moved to FUEL SHUTOFF and PROPELLER FEATHERING.



Overspeed Safety Devices

Overspeed is the condition in which the actual engine speed is higher than the desired engine speed as set on the propeller control by the pilot.

An overspeed governor is a backup for the propeller governor and is mounted on the reduction gearbox. It has its own flyweights and pilot valve, and it releases oil from the propeller whenever the propeller RPM exceeds a preset limit above 100%. Releasing the oil causes the blades to move to a higher pitch angle, which reduces the RPM. The overspeed governor is adjusted when installed and cannot be adjusted in flight—there are no cockpit controls for it.

Mechanical Controlled Propellers (PW PT6)

An overspeed governor is a back-up for the propeller governor and is mounted on the reduction gearbox. It has its own flyweights and pilot valve, and it releases oil from the propeller whenever the propeller RPM exceeds a preset limit. When the propeller speed reaches this limit the flyweights lift the pilot valve and bleed off propeller servo pressure oil into the reduction gearbox sump, causing the blade angle to increase. A greater pitch puts more load on the engine and slows down the propeller.

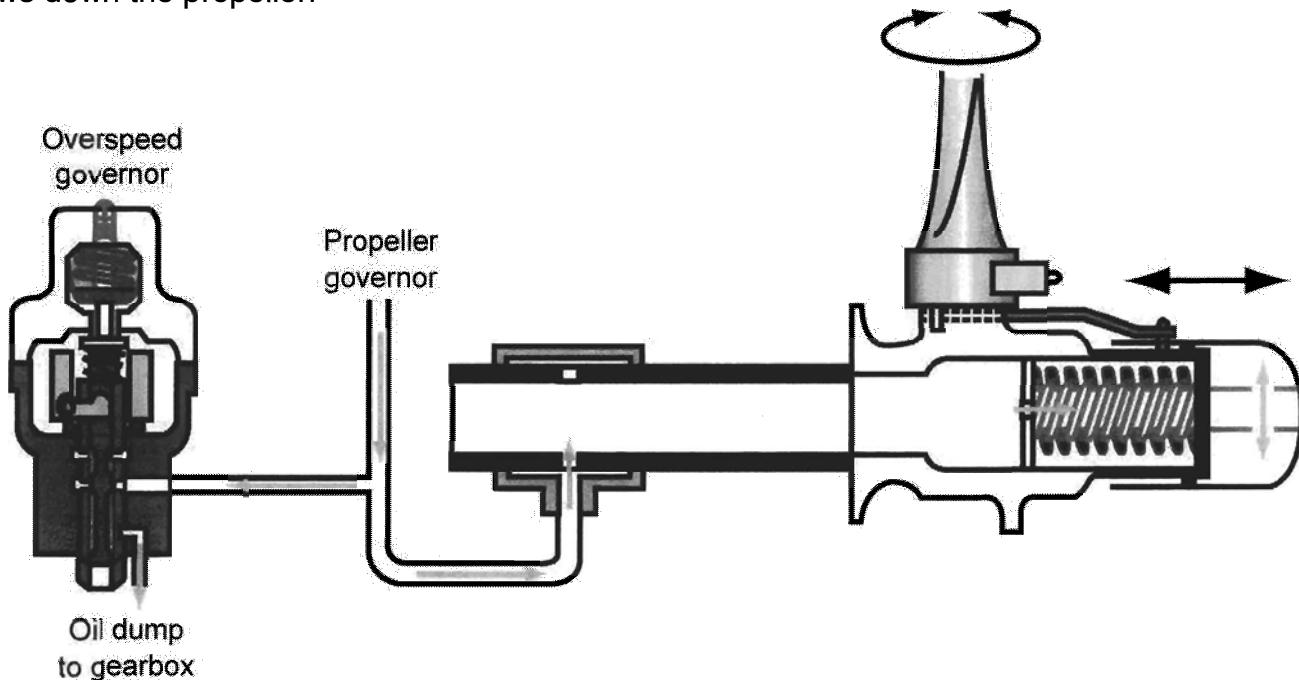


Figure 16.19: Overspeed Governor



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FADEC Controlled Propellers

The functions to limit the speed of the propeller/power turbine rotor are as follows:

The FADEC software adjusts the propeller blade angle through the pitch control unit (PCU) to control the propeller/power turbine rotor speed.

A hydro mechanical overspeed governor supplies the emergency protection if a propeller/power turbine rotor overspeed condition occurs (power changes momentarily or a failure occurs).

If the propeller/power turbine speed is more than the limit for the propeller governor, the FADEC software sends signals that decrease the fuel flow, and thus the engine power level.

The FADEC has microprocessor-independent over speed protection to stop the flow of the fuel. This prevents an overspeed condition that can cause damage to the engine.



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Gas Turbine Engine

15.17 Turbo-shaft Engines

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LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

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The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.17 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.17 - Turbo-shaft Engines

Configurations

A gas turbine engine that delivers power through a shaft to operate something other than a propeller is referred to as a turbo-shaft. The early turbo-shaft engine power output shaft was coupled directly to the gas generator turbine wheel. In more recent applications, the output shaft is driven by a free power turbine (separate turbine wheel).

The figure below shows the free power turbine in both the front and rear power output shaft configurations. It also shows that turbo-shaft engines are thought of as having two major sections, the gas generator section and the power turbine section.

Turbo-shaft engines are used in many applications, but in the aircraft sense they power helicopters. Whilst very similar to turbo-prop powerplant, drive systems are equipped with over running clutches that allow the pilot to perform auto-rotation descent in case of total power loss. The bigger helicopters are usually equipped with two engines that drive the transmission system together, the clutches also allow operation with single engine.

The function of the gas generator is to produce the required energy to drive the power turbine system. The gas generator extracts about two-thirds of the combustion energy, leaving approximately one-third to drive the power turbine, which, in turn, drives the aircraft transmission. The transmission is in actuality a high ratio reduction gearbox.

Occasionally, a turbo-shaft engine is designed to produce some hot exhaust thrust (up to 10%), while some are not. One consideration in this design is whether or not the rotor alone will produce the desired airspeed while another is whether or not the helicopter can satisfactorily hover with constant forward thrust.

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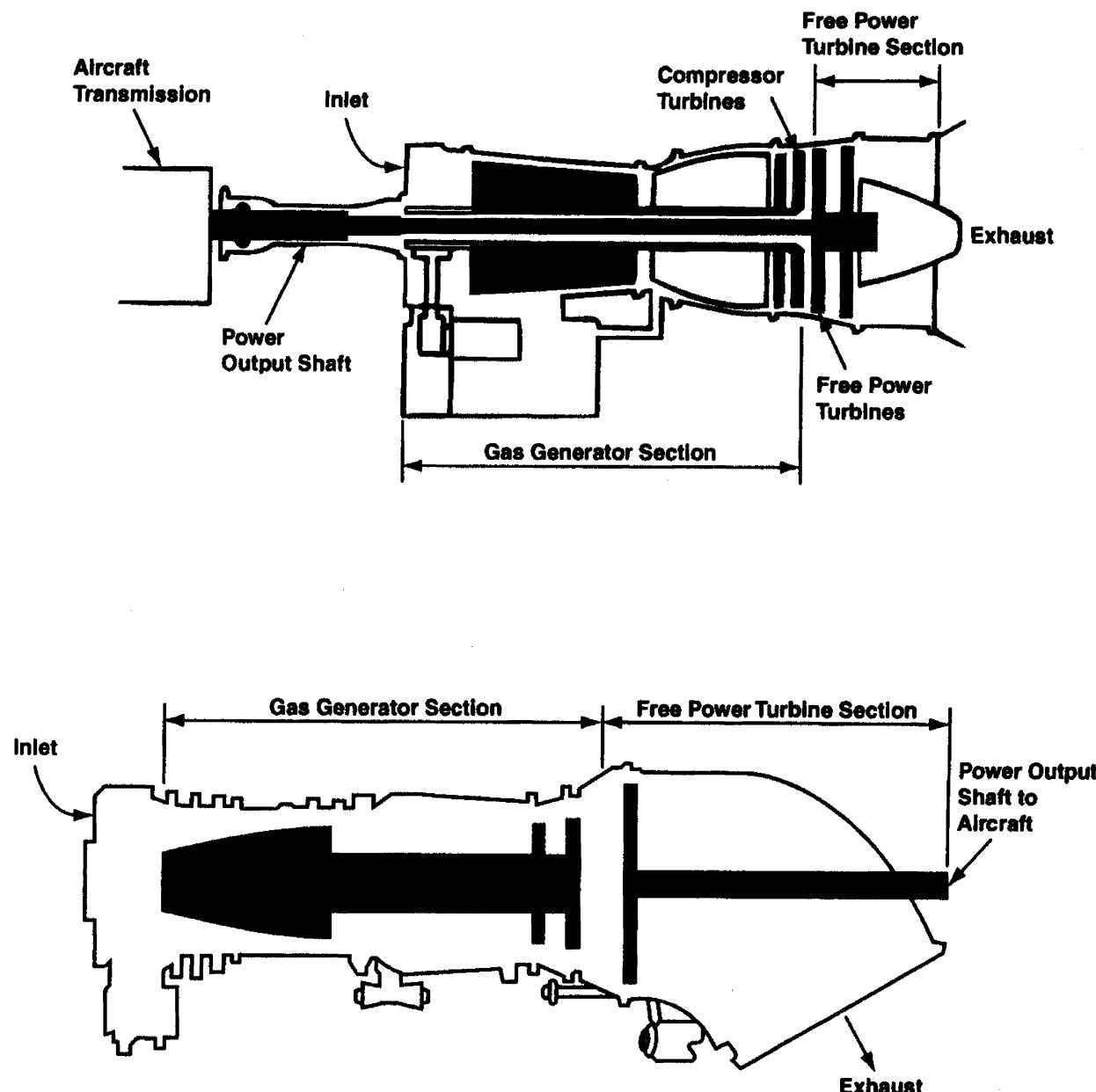


Figure 17.1: Turbo-shaft cross sections

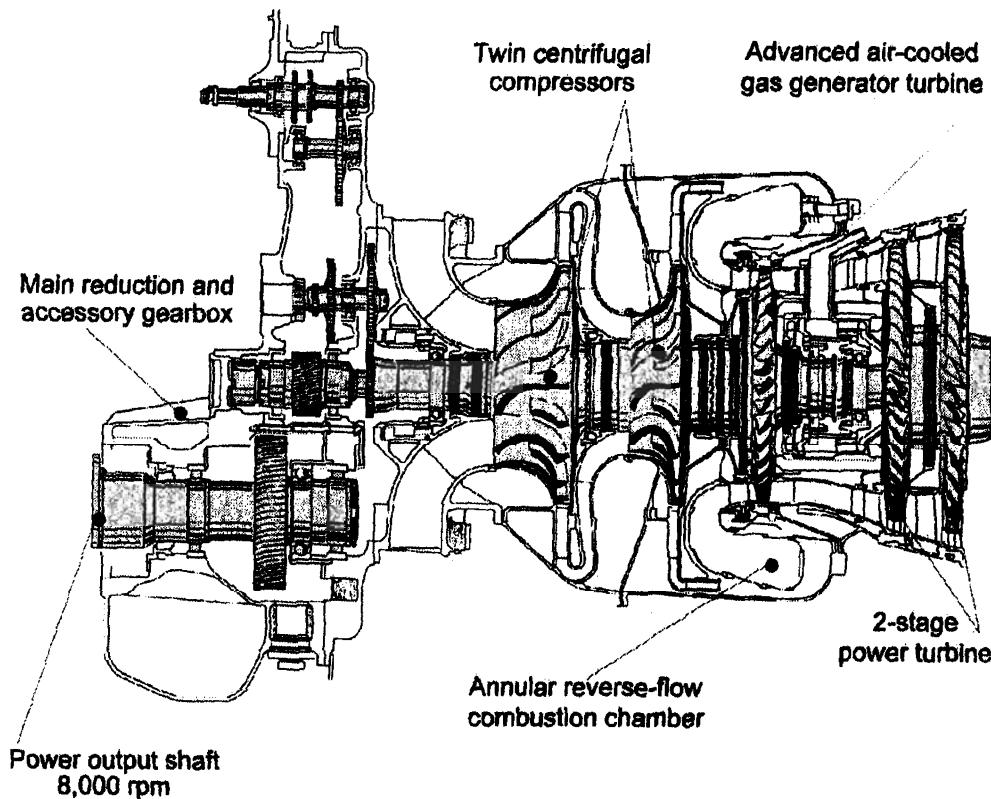


Figure 17.2: TPE 331

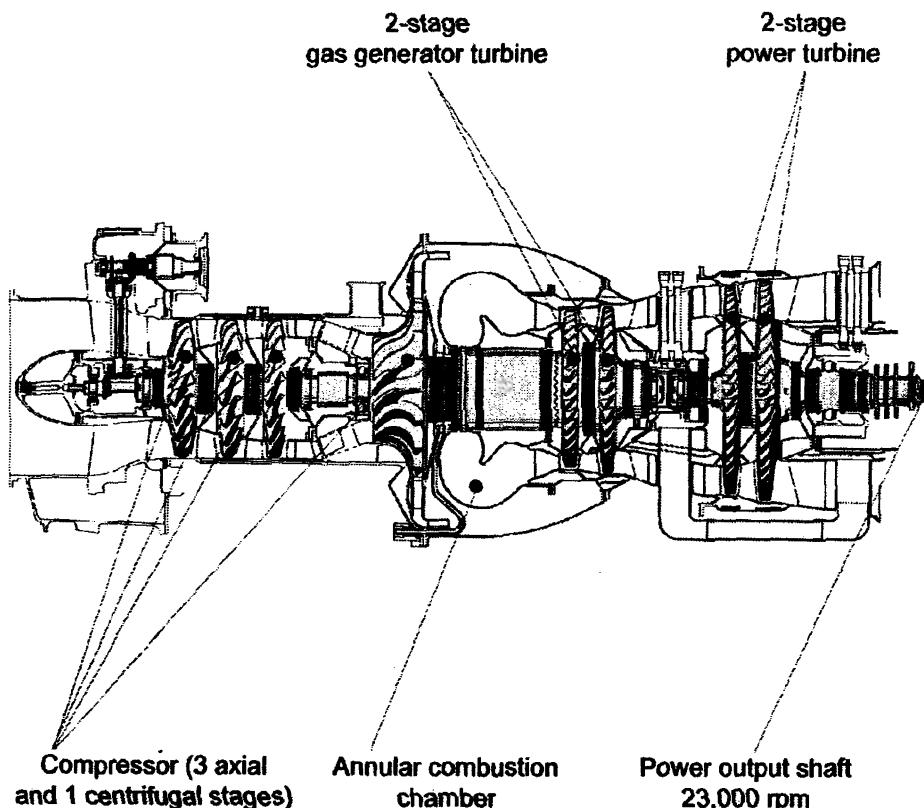


Figure 17.3: Typical power turbine engine



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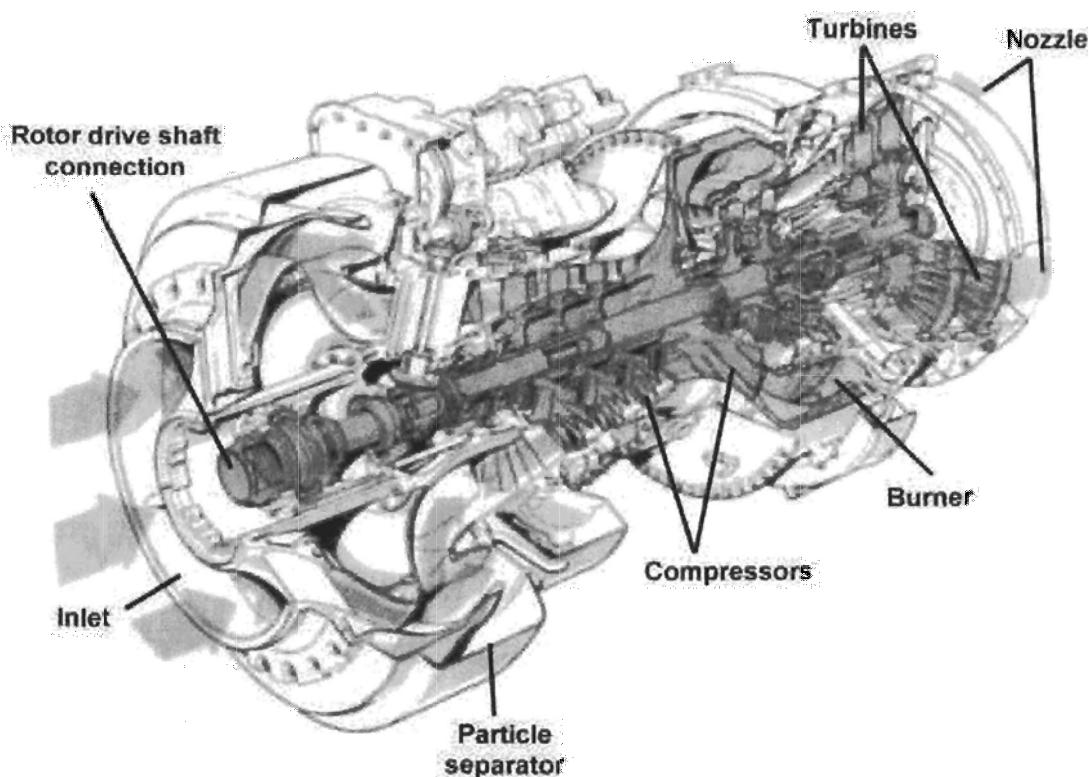
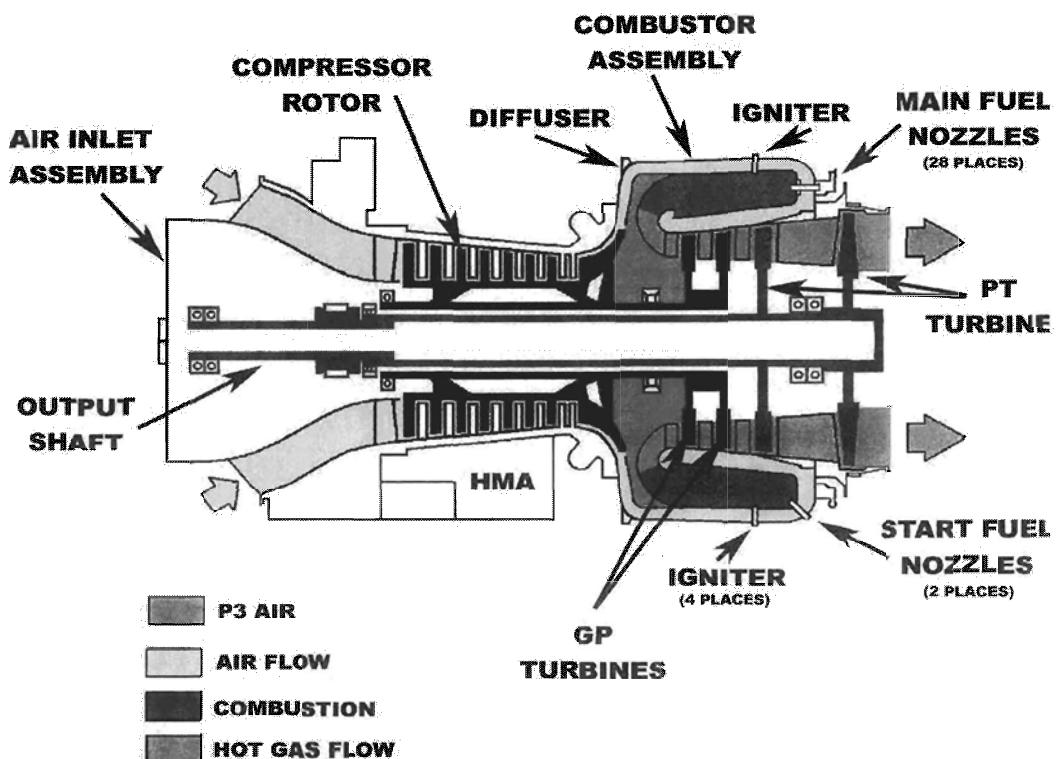


Figure 17.4: T55-714 diagram and cutaway



A typical power turbine of a turbo-shaft engine operates at about 35,000 RPM. On the other side a helicopter main rotor turns between 300 and 400 RPM. The tail rotor turns at around 2100 RPM.

Between the power turbine and the main rotor, the following components are installed:

- Power out pad
- Drive shaft
- Freewheeling unit (clutch)
- Transmission (main reduction gearbox)



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Drive Shafts and Couplings

Most turbine helicopters make use of a short shaft system to deliver power to the transmission. These short shafts vary in design, but all have some way to correct for misalignment and for movement of the transmission. Some of these shafts operate with no lubrication, while others require it. This lubrication is usually in the form of grease and is often hand-packed.

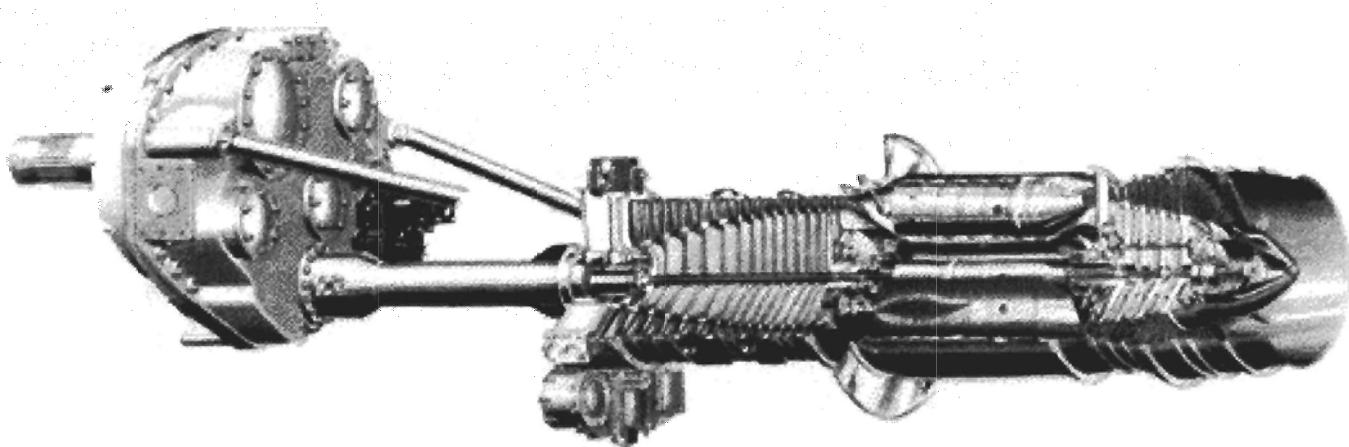


Figure 17.5: Typical drive shaft arrangement

The drive shaft consists of a shaft with two flexible couplings attached at each end. The shaft turns at high speed (6,000 to 30,000 RPM). Therefore, balance is important.

The drive shaft itself must also be provided with flexibility for the deflection caused by the transmission movements, but will not carry any tension or compression loads because of the housing.



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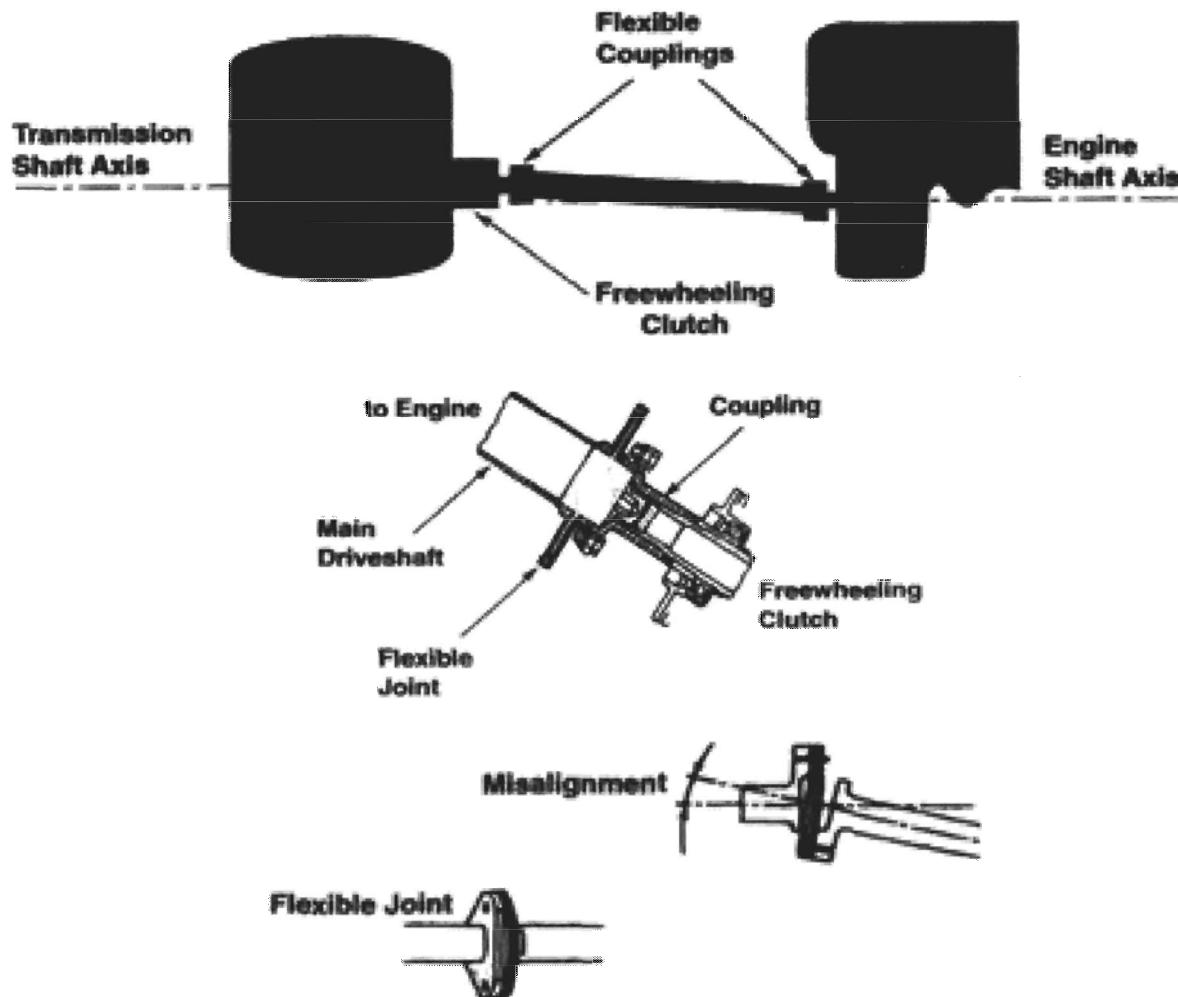


Figure 17.6: Flexible Couplings



Freewheeling Units

A freewheeling unit is sometimes referred to as the over-running clutch. This component will be found on all helicopters regardless of the powerplant. On multi-engine helicopters one will be located on each engine. The purpose of this freewheeling unit will allow the engine to drive the transmission and prevent the rotor from driving the engine. Without this unit the engine would be driven by the rotor any time an autorotation is attempted. In addition, any seizure of the engine would prevent the possibility of autorotation. For this reason the helicopter, equipped with two engines, must have a freewheeling unit on each engine output. Although practically all helicopters use the same type of unit, their location and size vary from one helicopter to another. The operation of the units will always be automatic.

Sprag Clutch

The most commonly used freewheeling unit on helicopters is the sprag clutch. This clutch allows movement in only one direction by having an inner and outer race, which are often at the end of the driveshaft.

The sprag assembly is made up of a number of sprags resembling the rollers in a roller bearing. The sprags, unlike the circular bearings, have a figure-eight shape. The vertical height of each of these sprags is slightly greater than the gap between the inner diameter of the outer race and the outer diameter of the inner race.

This engaged position places the sprags against both races at a slight angle. Rotation from the engine on the outer race jams the sprags between the outer and inner races and this interference fit drives the inner race, which is attached to the driveshaft. If the driveshaft attempts to drive the engine, the sprags will be relieved and the driveshaft will rotate without the engine. The same would happen if the engine stopped.

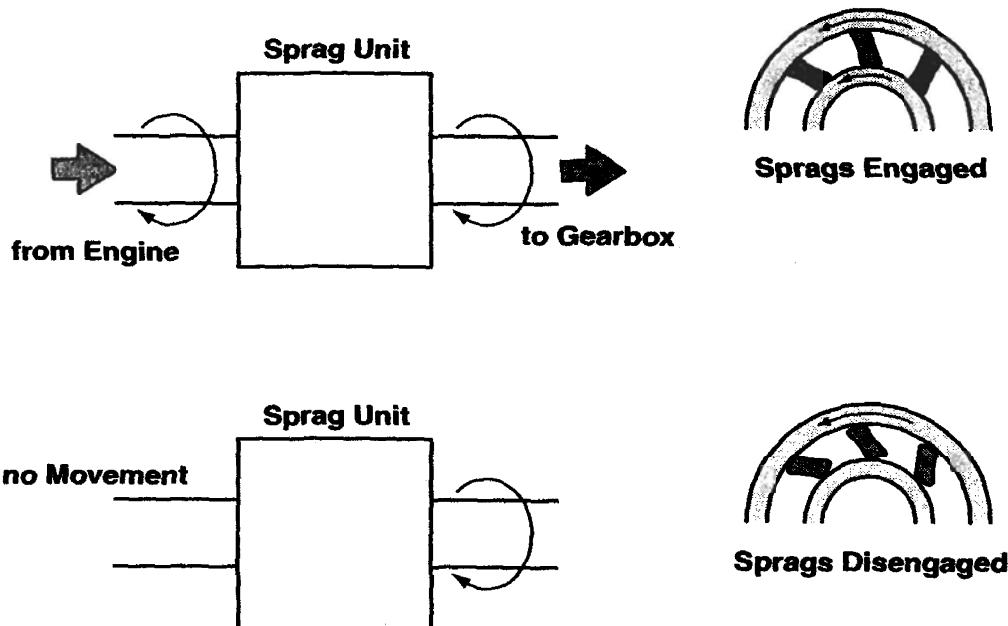


Figure 17.7: Sprag clutch operation

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Helicopter Couplings

Because of the requirement to make maintenance tasks such as engine removal/refit, gearbox removal/refit easier, it is necessary to have a means of coupling the turboshafts output shaft to the helicopter main rotor gearbox input shaft together. This coupling must possess qualities which will allow movement of both the engine and the rotor gearbox independently of each other i.e. it must be flexible. It must also be finely balanced to reduce vibration.

One of the most common couplings in use is the 'Thomas Coupling', sometimes referred to as the engine 'high speed drive shaft' (figure 17.8). The engine is joined to the main rotor gearbox by this high speed drive shaft. The shaft is belled at either end, one end being attached to the power take off shaft by means of Thomas flexible steel coupling. Each coupling consists of a number of steel discs, indexed by flats to ensure correct alignment when assembled. Two different numbered discs are used, each disc having a grain running either parallel to the flat or perpendicular to the flat. The discs are assembled alternately with the grains at 90° to each other. The bolts, nuts and washers securing the shaft to the engine are part of the fine balancing of the assembly and must always be replaced in the same position.

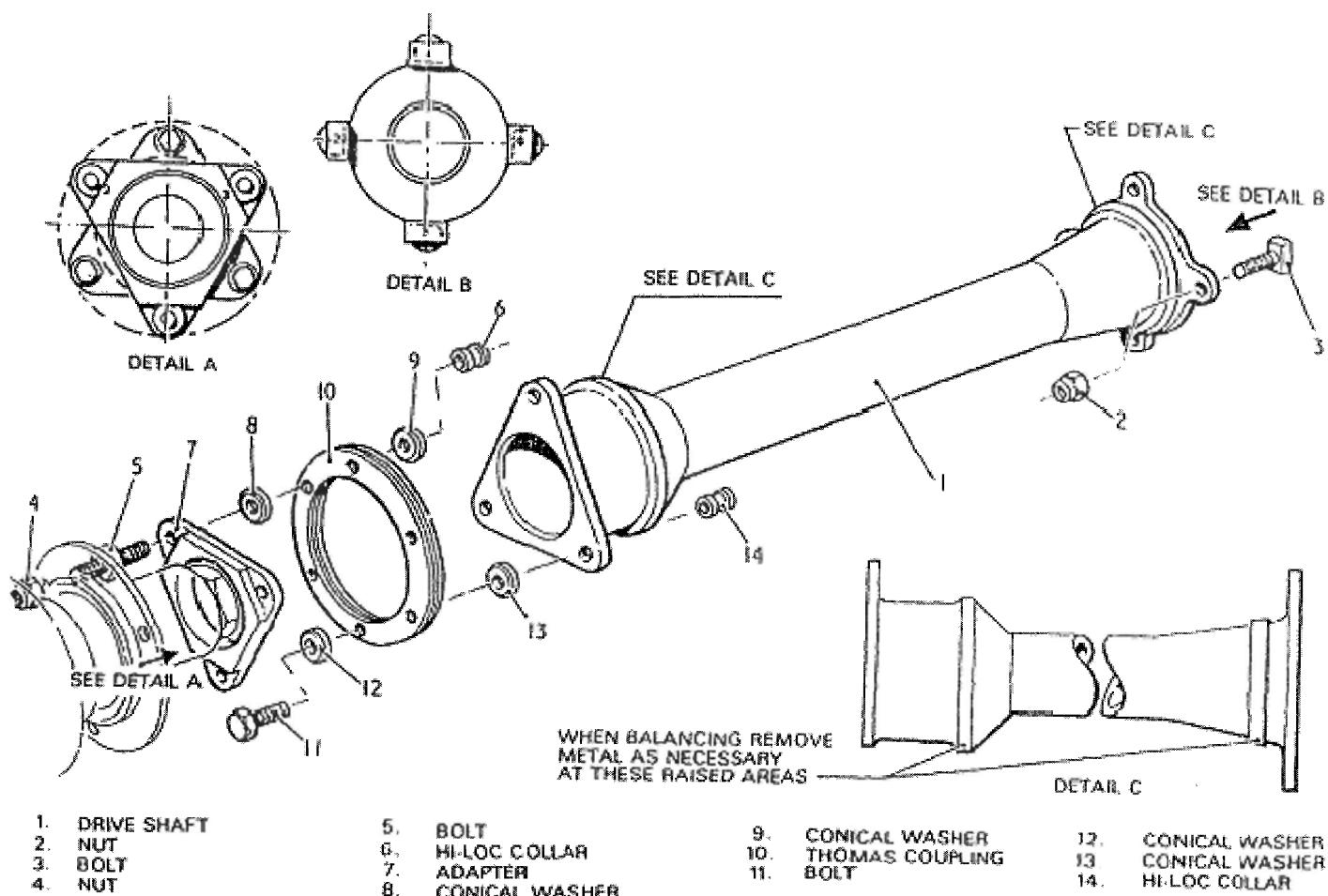


Figure 17.8: Thomas coupling

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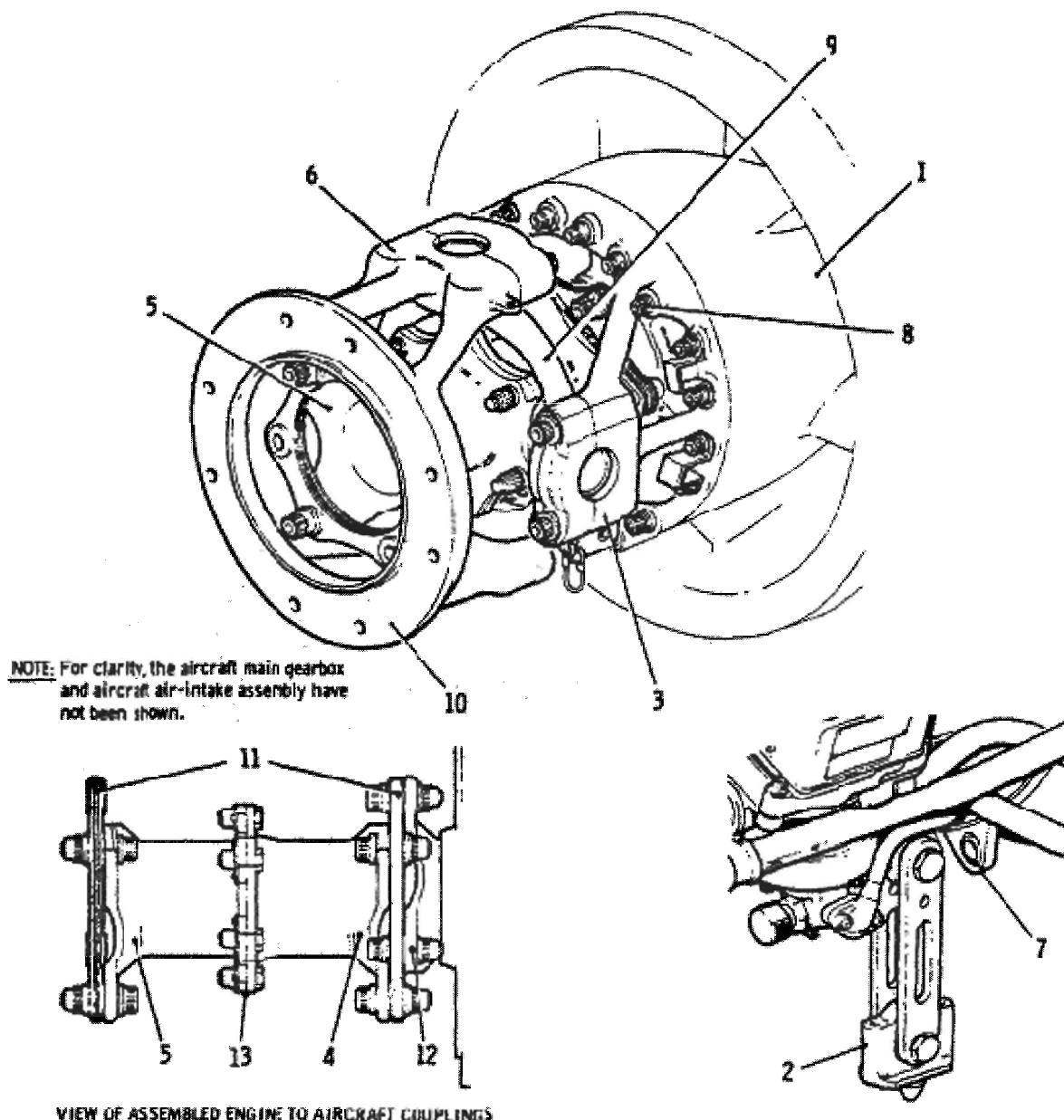
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Yet another method of coupling the engines power output to the main gearbox is shown in Figure 17.9.

The engine front mounting is bolted with the reduction gearbox to the hub of the air-intake case; it supports the engine in the aircraft and serves as a torque reaction point. The mounting, which is of the gimbal type, is bolted to a gimbal ring, which is bolted to a similar mounting on the aircraft main gearbox, thus forming a gimbal coupling.

The engine output drive is transmitted to the aircraft main gearbox by a flanged coupling, which is secured via a flexible laminated disc coupling (Thomas Coupling) to a drive assembly. The drive assembly consists of an engine coupling and an aircraft main gearbox coupling bolted together, with a flexible laminated disc coupling (Thomas Coupling) at each end.



1. ENGINE AIR-INTAKE CASE
2. ENGINE REAR MOUNTING
3. ENGINE FRONT MOUNTING
4. ENGINE COUPLING ASSEMBLY
5. AIRCRAFT MAIN GEARBOX COUPLING ASSEMBLY
6. AIRCRAFT MAIN GEARBOX SUPPORT ASSEMBLY
7. LOCATION LUG FOR AIRCRAFT LATERAL RESTRAINT STRUT
8. BOLT (ONE OF 20) SECURING REDUCTION GEARBOX AND FRONT MOUNTING (3) TO HJB OF AIR-INTAKE (1)
9. GIMBAL RING
10. MOUNTING FACE TO AIRCRAFT MAIN GEARBOX
11. SIX-BOLT FLEXIBLE LAMINATED DISCS
12. THREE-BOLT FLANGED COUPLING, ENGINE OUTPUT
13. COUPLINGS (4) AND (5) CONNECTED BY SIX BOLTS AND NUTS

Figure 17.9: The Thomas coupling and gimbal mount of an RR Gem engine



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Finally as an example of the end product of a typical, turboshaft engines power output Figure 17.11 shows the main rotor gearbox of a Westland S-61N helicopter. The two engines are Rolls Royce Gnome 1400 series turboshaft engines, each producing approximately 1400 S.H.P. Figure 17.10 shows the gearbox together with its monitoring devices and transmission.

The free-wheel system enables disconnection of one or both the engines in the event of failure.

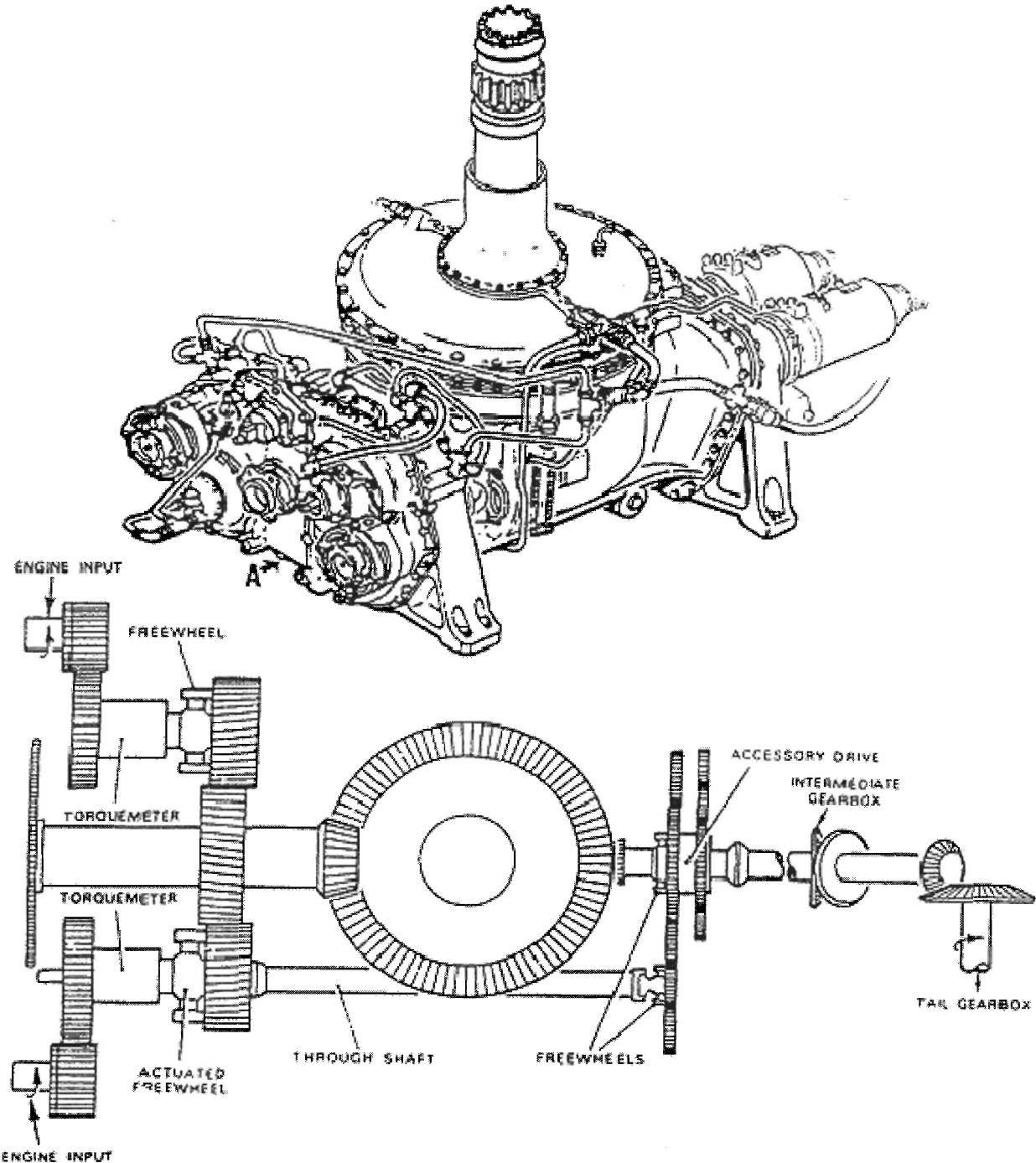


Figure 17.10: S61N Rotor gearbox

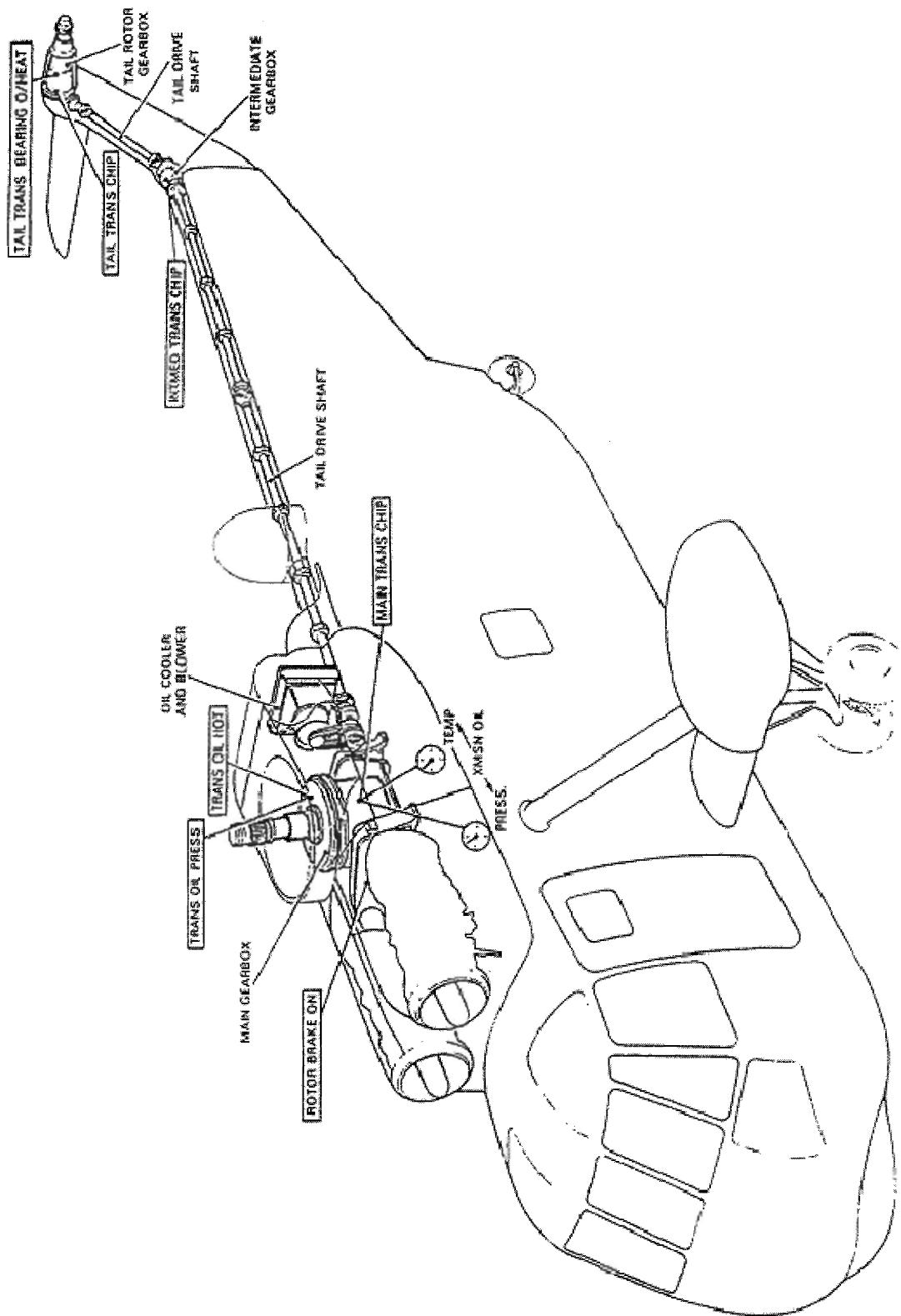


Figure 17.11: Sea King / S61 Transmission system

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Engine Control System

Power control of helicopter engine is done via a hand throttle (twist grip) built into the side collective stick. The power plant is connected to the drive system by a clutch. The collective stick, when raised, will increase the angle of attack of all rotor blades at the same time. As this will increase the drag the rotor assembly will tend to slow. The fuel system increases or decreases engine power to match load changes at the main rotor. Variation of fuel flow from the throttle valve takes place in the free turbine governor which passes the correct fuel via the HP valve to the burner. Matched to the requirements of the free turbine to keep the rotor on speed.

On some turbine engine helicopters the twist grip arrangement has been eliminated in favour of a power lever for the free turbine. The N1 usually has three positions: ground idle, flight idle and full N1. The N1 system will speed up and slow down as a function of N2 so a steady rotor RPM may be maintained during all flight conditions.

The free turbine governor is a flyweight controlled governor, driven from the power output section and therefore the speed will be directly related to the speed of the free turbine and rotor, causing the governor to act as a constant speed unit for the rotor.

Turbo-shaft Engine Fuel Controls

Like fuel controls for turbojet and turbofan engines, the fuel control for a turboprop or a turbo-shaft engine receives a signal from the pilot for a given level of power. The control then takes certain variables into consideration. It adjusts the engine fuel flow to provide the desired power without exceeding the RPM and turbine inlet temperature limitations of the engine. But the turbo-shaft engine control system has an additional job to do that is not shared by its turbojet and turbofan counterparts. It must control the speed of the free turbine.

Many turbo-shaft engines in production today are the free turbine type. Engines of this kind act principally as gas generators to furnish high-velocity gases that drive a freely rotating turbine mounted in the exhaust gas stream. The free turbine rotates a helicopter rotor through reduction gears.

FADEC Fuel Control

The engine control system incorporates all control units necessary for complete control of the engine. The system provides for the more common functions of fuel handling, computation, compressor bleed and VG control, power modulation for rotor speed control, and overspeed protection. The system also incorporates control features for torque matching of multiple engine installations and over-temperature protection.

The FADEC system is designed for simple operation requiring a low level of pilot attention. The system performs many of the controlling functions formerly performed by the pilot.

Basic system operation is governed through the interaction of the Electronic (ECU) and Hydro-mechanical (HMU) control units. In general, the HMU provides for gas generator control in the areas of acceleration limiting, stall and flame out protection, gas generator speed limiting rapid response to power demands, and VG actuation. The ECU trims the HMU to satisfy the



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requirements of the load to maintain rotor speed, regulate load sharing, and limit engine power turbine inlet temperature.

Metering of fuel to the engine and basic engine control computations are performed in the HMU. The electrical and hydro-mechanical control units compute the fuel quantity to satisfy power requirements of the engine. The fuel and control system contains the following components:

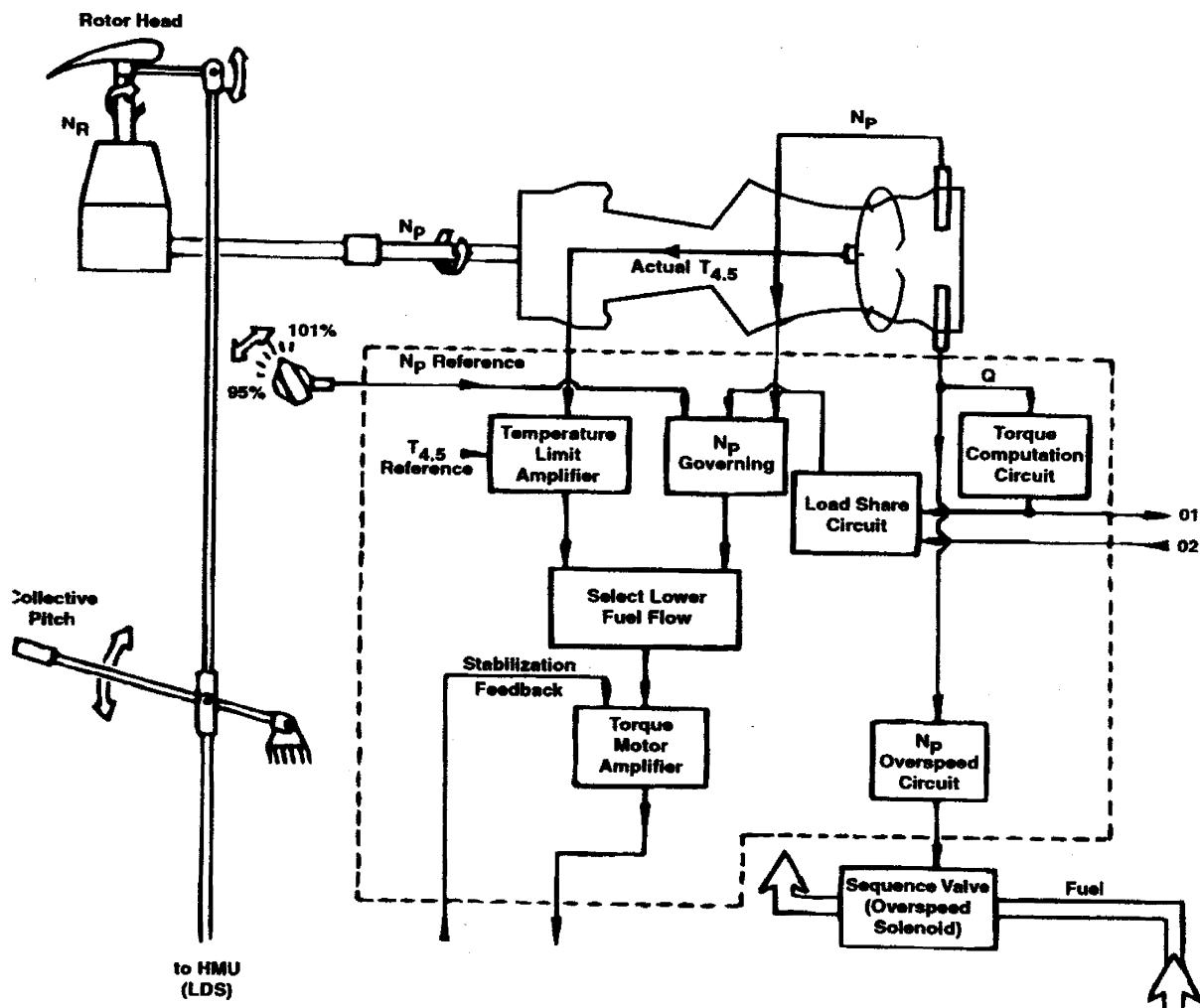


Figure 17.12: Helicopter Electronic Control Unit (ECU) Schematic



Hydro Mechanical Power Control

Like turboprop engines, turbo-shaft engines are designed to deliver constant RPM. Depending on the power demand from pilot action on flight control the fuel control will keep RPM of the power turbine section at a constant rate increasing or decreasing fuel flow to the burner. The power plant is controlled between ground and flight idle by the throttle twist grip. Between flight idle power and maximum power, control is automatic by the free turbine governor.

When the rotor speed drops due to increasing load the turbine slows slightly down, the Free Turbine Governor will sense this and pass more fuel to bring the turbine back on speed condition thus increasing power of the rotor. If rotor load decreases the reverse of this takes place.

On most engines the pilot has the option to select extra power by operating a switch (Beeper System), to set the Free Turbine Governor datum. This is needed because the governor does not fully compensate for load changes on the main rotor.

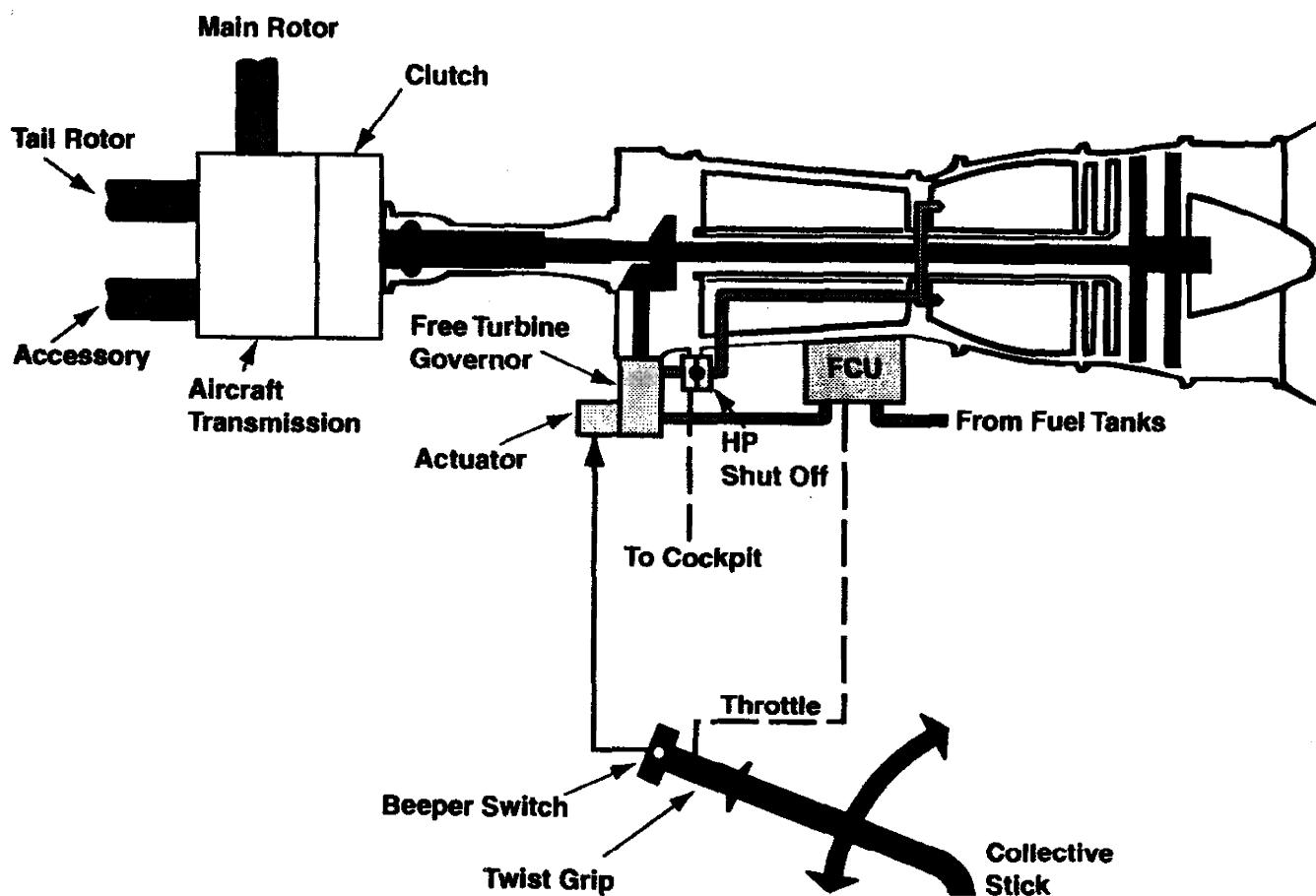


Figure 17.13: Hydro-mechanical control schematic



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Gas Turbine Engine

15.18 Auxiliary Power Units (APUs)

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A detailed knowledge of the theoretical and practical aspects of the subject.

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Module 15.18 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.18 - Auxiliary Power Units (APUs)

Introduction

The auxiliary power unit or APU as it is commonly known, is a small gas turbine engine as shown below, fitted to aircraft to provide: -

Electric power from shaft driven generators,

Pneumatic duct pressure for air conditioning and engine starting purposes.

It is called an auxiliary power unit since it is not the primary source of power for the aircraft, and is mainly used on the ground when the aircraft engines are not running. The APU provides the above two services, but can also, on certain occasions, be used in the air.

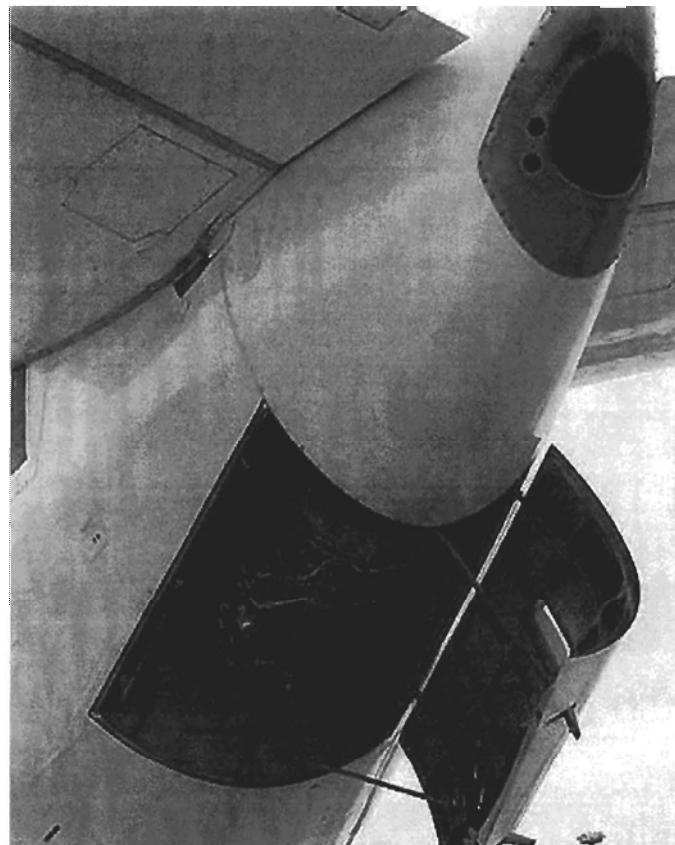


Figure 18.1: APU location (B737)



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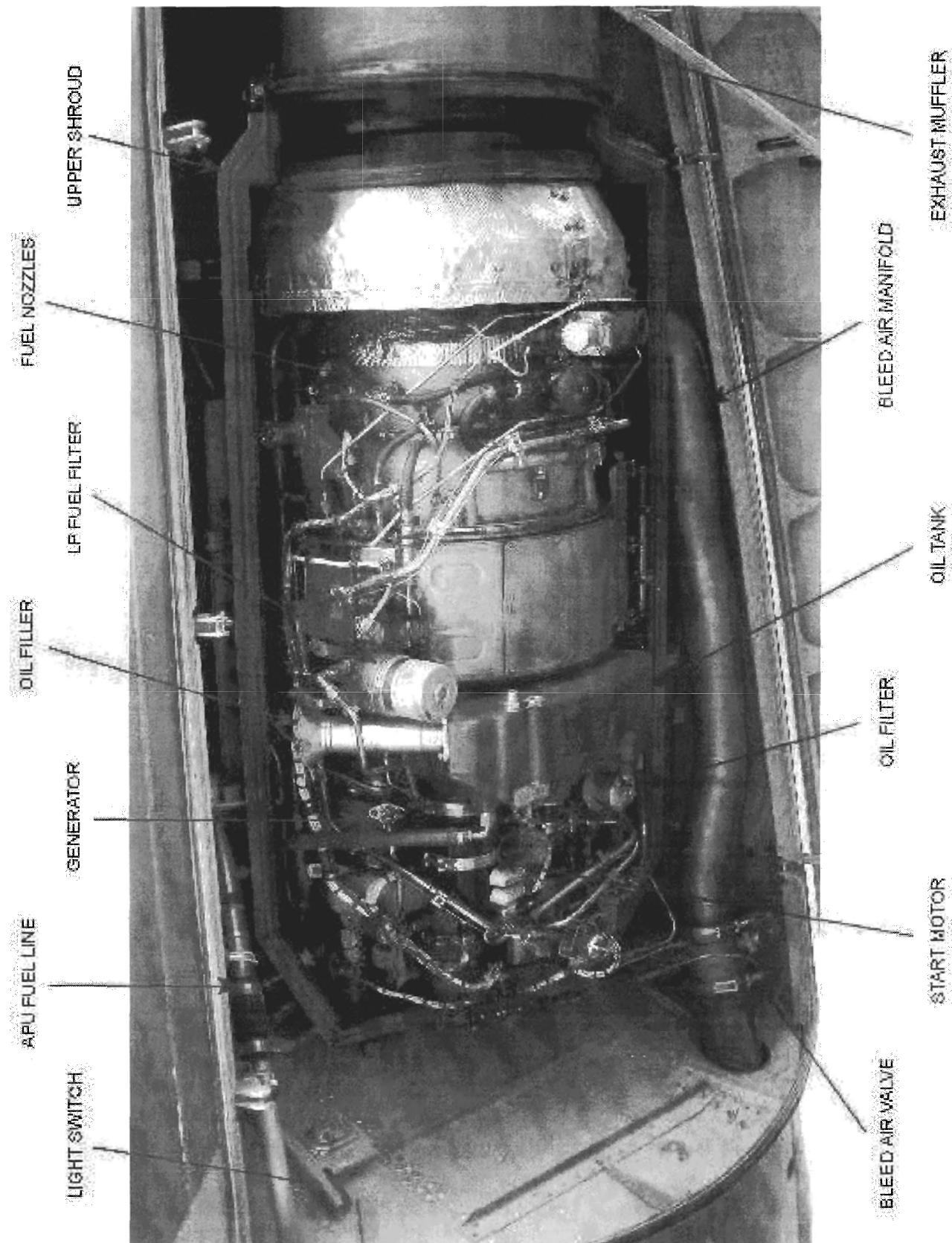


Figure 18.2: APU components (B737)

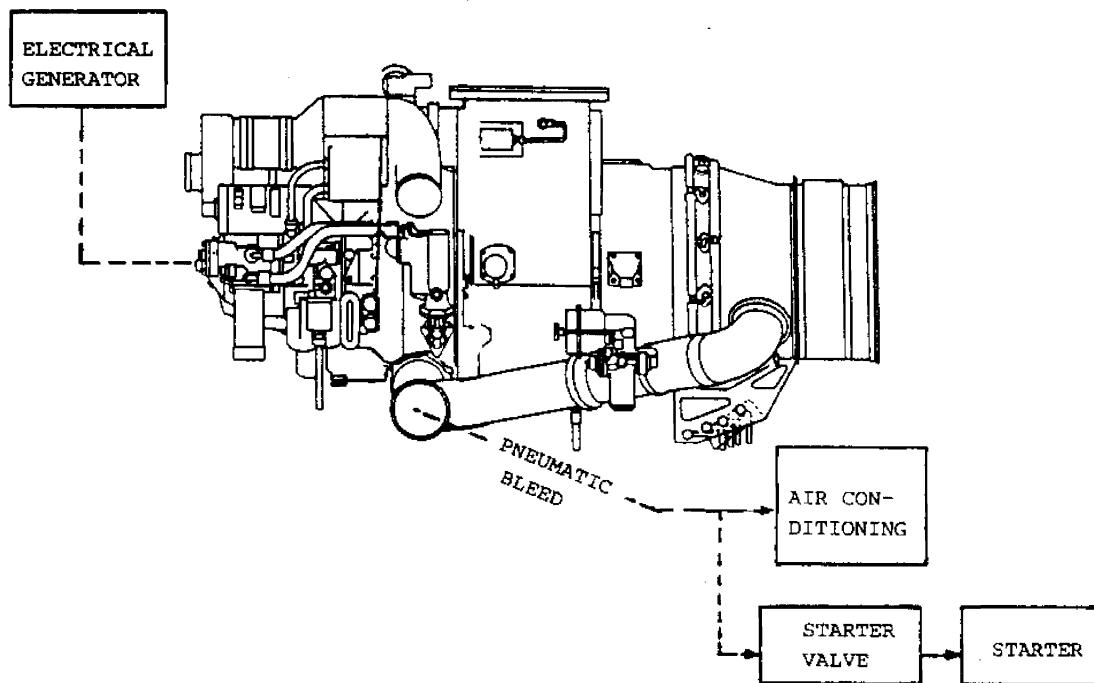


Figure 18.3: APU output functions

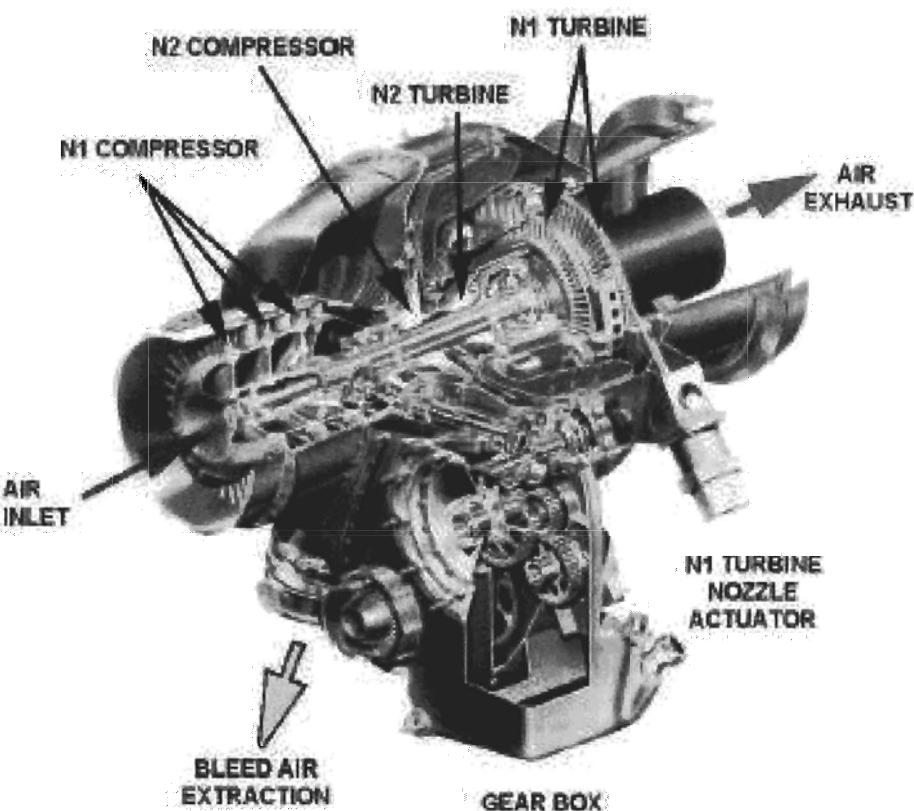


Figure 18.4: APUs with two shafts (N1 & N2) which extracts the bleed air from the N1-Compressor driven from the N1-Turbine (MD-11).

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APU General Arrangement

The basic arrangement of the APU is shown in figure 18.5.

Here we have a small turbine engine, known as the power section, driving a load compressor to produce pneumatic power. The load compressor also drives the accessory gearbox containing the electrical generator.

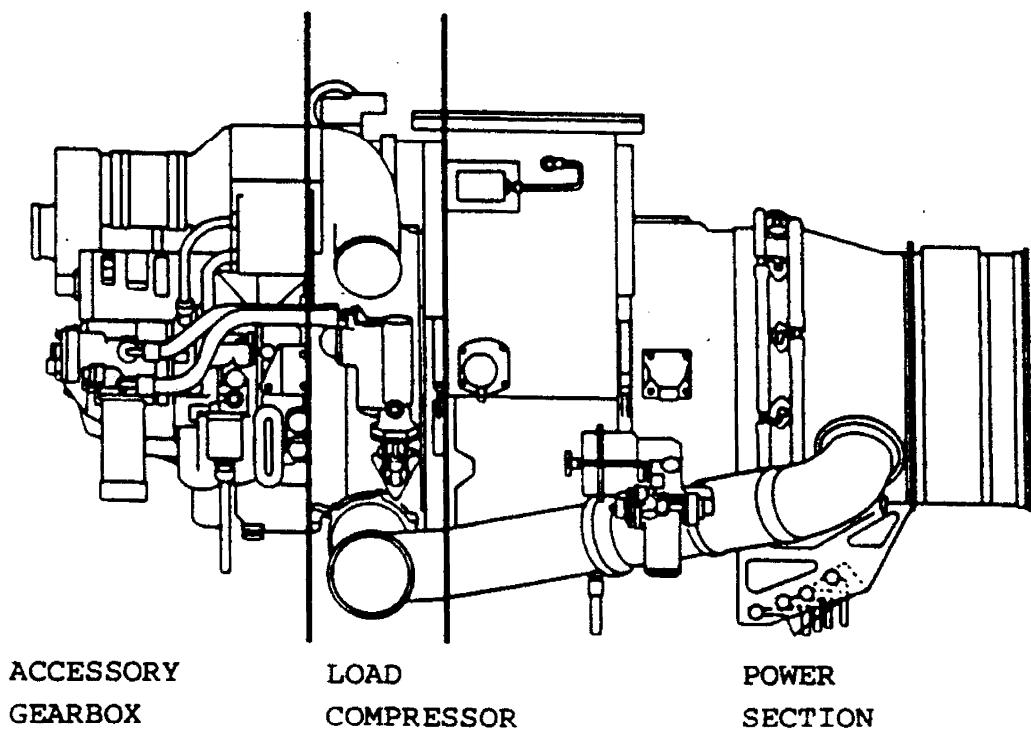


Figure 18.5: APU arrangement

Consider the schematic diagram of an APU (figure 18.6). The layout is similar to a basic gas turbine engine.

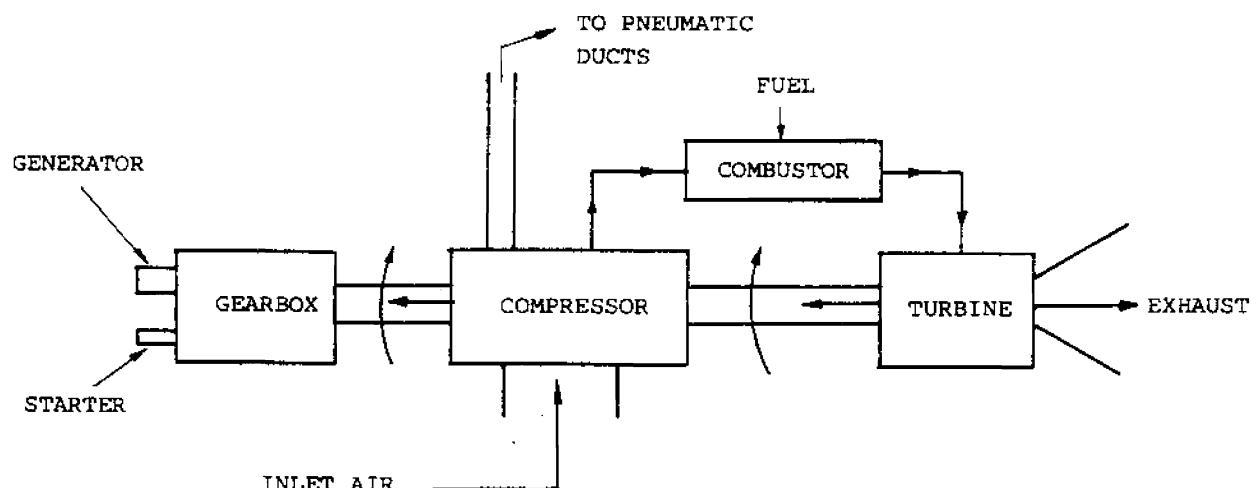


Figure 18.6: APU schematic



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With this configuration we can see that air is taken from the compressor when pneumatic power is required. Although such an APU layout is acceptable on smaller aircraft where pneumatic power demand is small, it was found to be unacceptable on larger aircraft as the air being drawn from the compressor for pneumatic purposes, reduces the air going to the turbines for cooling purposes. This reduction of cooling air leads to a reduction in the life of the turbine.

On later models of APU this problem has been eliminated by the inclusion of a load compressor.

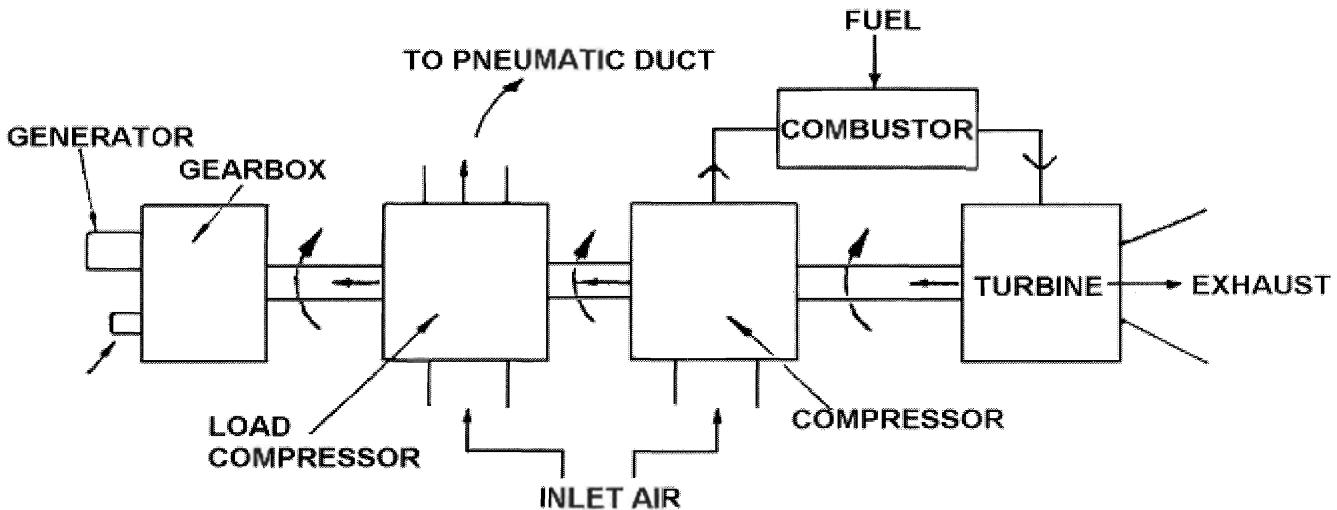


Figure 18.7: APU schematic

In this configuration, the inlet air is directed into the load compressor as well as into the power section compressor. The load - compressor now satisfies all pneumatic loading requirements without extracting any air from the power section.

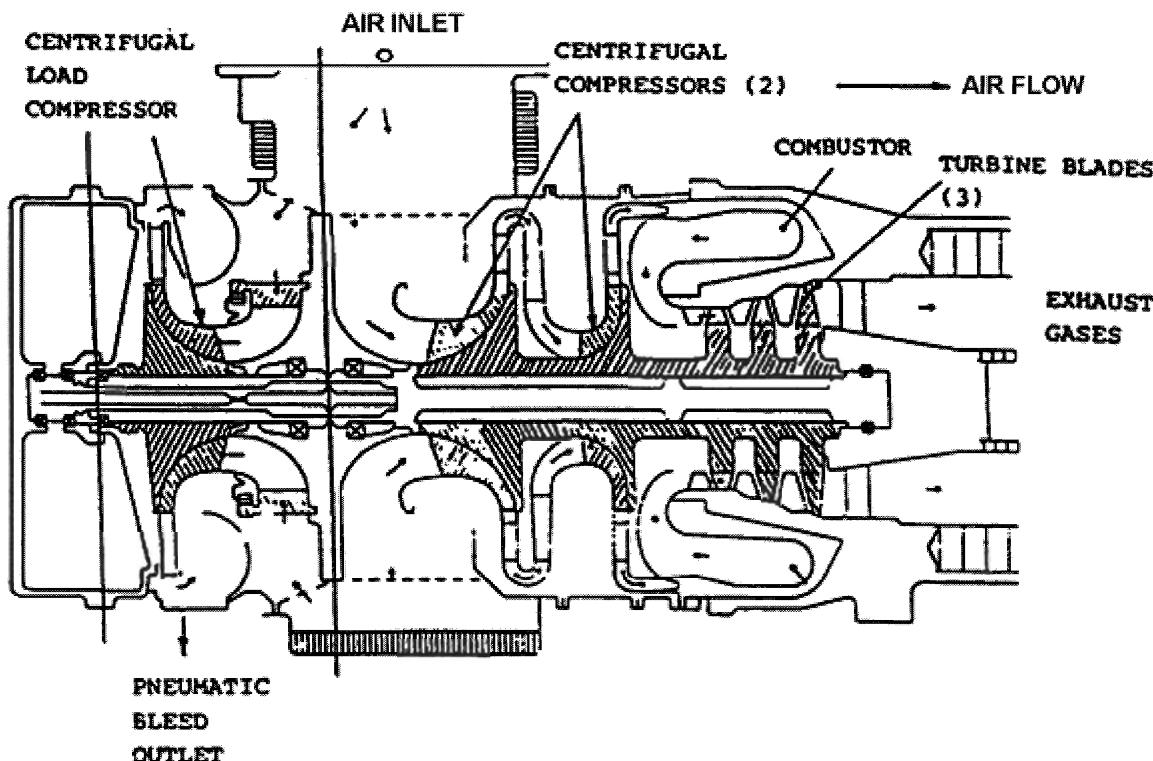


Figure 18.8: Cross section of APU with a load

Figure 18.8 represents a typical cross section of an APU with a load compressor. As you can see the power section with two centrifugal compressor stages is driving a centrifugal load compressor, this produces pneumatic pressure when a demand is made on the system.

The location of the APU on the aircraft is generally dictated by the requirements of the manufacturer.

Because of the noise factor and the problem of hot exhaust gases, it is located as far away from ground servicing areas as possible. The normal place for it to be fitted is in the tail section of the aircraft; however, this may be impracticable due to the location of a tail mounted engine. On some aircraft the APU may be fitted into landing gear bays or wing structures.



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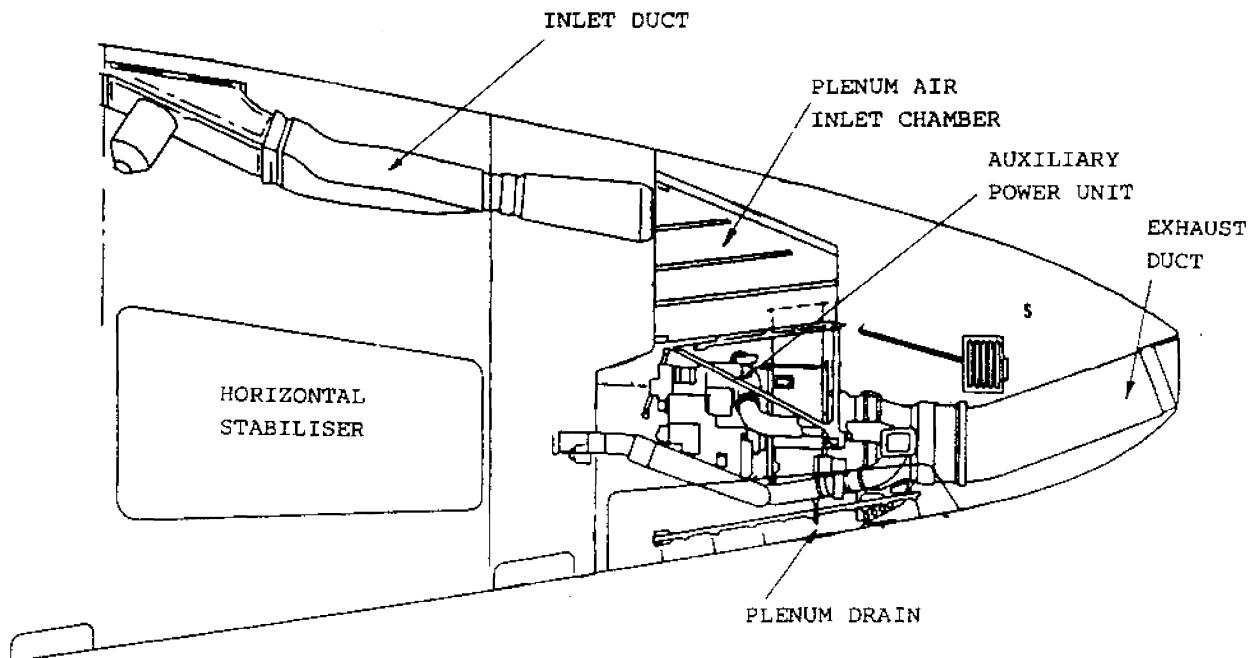


Figure 18.9: APU installation

Wherever the APU is located, ducting will be required to bring the air to the APU inlet and to vent exhaust gases overboard.



Inlet Duct Arrangement

The length of the inlet ducts will depend upon the location of the APU and its distance from the inlet door.

The inlet duct connecting the inlet door to the APU plenum chamber is divided into three parts. The plenum chamber has the APU inlet duct bolted to its structure, thus reducing a complicated duct joint arrangement.

When the duct length is short, steel ducts may be used. When ducts cover a large distance an unacceptable weight problem may result. Ducts of this length are therefore manufactured from composite materials.

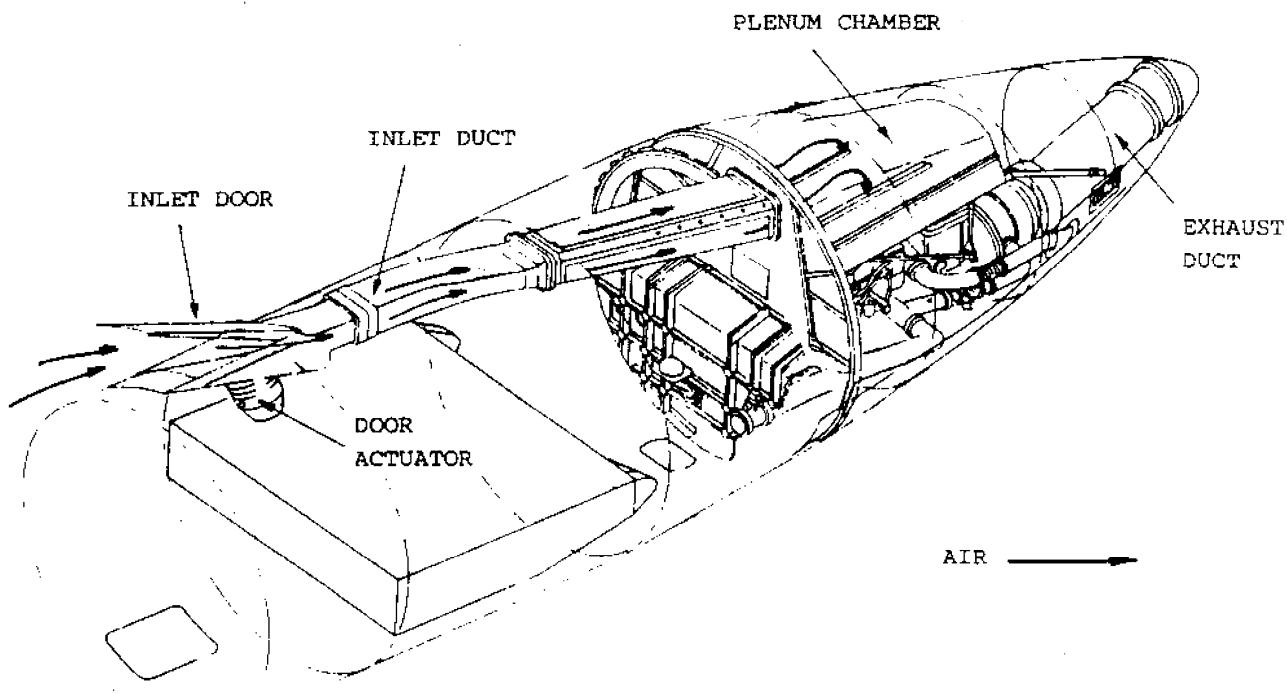


Figure 18.10: Inlet duct arrangement

One of the main problems of APUs is the ingestion of foreign objects, or FOD; fitting wire mesh grills either in the ducting or around the APU air inlet can eliminate this.

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Exhaust Duct Arrangement

Exhaust ducts do create more problems when the APU is running on the ground, the hot gases must be directed away from the maintenance crews and also the aircraft structure. This is usually achieved by angling the exhaust duct up into the air. Figure 18.11 shows a typical duct arrangement.

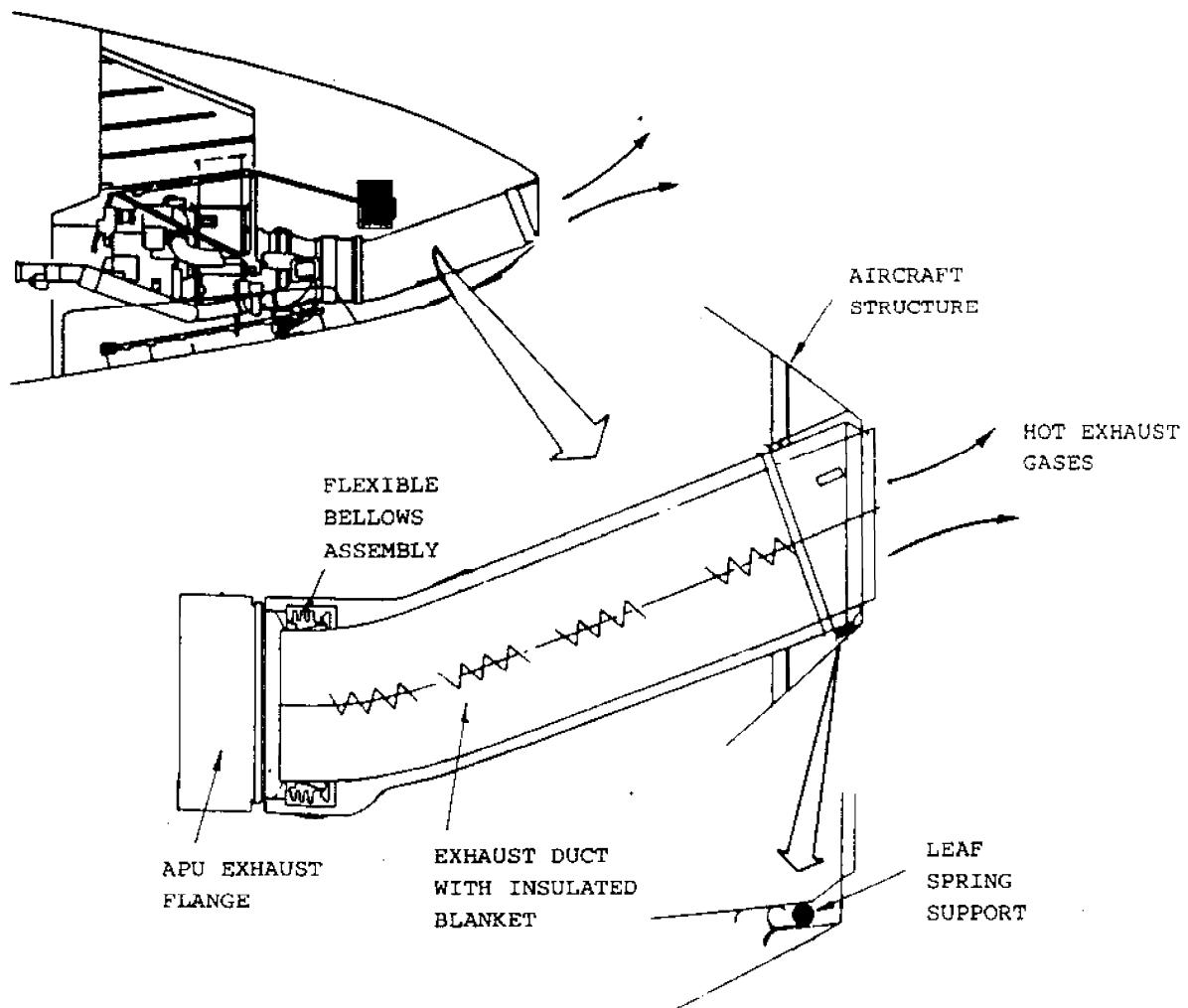


Figure 18.11: Typical exhaust duct arrangement



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Inlet Door Arrangement

The APU inlet door-serves two functions: -

- It seals off the inlet duct from harmful weather conditions and foreign objects when the APU is not in use
- It opens to allow air into the APU when the start sequence is initiated.

A general arrangement of the APU door is shown opposite.

Operation of the door opening and closing sequence is achieved by using an electrical actuator, which receives its signal from a command from the flight deck APU switch.

In the event of an electrical failure to an actuator, there is normally incorporated into the actuator a means of disengaging the clutch drive mechanism. This enables the actuator to be manually turned to open or close the inlet door.

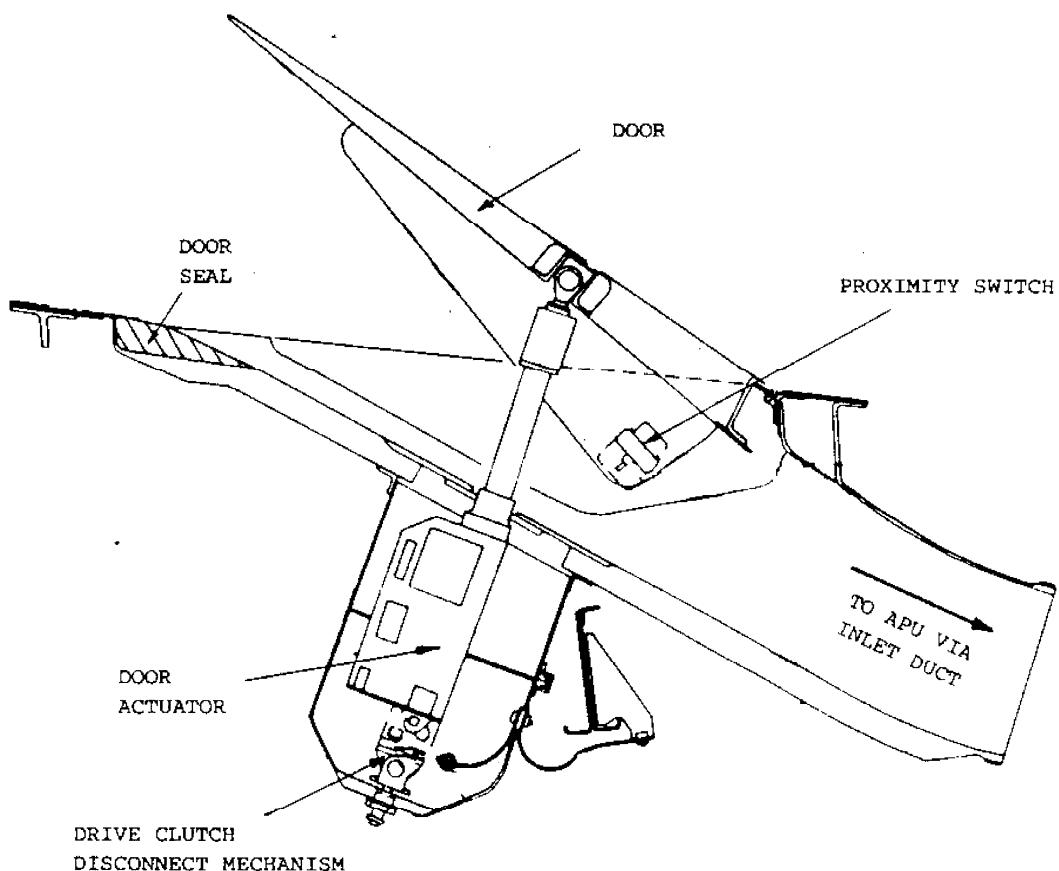


Figure 18.12: Inlet door mechanism

A proximity switch ensures that the door is fully open before the APU start sequence is initiated.

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APU Starting Sequence

In the schematic diagram shown in figure 18.13, the APU control unit receives its power from the aircraft battery.

By moving the APU switch to 'ON', power is provided to the door actuator and it starts to open. On reaching the fully open position, the proximity switch is energized. This then allows a signal to pass back to the control unit, which passes current to the starter, which then turns the APU.

The igniters are then energized and the APU reaches a sustained idle speed.

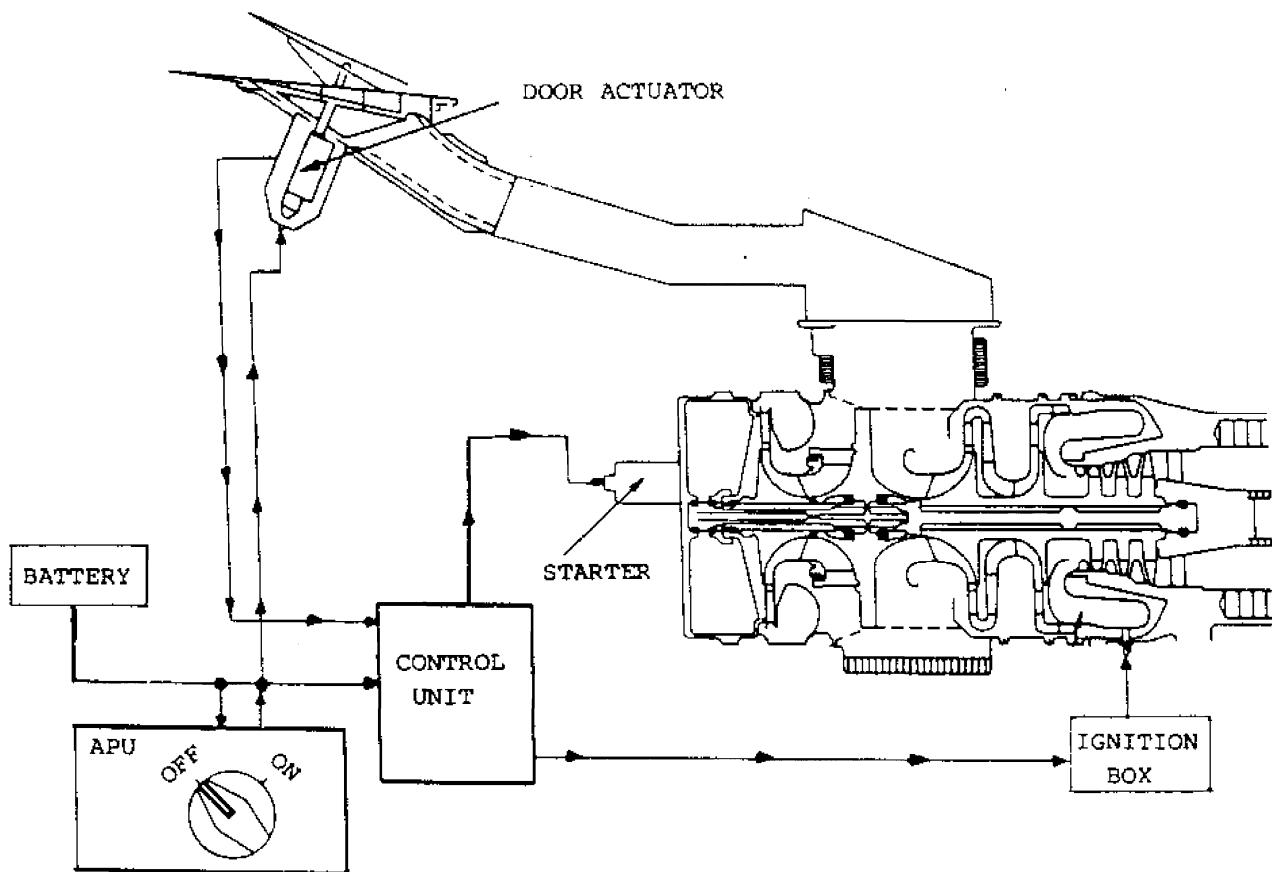


Figure 18.13: Start system schematic

Note: Boeing 757 and 767 aircraft utilize a separate battery for APU starting. In some instances a tapping from the aircraft 115VAC is taken via a TRU, thus saving either battery.

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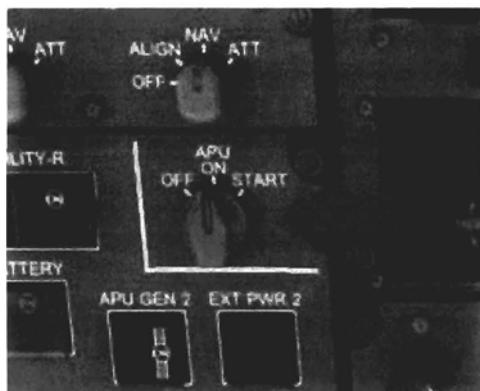
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APU Control and Monitoring

General

In modern aircraft the APU is normally fully automatically controlled and monitored by an Electronic Control Box (ECB) or also named APU Electronic Control Unit (ECU).



Starting and normal stopping procedures must be performed manually by an APU MASTER switch and for airbus aircraft with an additional APU START switch. Other aircraft have only a MASTER switch with a START /RUN / STOP position.

For emergency and fire stopping procedures the ECB receives stop signals from the APU FIRE Pushbutton or from the APU SHUT-OFF switch on the external control panel or from the APU fire warning system. In the event of any of these signals being received the ECB will perform a 'protective shutdown' without any input from the flight deck.

Figure 18.14: APU start switch

The ECB tests the electrical APU components prior to the start sequence. If this Pre-Start Test fails, the APU will not start and the FAULT light in the master switch comes on.

During start and run condition the ECB continuously monitors the APU components and parameters. If a dangerous condition occurs the ECB will automatically shutdown the APU. The ECB stores component failures and automatic shutdowns. For fault isolation the memories can be interrogated via the Centralized Fault Display System (Airbus) or on some ECBs with test switches and fault display lights on the ECB front panel.(Boeing)

APU Starting Sequence

The exact sequence differs from aircraft to aircraft, but is generally as follows:

- Aircraft APU fuel valve opens and fuel pump runs
- Air inlet door opens
- Pre-Start test runs
- Starter is energized
 - 3-10% RPM - ignition energized, fuel solenoid valve opens
 - 50% RPM - starter motor de-energized
 - 95% RPM - ignition de-energized, generator and pneumatics enabled.
 - 100% RPM - APU is on normal speed.



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The APU will control at this constant speed for as long as the APU is switched on. There is no limit as to time run, however there is a limit on starts – usually 3 consecutive starts then a 60 minute cool down period.

APU Normal Stopping Procedures

The normal stopping sequence is initiated by setting the APU Master switch to “OFF” position. The ECB then initiates the shutdown sequence.

The APU is only allowed to shut-down, after it has operated for a sufficient time without pneumatic or electrical load. This cool down time is important to reduce the thermal stress of the APU during shut-down.

On modern aircraft the cool down procedure (removing the electrical and pneumatic load) is automatically performed by the ECB. The cool down time is normally between 60 seconds and 120 seconds.

Following the cool down time, the ECB closes the fuel supply to the combustion chamber and the APU stops. After run down the ECB closes the air inlet door and cuts-off its power supply.

Normally the ECB tests the overspeed protection circuits during the normal shutdown sequence. If this test fails, the failure will be stored in the shutdown memory.

APU Automatic Shut-Down

An automatic shut-down is automatically activated by the ECB to protect the APU from damage if operating limits are exceeded or important APU components fail.

An automatic shut-down will stop the APU immediately without any cool down time.

APU Emergency Shut-down

In case of emergency, the APU must be switched off immediately without any cool down time.

An emergency shut-down is manually initiated by switches like the APU fire handle or the external emergency shut-down switch. On some aircraft the emergency shutdown is initiated automatically by the fire warning system on ground. The emergency shut-down switches are located in areas of the aircraft where they are easily accessible for the ground staff.



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Figure 18.15: APU fire handle on main engine fire panel (B737)



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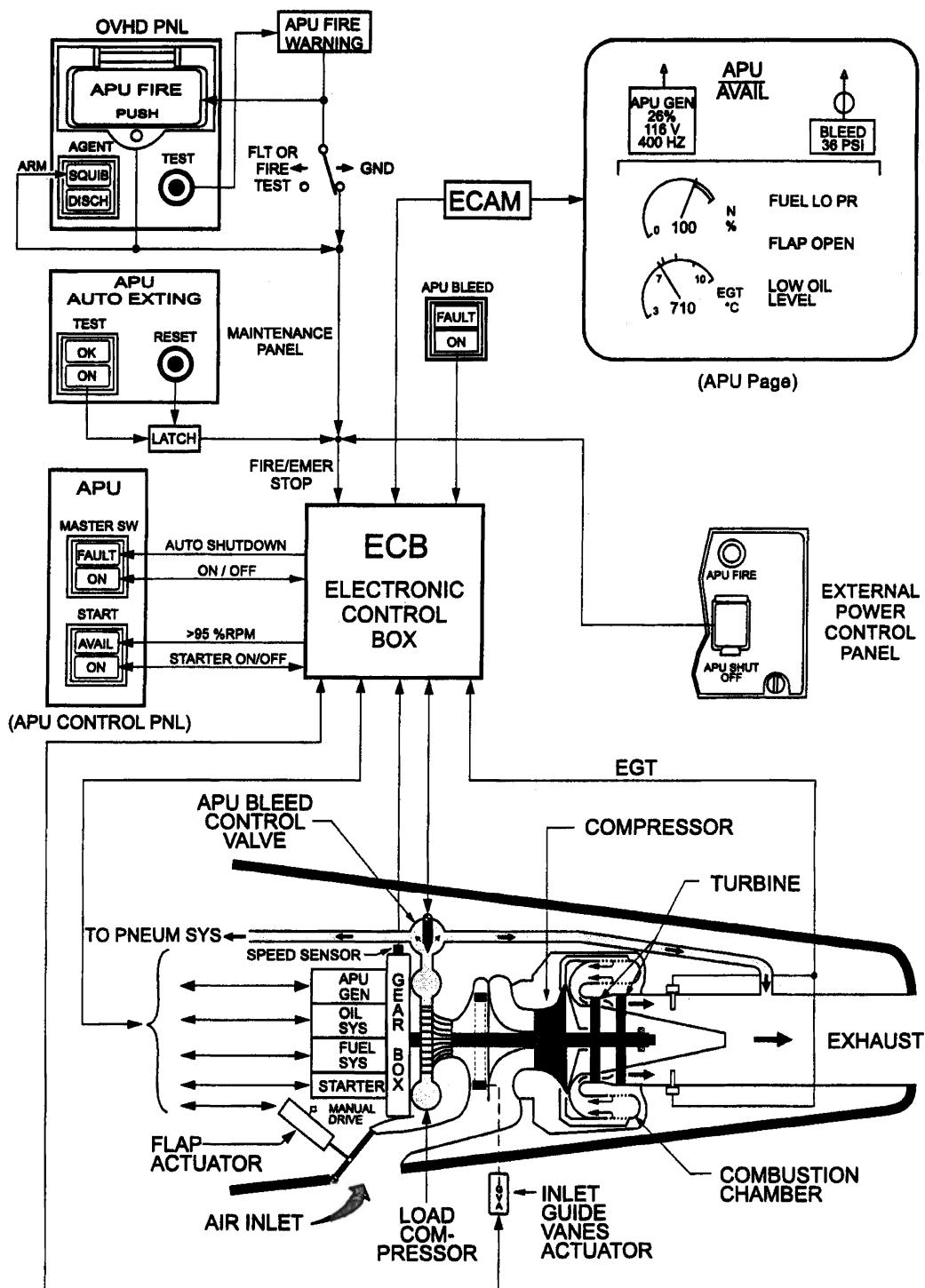


Figure 18.16: APU control and monitoring (A320)



TTS Integrated Training System

Module 15 Licence Category B1

Gas Turbine Engine

15.19 Powerplant Installations

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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.19 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.19 - Powerplant Installation

Introduction

New or reconditioned turbine engines are normally supplied as an engine change unit (ECU), the Unit including the basic engine and equipment which is common to the engines on the particular aircraft. Items which are handed to suit different engine positions and items not common to all engine applications such as thrust reversers cowlings etc are added to suit a particular airframe. This complete installation is known as the **Powerplant**.

Powerplant Location

The power plant location and aircraft configuration are of an integrated design and this depends upon the duties that the aircraft has to perform. Turbo-jet engine power plants may be in the form of pod installations that are attached to the wings by pylons, or attached to the sides of the rear fuselage by short stub wings or they may be buried in the fuselage or wings. Some aircraft have a combination of rear fuselage and tail-mounted power plants, others have wing mounted pod installations with a third engine buried in the tail structure. Turbo-propeller engines, however, are normally limited to installation in the wings or nose of an aircraft.

The position of the powerplant must not affect the efficiency of the air intake, and the exhaust gases must be discharged clear of the aircraft and its control surfaces. Any installation must be such that it produces the minimum drag effect.

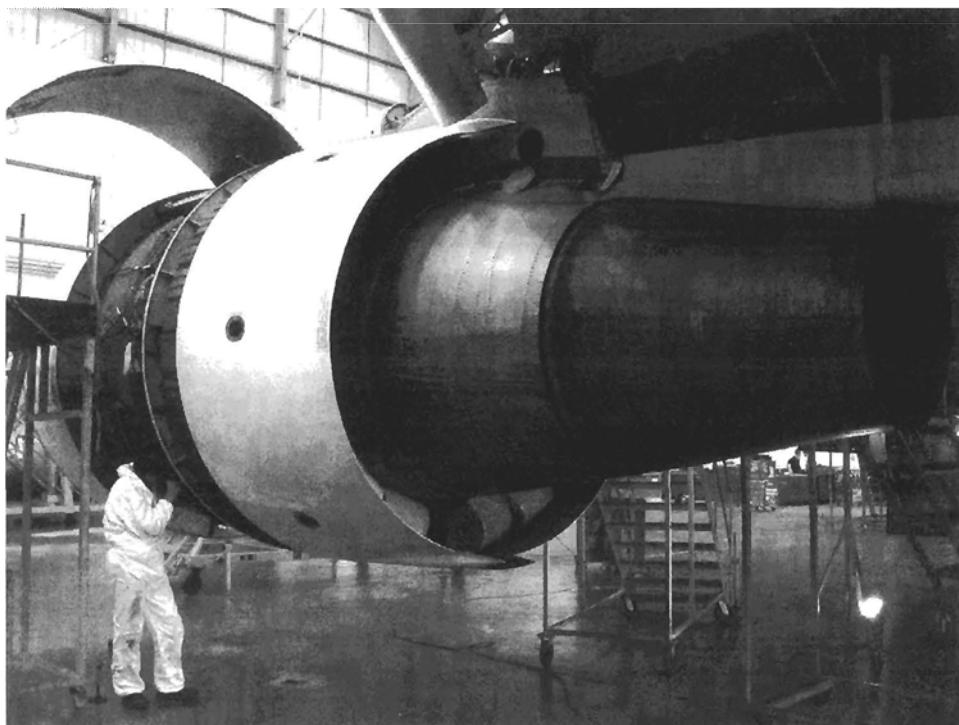


Figure 19.1: Underwing powerplant installation



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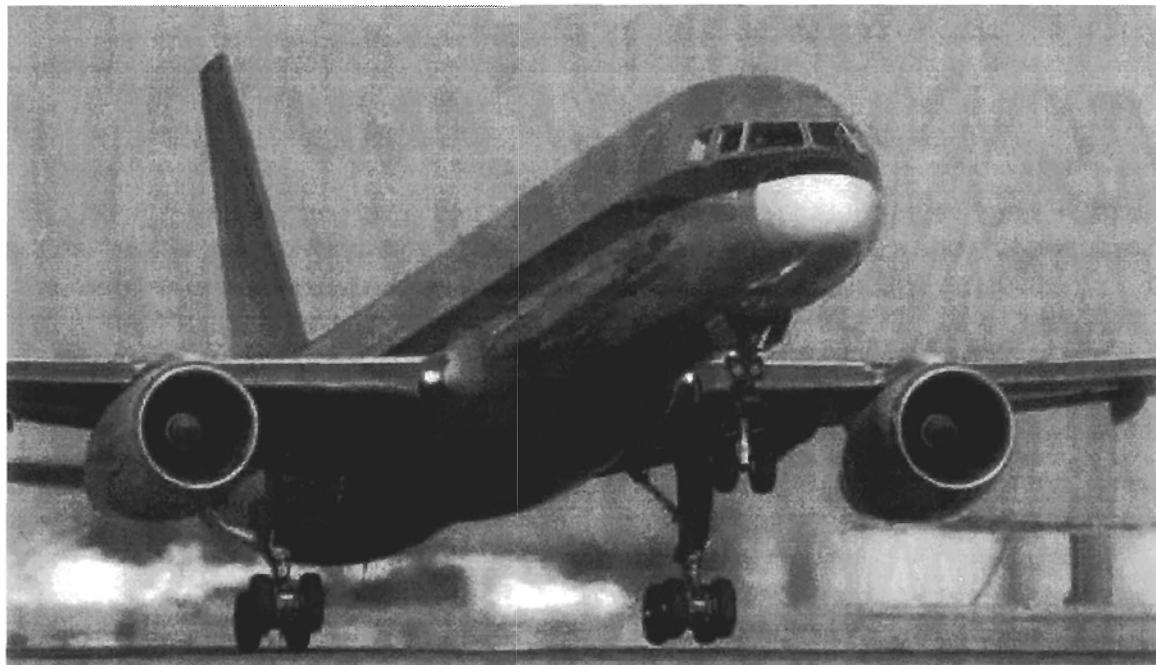


Figure 19.2: Underwing powerplant installation



Figure 19.3: Tail powerplant installation



Figure 19.4: Tail and underwing powerplant installation



Figure 19.5: Integral wing root installation



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Nacelles and Pods

Nacelles and pods are streamlined enclosures used on multi-engine aircraft primarily to house the engines. They are located below, or at the leading edge of the wing or on the tail of the aircraft.

An engine nacelle or pod consists of skin, cowling, structural members, a fire-wall, and engine mounts. Skins and cowlings cover the outside of the nacelle. Both are usually made of sheet aluminium alloy, stainless steel, or titanium. Regardless of the material used, the skin is usually attached to the framework by rivets.

The framework can consist of structural members similar to those of the fuselage. The framework would include lengthwise members, such as longerons and stringers, and widthwise/vertical members, such as bulkheads, rings, and formers.

A nacelle or pod also contains a firewall, which separates the engine compartment from the rest of the aircraft. This bulkhead is usually made of stainless steel, or titanium sheet metal.

Cowlings

Openings in structures are necessary for entrance and egress, servicing, inspection, repair and for electrical wiring, fuel and oil lines, air ducting, and many other items.

Access to an engine mounted in the wing or fuselage is by hinged doors; on pod and turbo-propeller installations the main cowlings are hinged. Access for minor servicing is by small detachable or hinged panels. All fasteners are of the quick-release type.

A turbo-propeller engine, or a turbo-jet engine mounted in a pod, is usually far more accessible than a buried engine because of the larger area of hinged cowling that can be provided. The accessibility of a wing pylon mounted turbo-fan engine is shown in figure 19.6 and that of wing mounted turbo-propeller engine is shown in figure 19.7.



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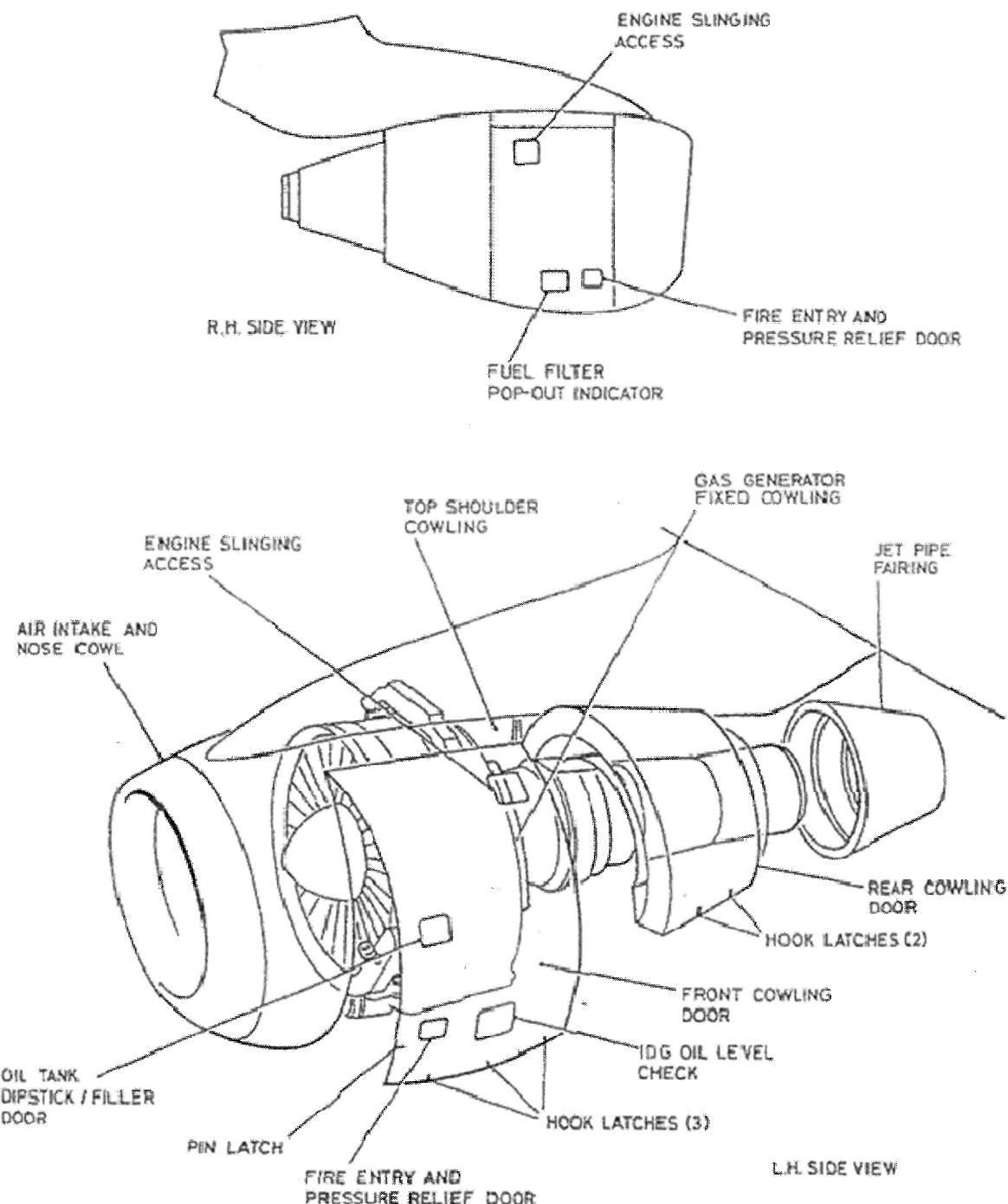


Figure 19.6: Nacelle components



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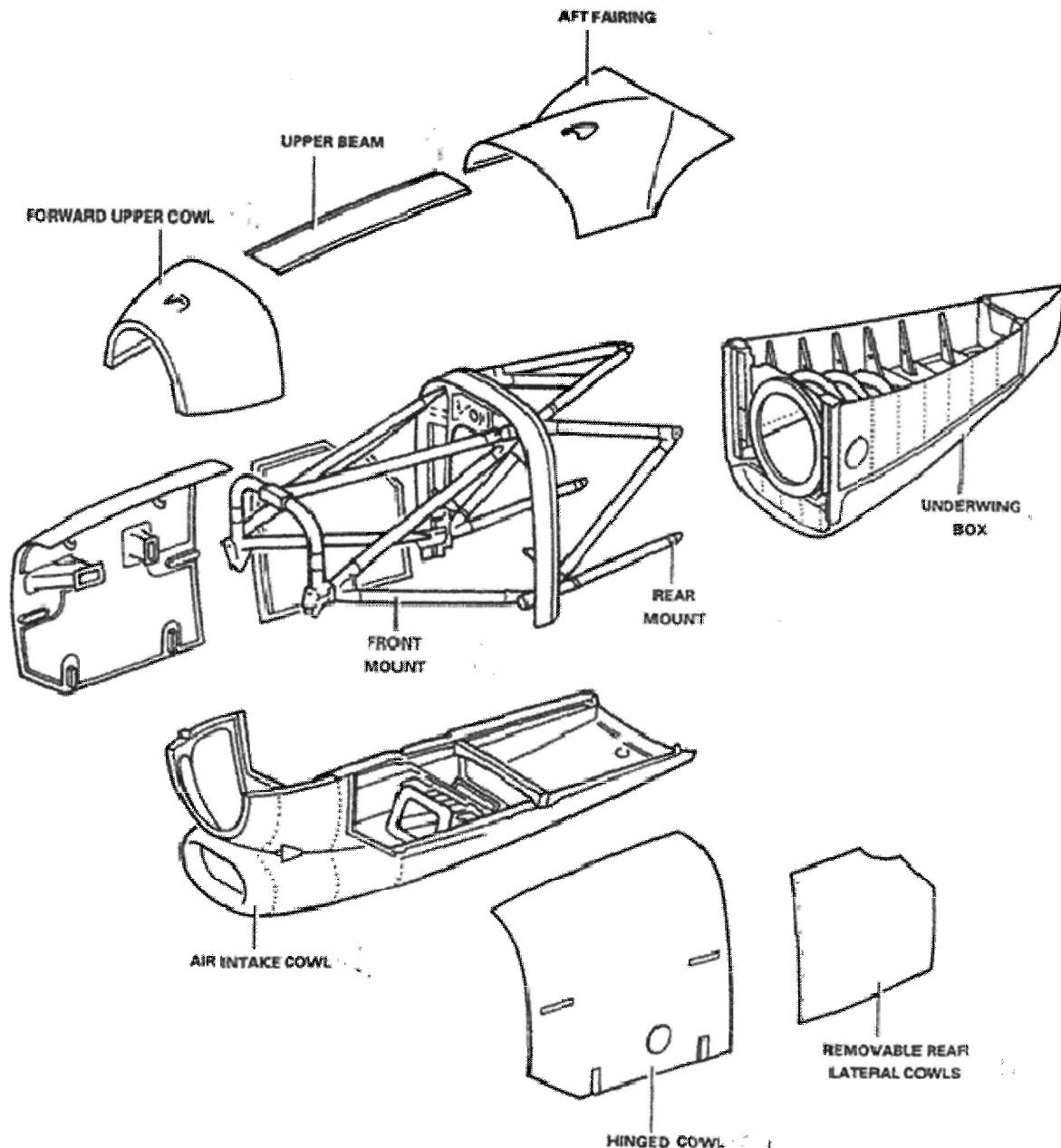


Figure 19.7: Turboprop nacelle and cowlings

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Firewalls

The firewall is a seal which separates the engine into two zones. Sometimes referred as the “wet zone” and “dry zone”, but more commonly called zone one (front) and zone two (rear). The firewall forms a barrier that prevents combustible fumes that may form in the front section (zone-1), from passing into the rear section (zone 2), and igniting on the hot exhaust section. Dependant upon aircraft/engine design the fire walls design and location will differ, Figures 19.8 and 19.9 refer.

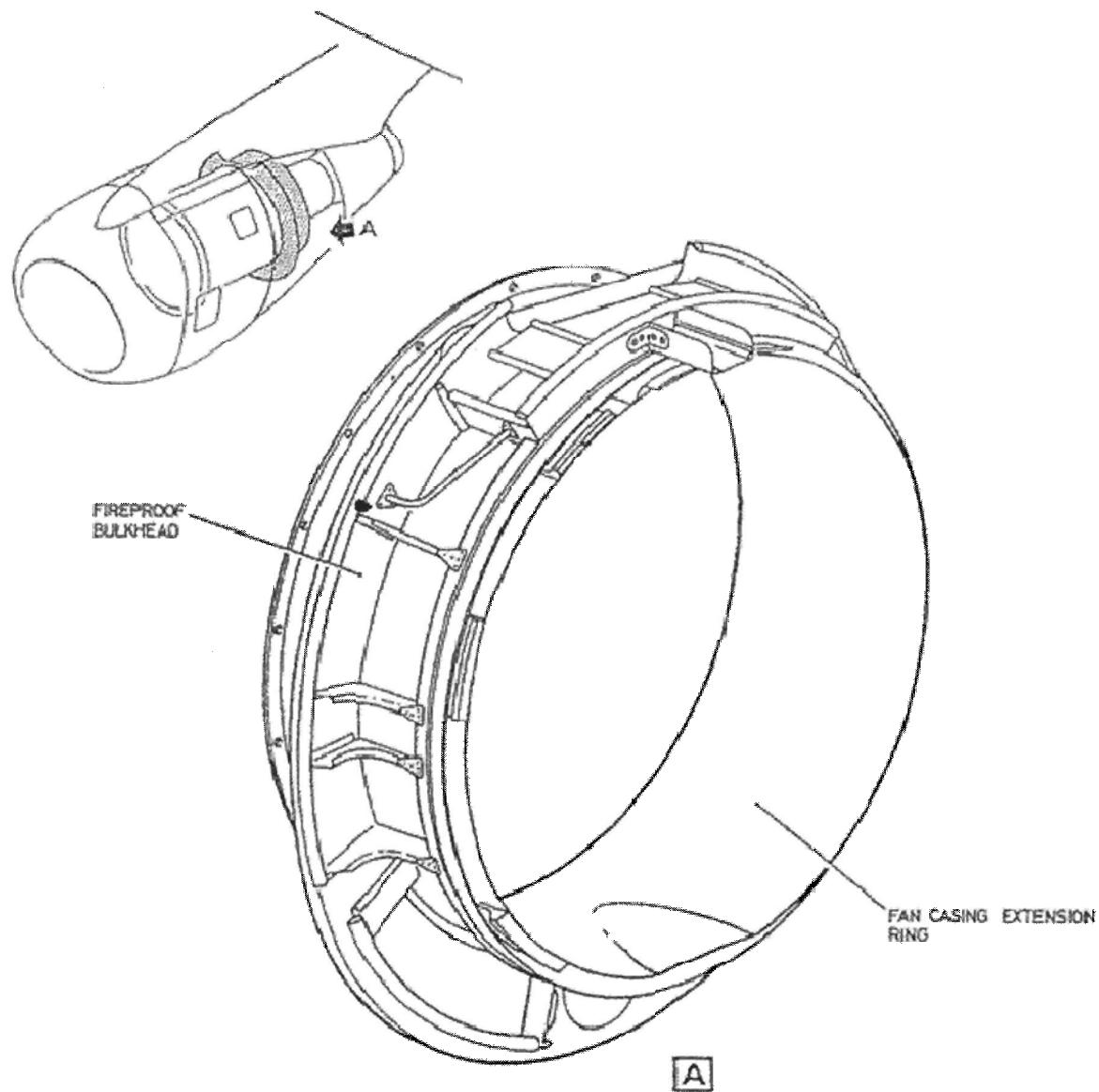


Figure 19.8: A turbofan firewall



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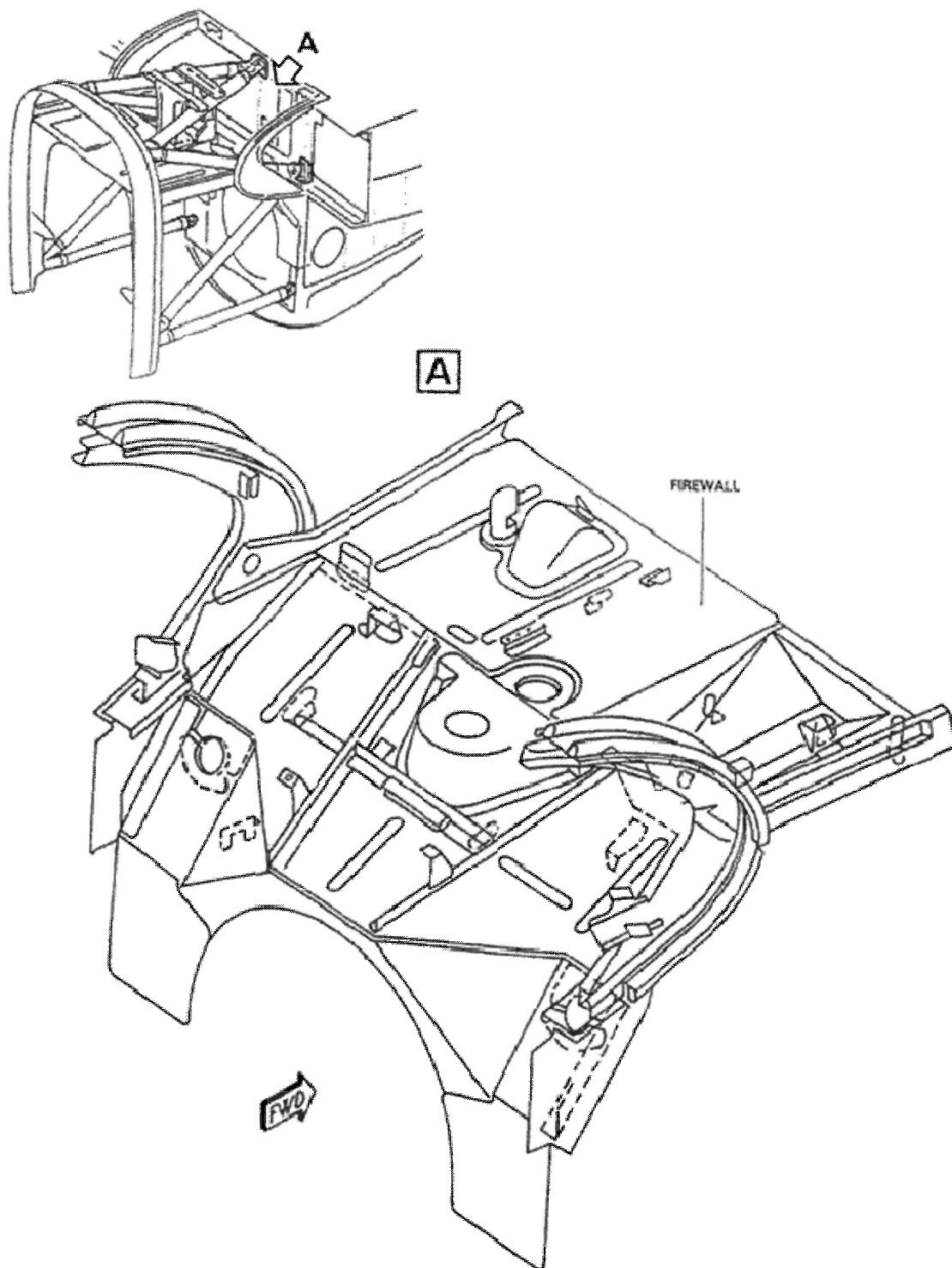


Figure 19.9: Turboprop firewall



Cooling

Turbine engines are designed to convert heat energy into mechanical energy. The combustion process is continuous and, therefore, heat is produced. On turbine engines, most of the cooling air must pass through the inside of the engine. If only enough air were admitted into a turbine engine to support combustion, internal engine temperatures would rise to more than 4,000 degrees Fahrenheit. In practice, a typical turbine engine uses approximately 25 percent of the total inlet airflow to support combustion. This airflow is often referred to as the engine's primary airflow. The remaining 75 percent is used for cooling, and is referred to as secondary airflow. When the proper amount of air flows through a turbine engine, the outer case will remain at a temperature between ambient and 1,000 degrees Fahrenheit depending on the section of the engine. For example, at the compressor inlet, the outer case temperature will remain at, or slightly above, the ambient air temperature. However, at the front of the turbine section where internal temperatures are greatest, outer case temperatures can easily reach 1,000 degrees Fahrenheit. (Figure 19.11)

Cooling Requirements

To properly cool each section of an engine, all turbine engines must be constructed with a fairly intricate internal air system. This system must take ram and/or bleed air and route it to several internal components deep within the core of the engine. In most engines, the compressor, combustion, and turbine sections all utilise cooling air to some degree.

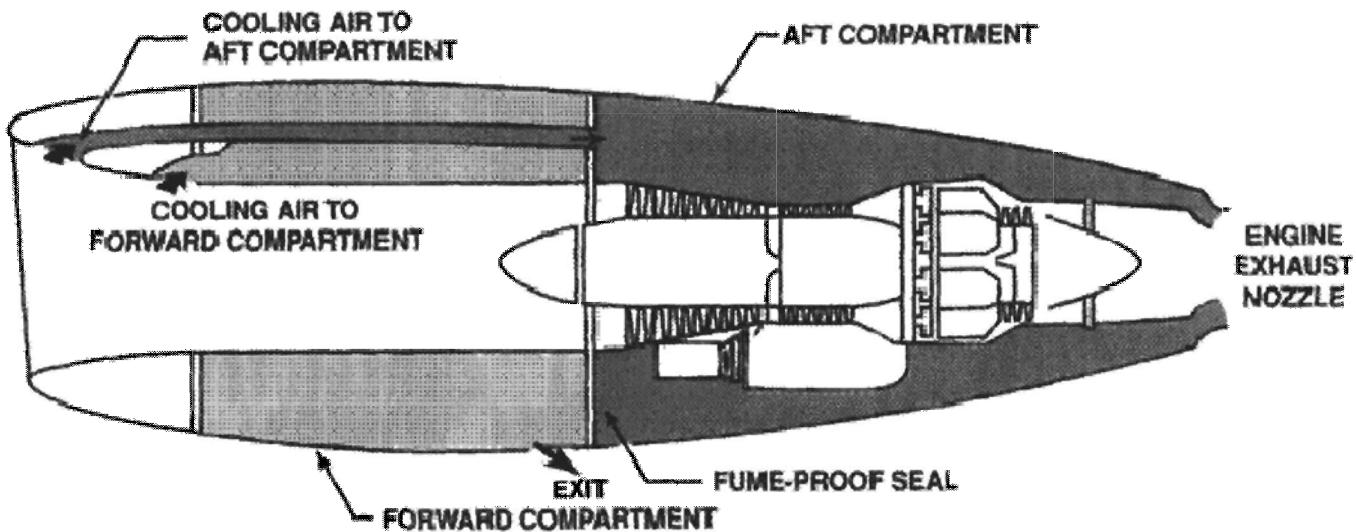


Figure 19.10: Typical nacelle cooling using ram air from the intake duct

For the most part, an engine's nacelle is cooled by ram air as it enters the engine. To do this, cooling air is typically directed between the engine case and nacelle. To properly direct the cooling air, a typical engine compartment is divided into two sections; forward and aft. The forward section is constructed around the engine inlet duct while the aft section encircles the engine. A seal or firewall separates the two sections.



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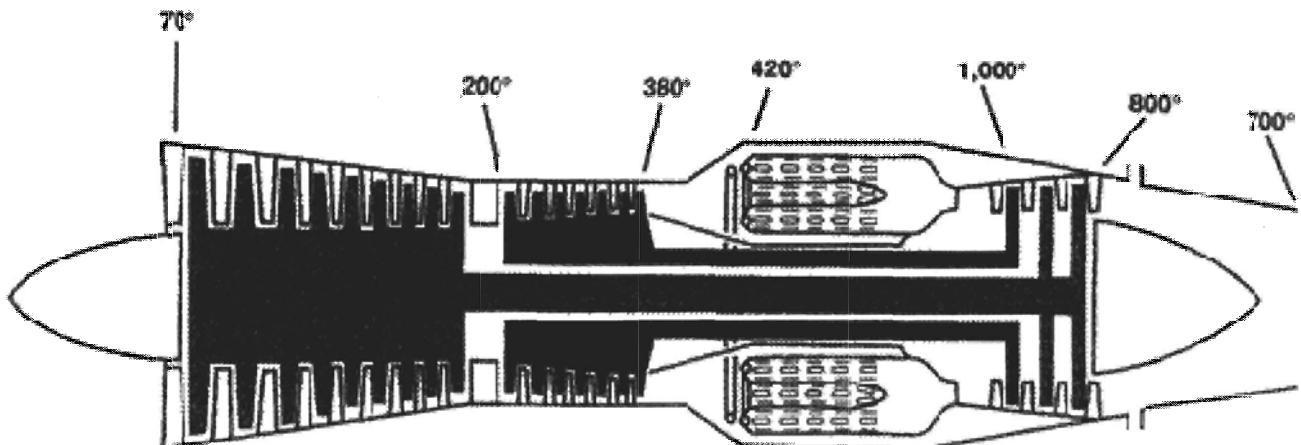


Figure 19.11: Temperatures that may be experienced around a turbojet engine (°F)

In flight, ram air provides ample cooling for the two compartments. However, on the ground, airflow is provided by the reduced pressure at the rear of the nacelle. The low pressure area is created by the exhaust gases as they exit the exhaust nozzle. The lower the pressure at the rear of the nozzle, the more air is drawn in through the forward section.



Acoustic Linings

One method of suppressing the noise from the fan stage of a high by-pass ratio engine is to incorporate a noise absorbent liner around the inside wall of the by-pass duct. The lining comprises a porous face-sheet which acts as a resistor to the motion of the sound waves and is placed in a position such that it senses the maximum particle displacement in the progression of the wave. The depth of the cavity between absorber and solid backing is the tuning device, which suppresses the appropriate part of the noise spectrum. Figure 19.12 shows two types of noise absorbent liner. Figure 19.13 shows the location of a liner to suppress fan noise from a high by-pass ratio engine and also the use of a liner to suppress the noise from the engine core. The disadvantage of using liners for reducing noise are the addition of weight and the increase in specific fuel consumption caused by increasing the friction of the duct walls.

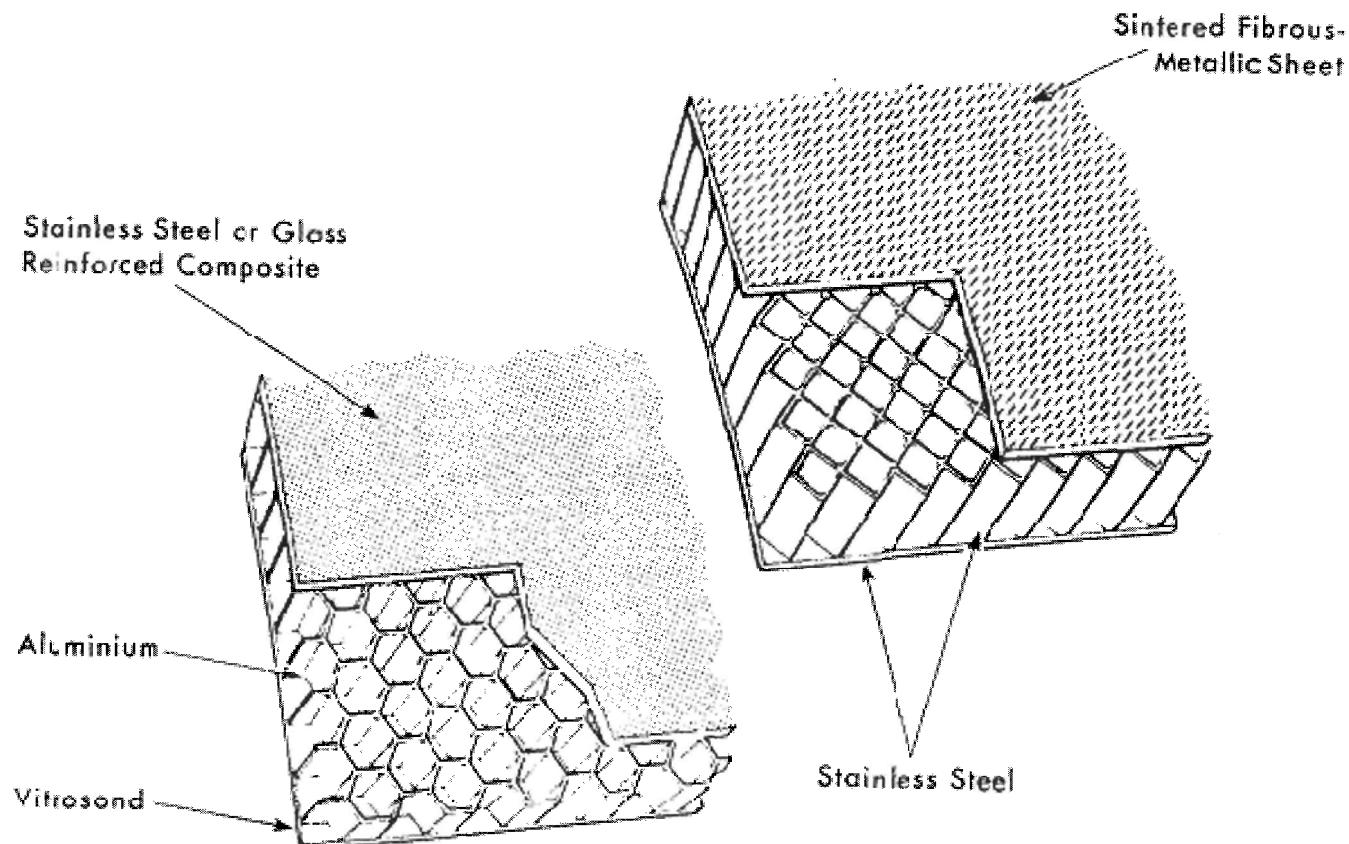


Figure 19.12: Two types of acoustic lining



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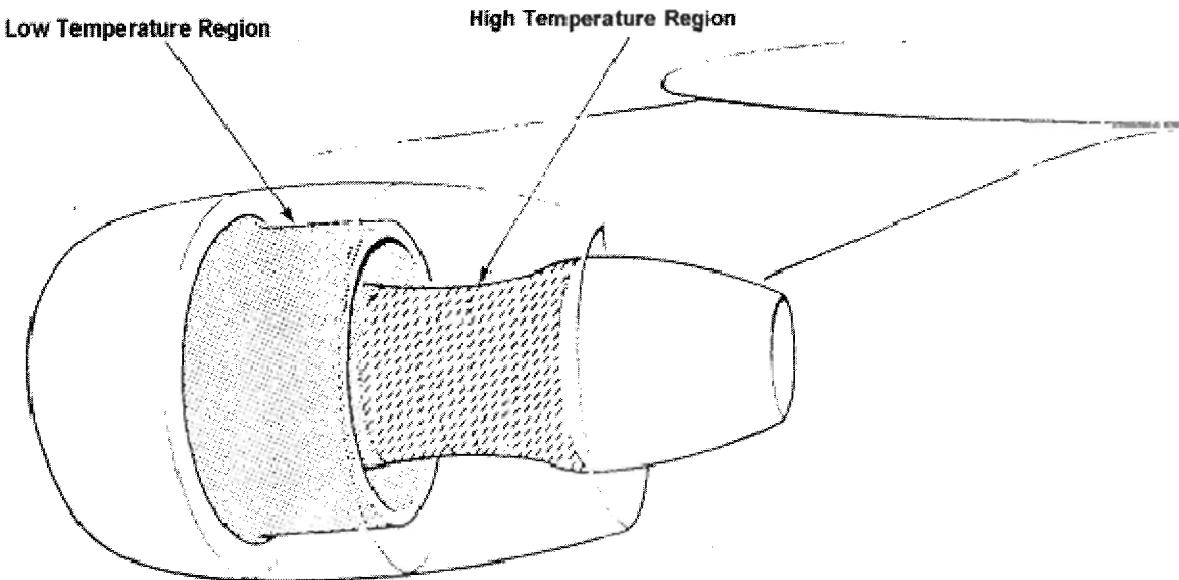


Figure 19.13: Acoustic panel locations in a high bypass engine

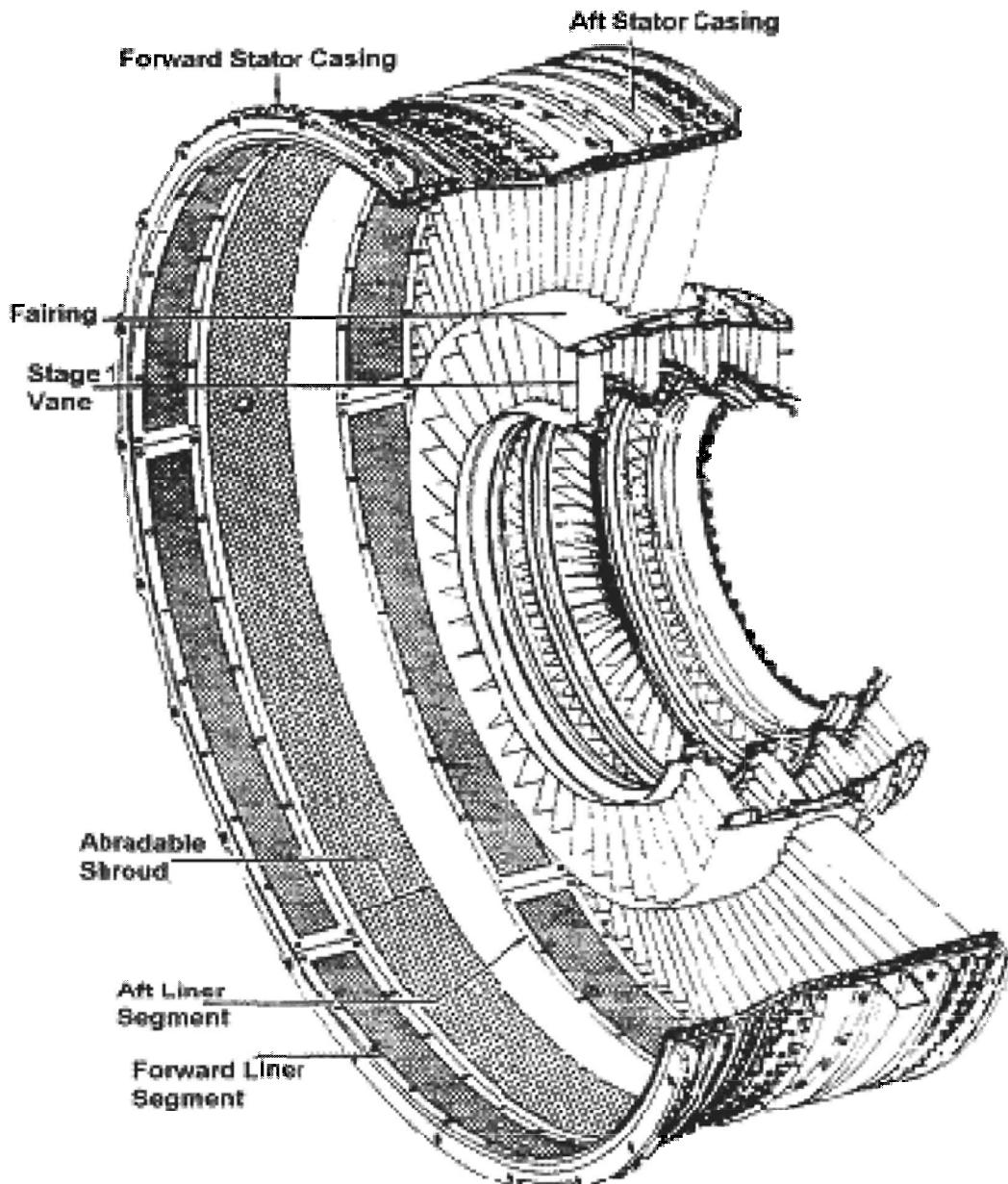


Figure 19.14: Acoustic panel location around the fan



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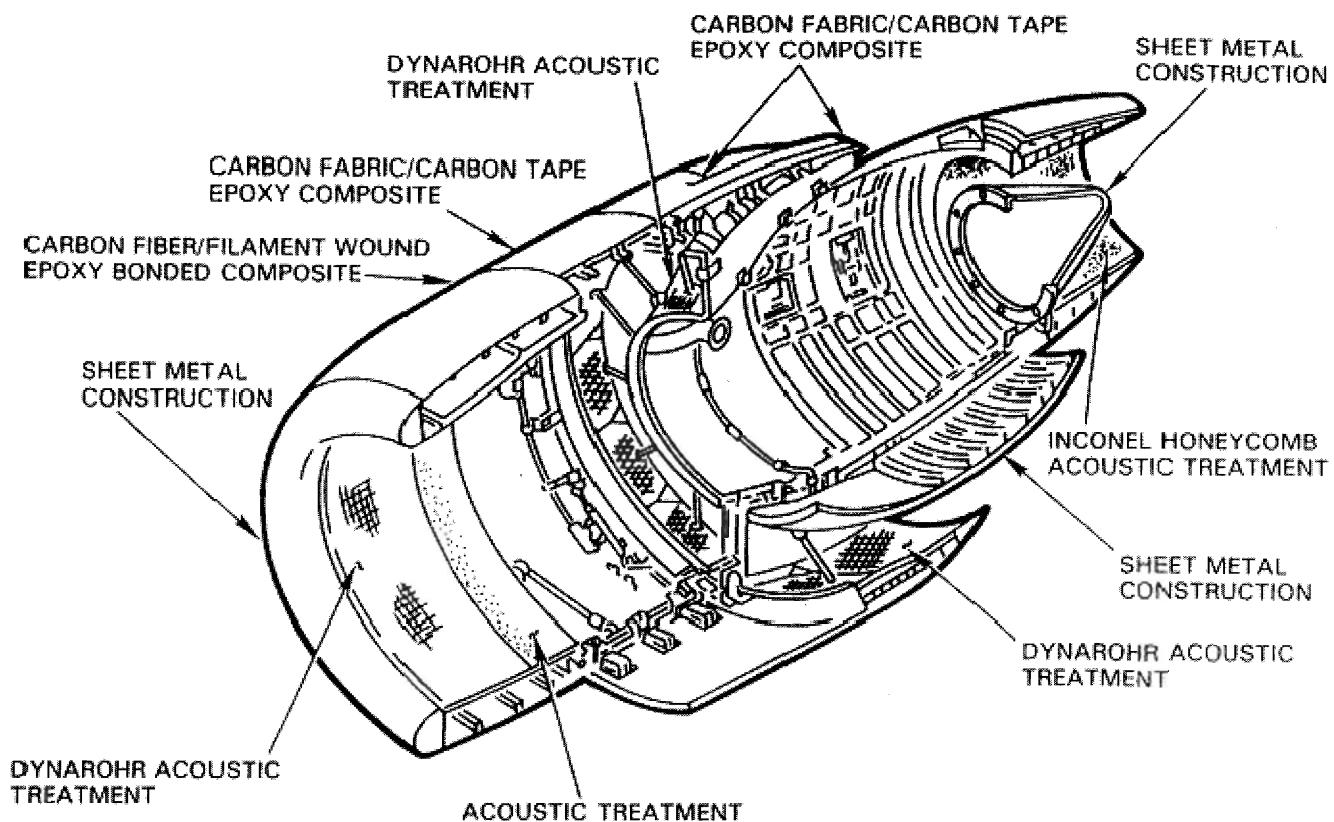


Figure 19.15: Section through an engine case

Abradable Linings

Abradable Linings are usually made of a composite material which will be abraded away should the tip of a rotating blade touch the material. In flight the casings of an engine are subject to large changes in ambient temperature, so they will expand or contract. As we know the air temperature at 30,000ft is close to -50°C this would cause the casings to contract onto the rotor and the blades will then rub. To overcome this problem abrasive materials were used on early engines to wear down the tip of the blades, but this may cause balance problems. So most engines now use abradable linings that maintain minimum tip clearance but do not affect balance. They are usually found on the fan as this is the cold area of the rotating assemblies (see figure 19.14)



Engine Mounts

Engine mounts are designed to meet particular conditions of installation, such as the location and the method of attachment of the engine mount and the size, type, and characteristics of the engine it is intended to support. An engine mount is usually constructed quickly and easily from the remaining structure. Engine mounts are commonly made of welded chrome/molybdenum steel tubing, and forgings of chrome/nickel/molybdenum are used for the highly stressed fittings.

Wing Pylon Mounted Engine (Turbofan)

Figure 19.16 shows a typical method of mounting an engine onto a wing pylon.

The engine is usually suspended on three attachment points. The two front points are located at the lower end of a pylon mounted yoke and engage with the mounting bracket assemblies on the left-hand and right-hand side of the fan casing. The assemblies differ inboard and outboard. The inboard bracket assembly takes side, vertical and thrust loads. The outboard bracket assembly takes vertical and thrust loads.

The rear attachment point is an engine mounted lower link assembly bolted to a pylon mounted upper link assembly. This attachment point carries vertical loads only and allows for engine axial expansion.



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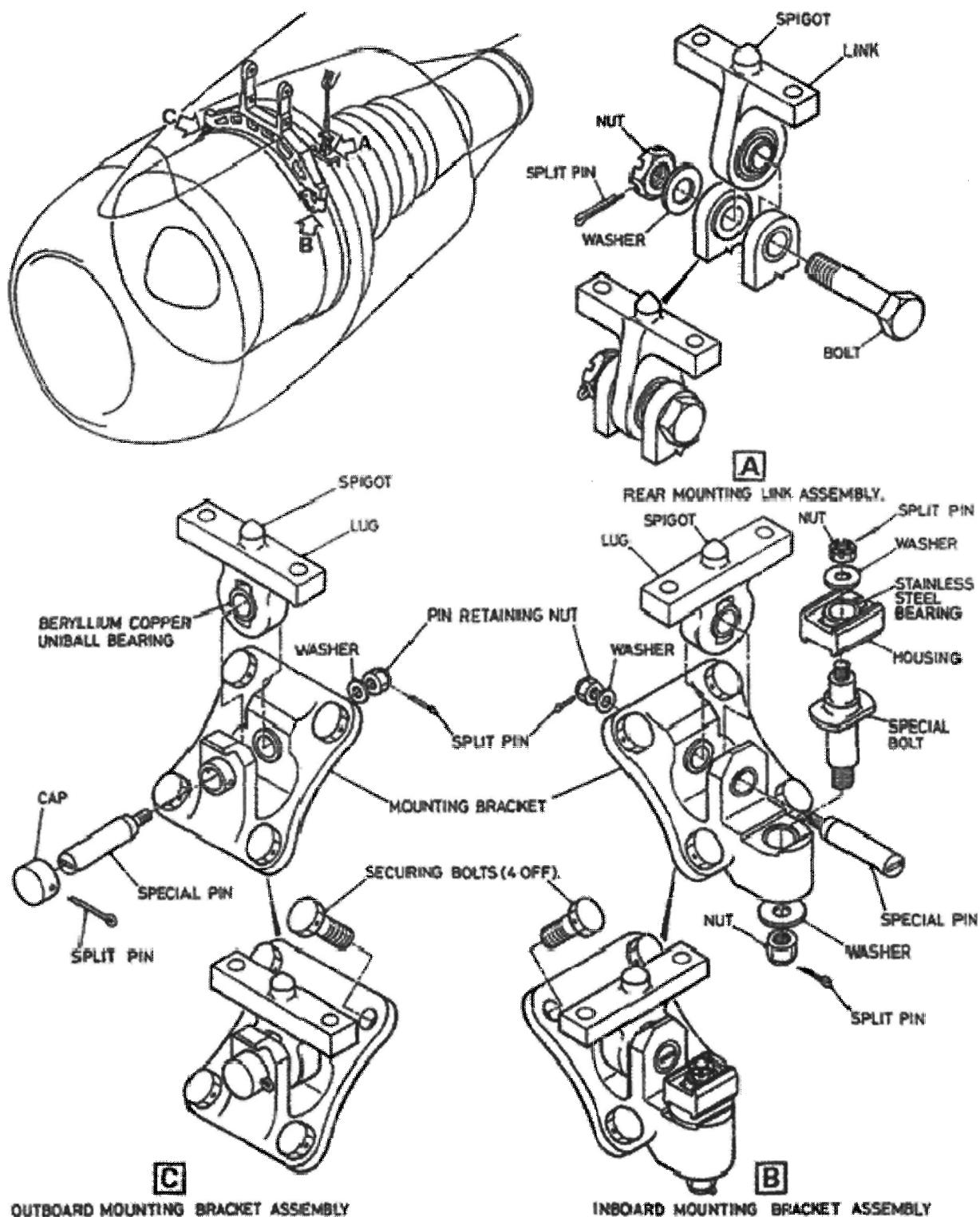


Figure 19.16: Wing-pylon mounted engine mounts



Wing Mounted Engine (Turboprop)

The engine is connected to the structure by means of a flexible attachment system consisting of:

- 2 forward lateral shock-mounts.
- 1 forward upper shock-mount.
- 2 aft lateral shock-mounts on the Left Hand and Right Hand sides.
- A torque compensation system with a torque tube.



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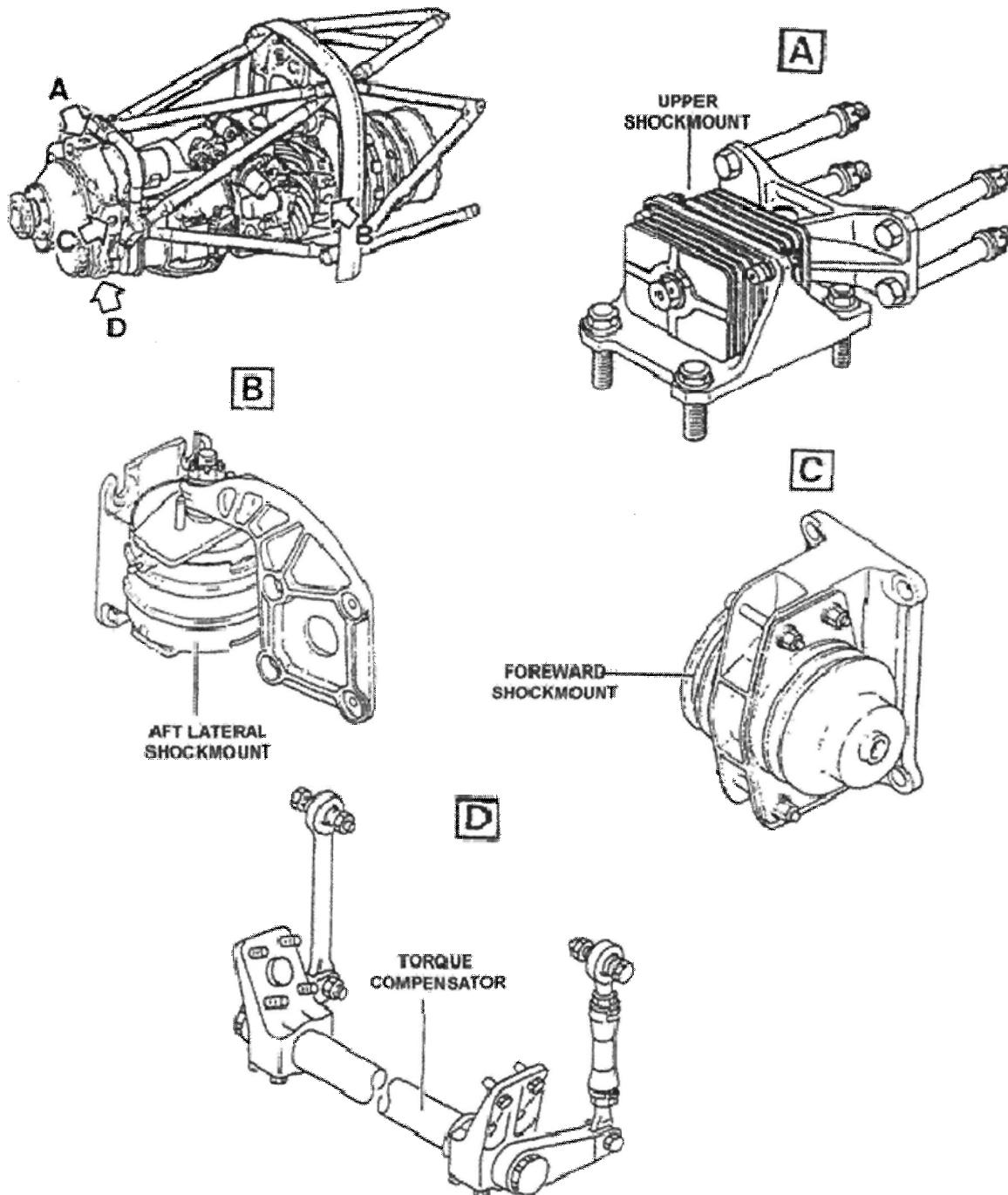


Figure 19.17: Wing-mounted turboprop engine mounts



Rear Fuselage Engine Turbofan

Two crane beams in the nacelle carry the weight of the engine. The crane beams are connected to the frames of the fuselage. Vibration isolators are on the engine mounting Points to absorb vibration. There are three mounting points:

- the rear mount.
- the front mount
- the trunion

The trunion transmits the engine thrust to the airframe. The Trunion fits in the trunion housing on the forward crane beam attachment.

Between the trunion housing and the aft beam attachment is a thrust strut. This strut divides the engine thrust between the forward and aft beams attachment. The shear shell between the crane beams makes the engine mounting more rigid.

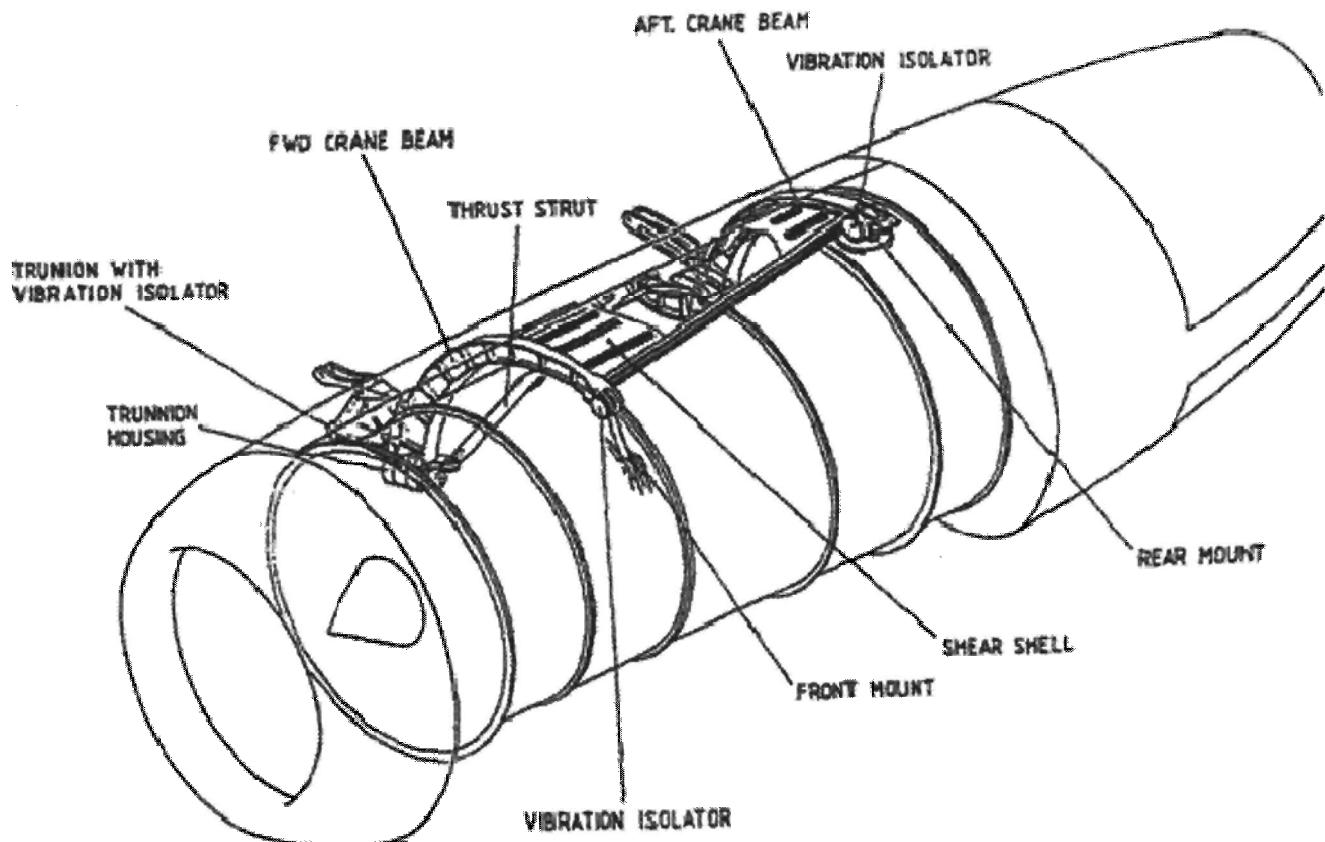


Figure 19.18: Rear fuselage mounted turbofan engine mounts



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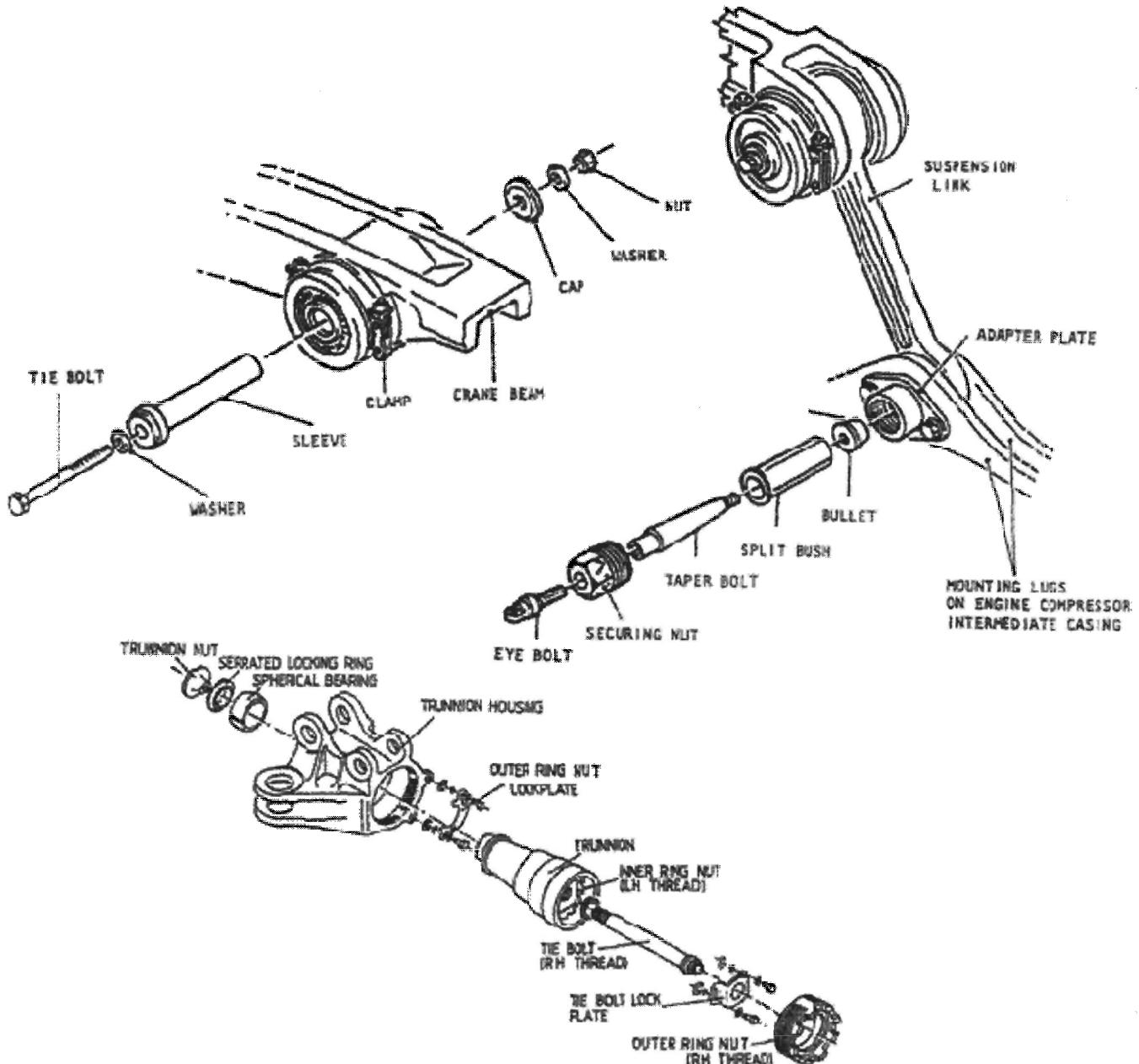


Figure 19.19: Fuselage-mounted engine mounts in detail



Engine Drains

There are two types of drains:

- Controlled drains – the result of normal operation.
- Uncontrolled drains – the result of abnormal operation.

Controlled Drains

When an engine stops, fuel from the fuel manifold and combustion chamber drains either overboard, or as is more usual into an 'ecology drain tank'. This tank is automatically emptied, (the fuel being fed back into the engine) next time the engine is run. (figure 19.20)

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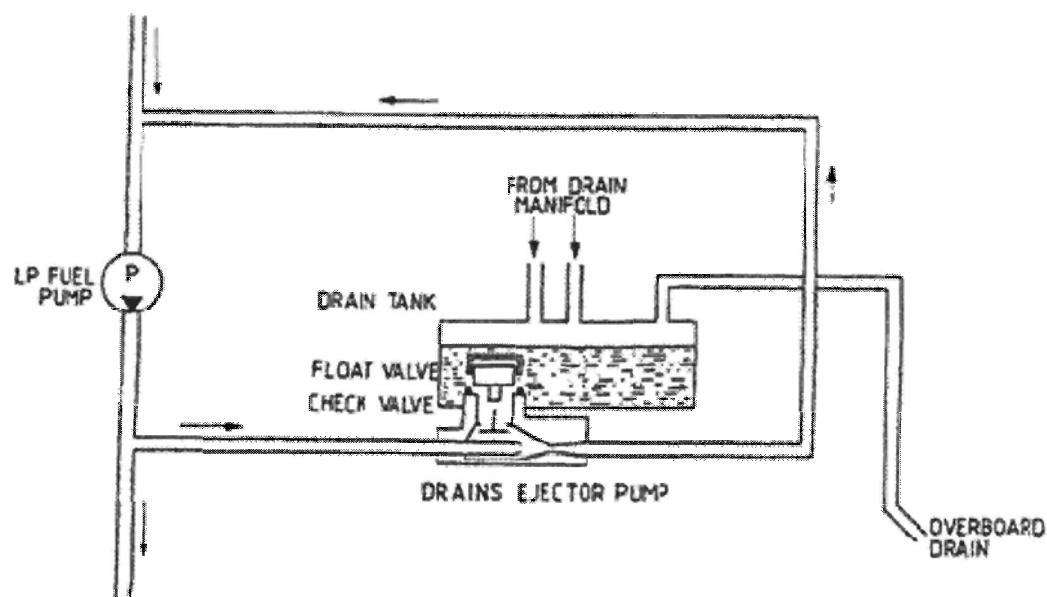
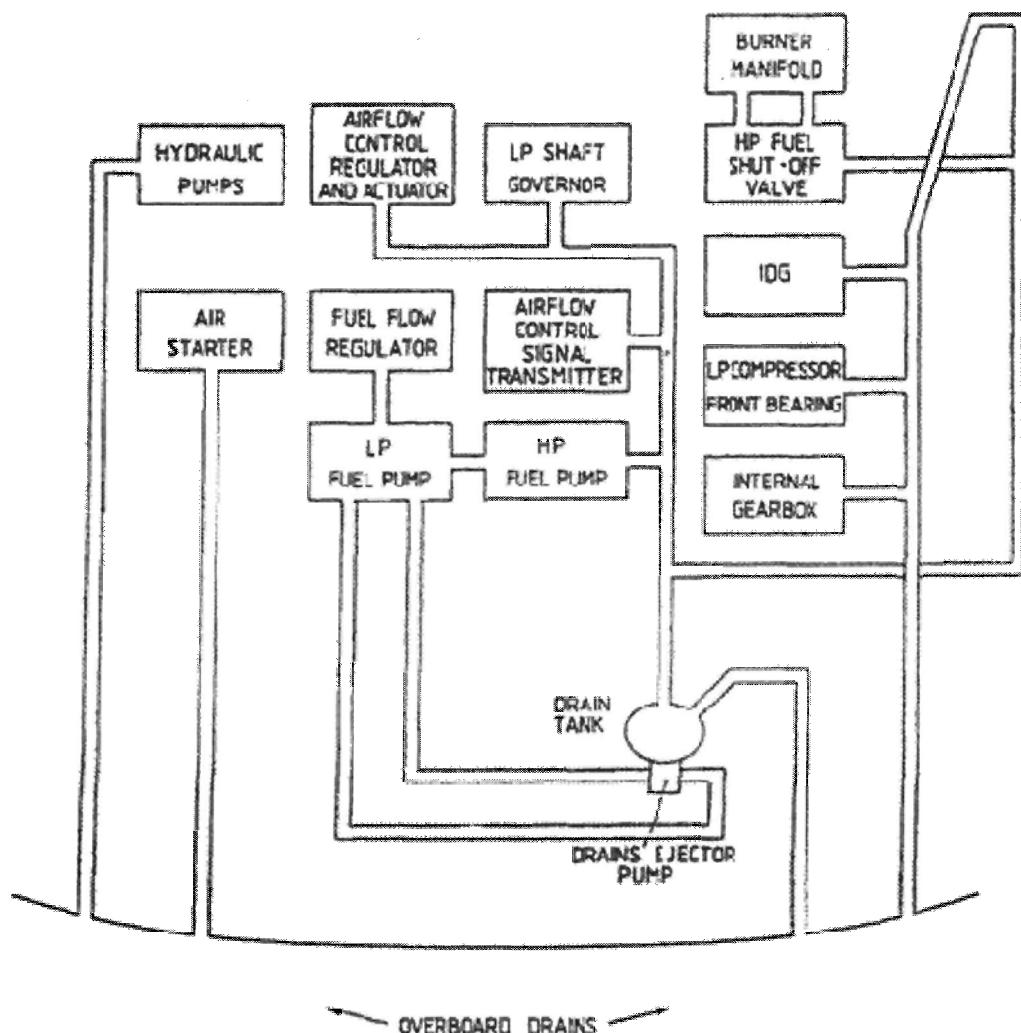


Figure 19.20: Controlled drains system



Uncontrolled Drains

Engine driven accessory drive shafts require lubrication. This will be provided by the engine lubrication system. To ensure proper lubrication, the drive shaft bearings are sealed to prevent loss of oil. These bearing seals are monitored for leaks, by the engine drain system which consists of a number of shrouds, enclosing the drive shaft bearing, and pipes leading either an overboard series of drain pipes (figure 19.21) or a collector tank (figure 19.22). These drains are often referred to as 'witness drains or dry drains' as if they exhibit signs of leakage they bear witness to a potential drive shaft failure.

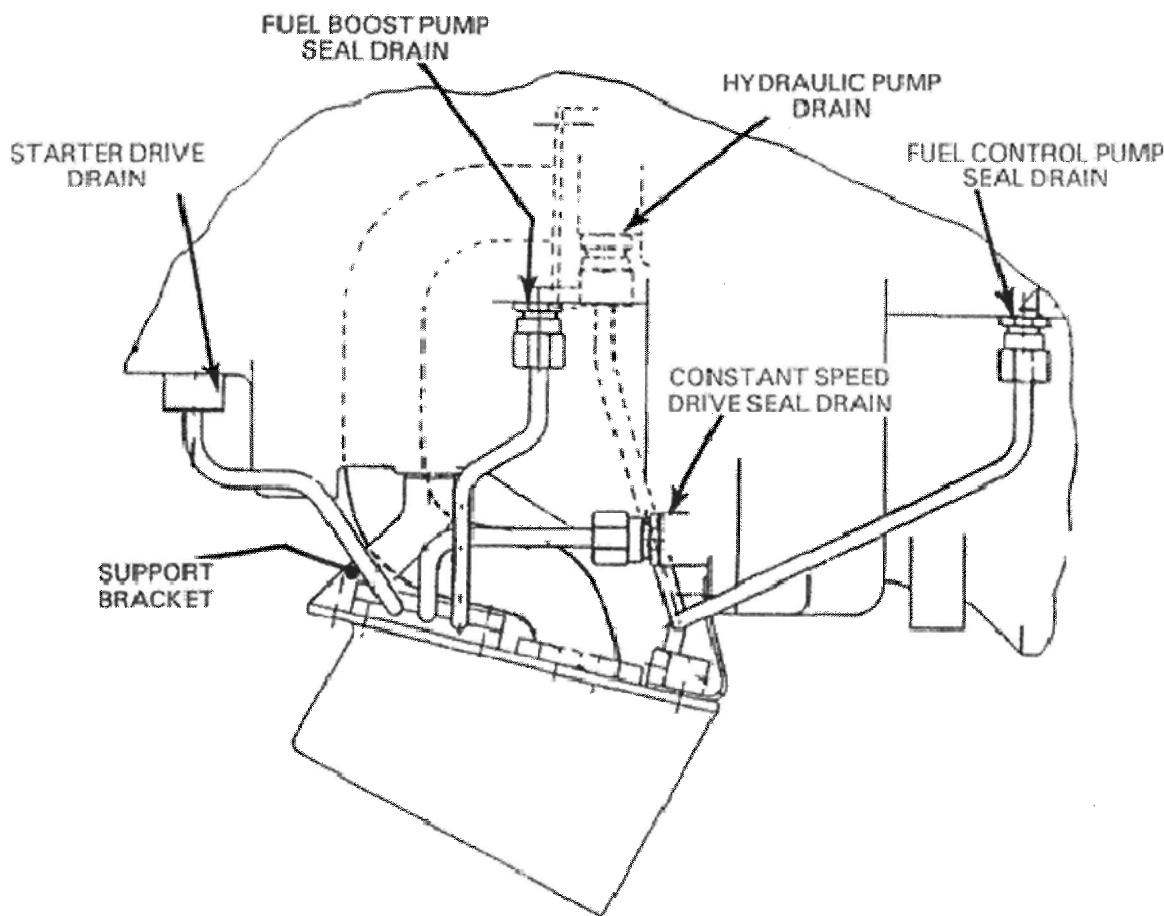


Figure 19.21: Uncontrolled drains with a drains mast



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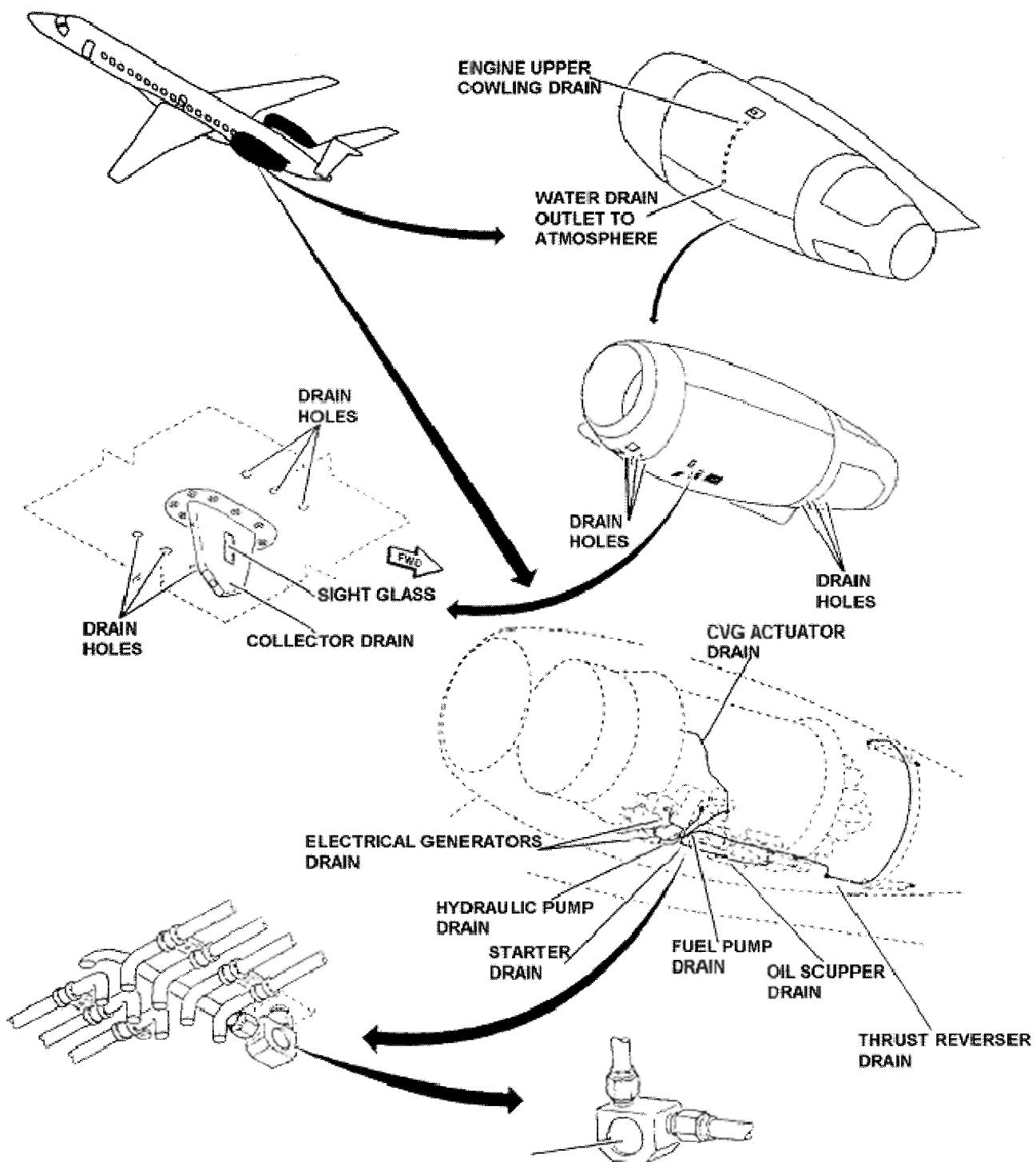


Figure 19.22: Typical drains system



Engine Controls

Mechanical Throttle Control

Engine controls are very similar to flying controls, and the same types of equipment are used, such as rods, bellcranks and cables. Most control systems use either one or two systems to control the engine.

In a two path system the high pressure cock is controlled separately from the throttle, in a single path system they are combined.

Turbofan Engine Controls

Figure 19.23 shows a typical mechanical control system for a turbofan powered aircraft. It uses a single path system to transmit power requirements to the engine. The thrust lever is connected to a rod that transmits the movement down below floor level to a quadrant. The quadrant outputs to two cables which initially run under the floor of the flightdeck and then along the roof of the passenger cabin. They then pass through pressure seals and along the leading edge of the wing before dropping down to a cable compensator in the top of the pylon. The output from the compensator quadrant is a Teleflex push/pull cable. This Teleflex cable passes down into the engine nacelle to a torque shaft mounted on the nose cowl assembly. The output from the torque shaft moves a rod which provides the input to the fuel control unit. The Teleflex cable has a disconnect break mechanism in it to facilitate engine changes.

To allow autothrottle functions the quadrants below the thrust levers can be moved by an actuator which drives all four levers via clutches.



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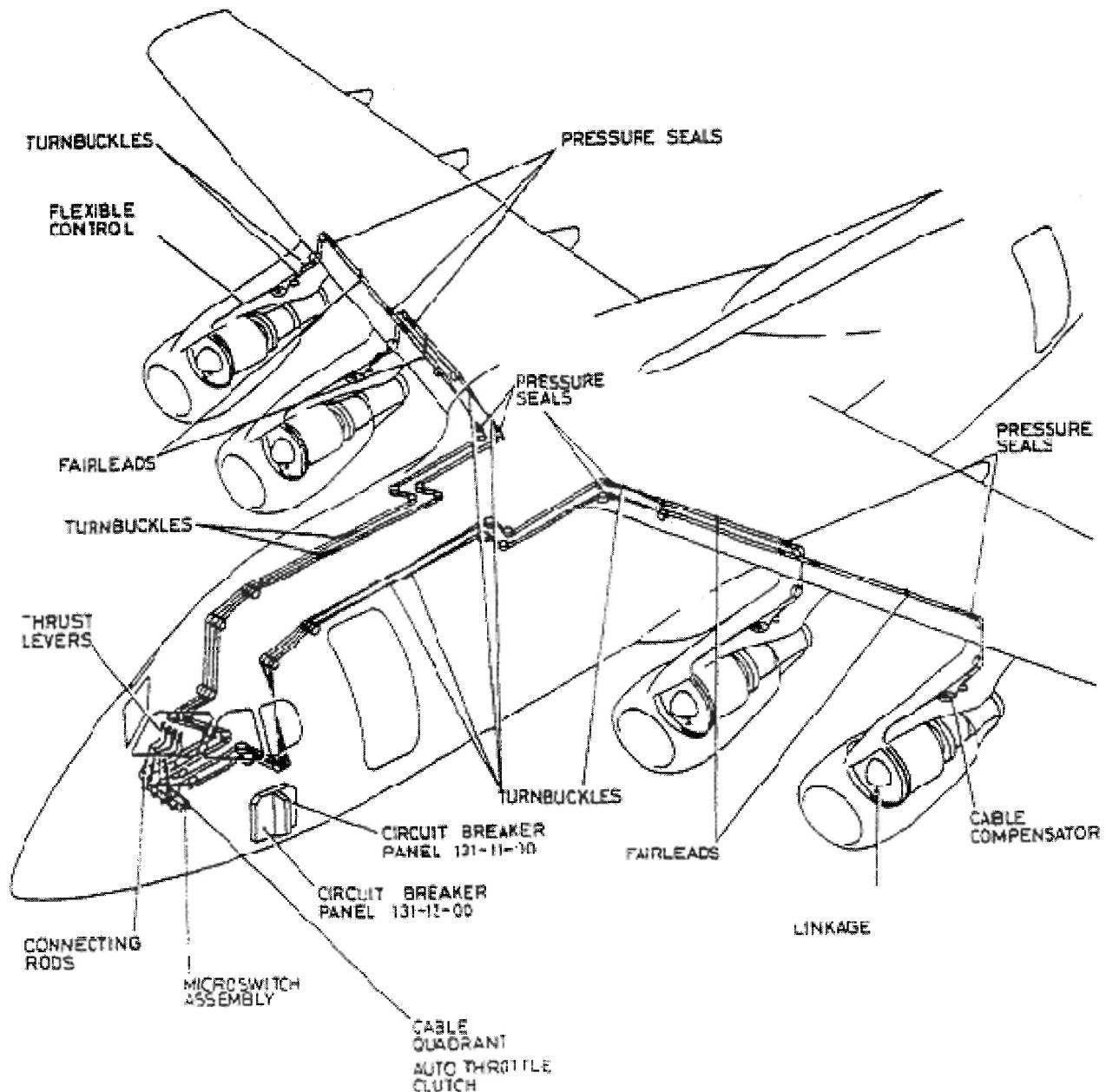


Figure 19.23: A typical mechanical engine control system



Turboprop Engine Controls

Figure 19.24 shows a typical mechanical control system for a turboprop engine. It uses a double path system to transmit power requirements to the power unit, i.e. the power lever controls engine power in the normal operating modes and both power and propeller blade angle in the beta mode. A condition lever controls propeller blade angles in the normal mode, and also controls the feathering of the propeller and the HP shutoff cock.

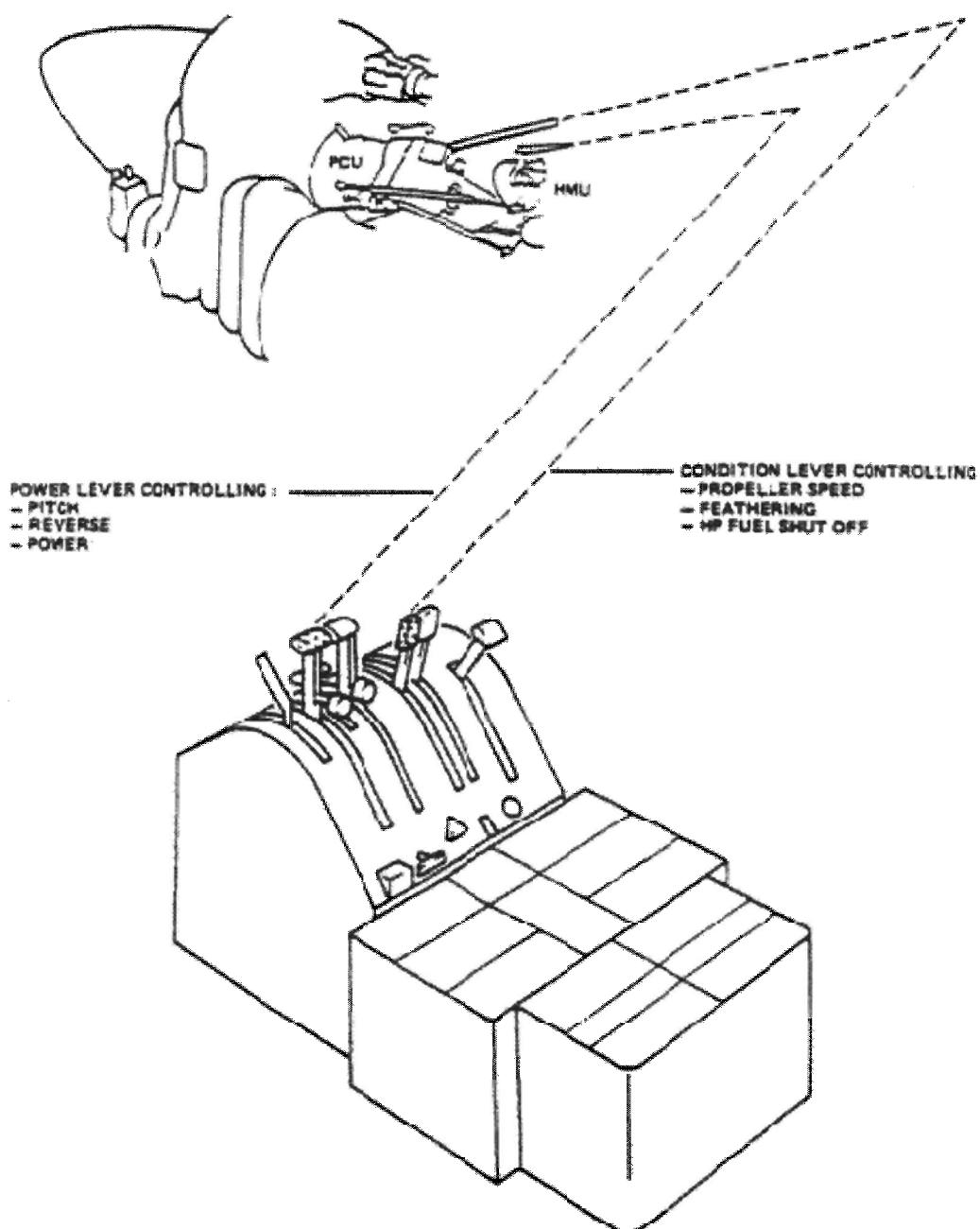


Figure 19.24: Power and Condition Levers



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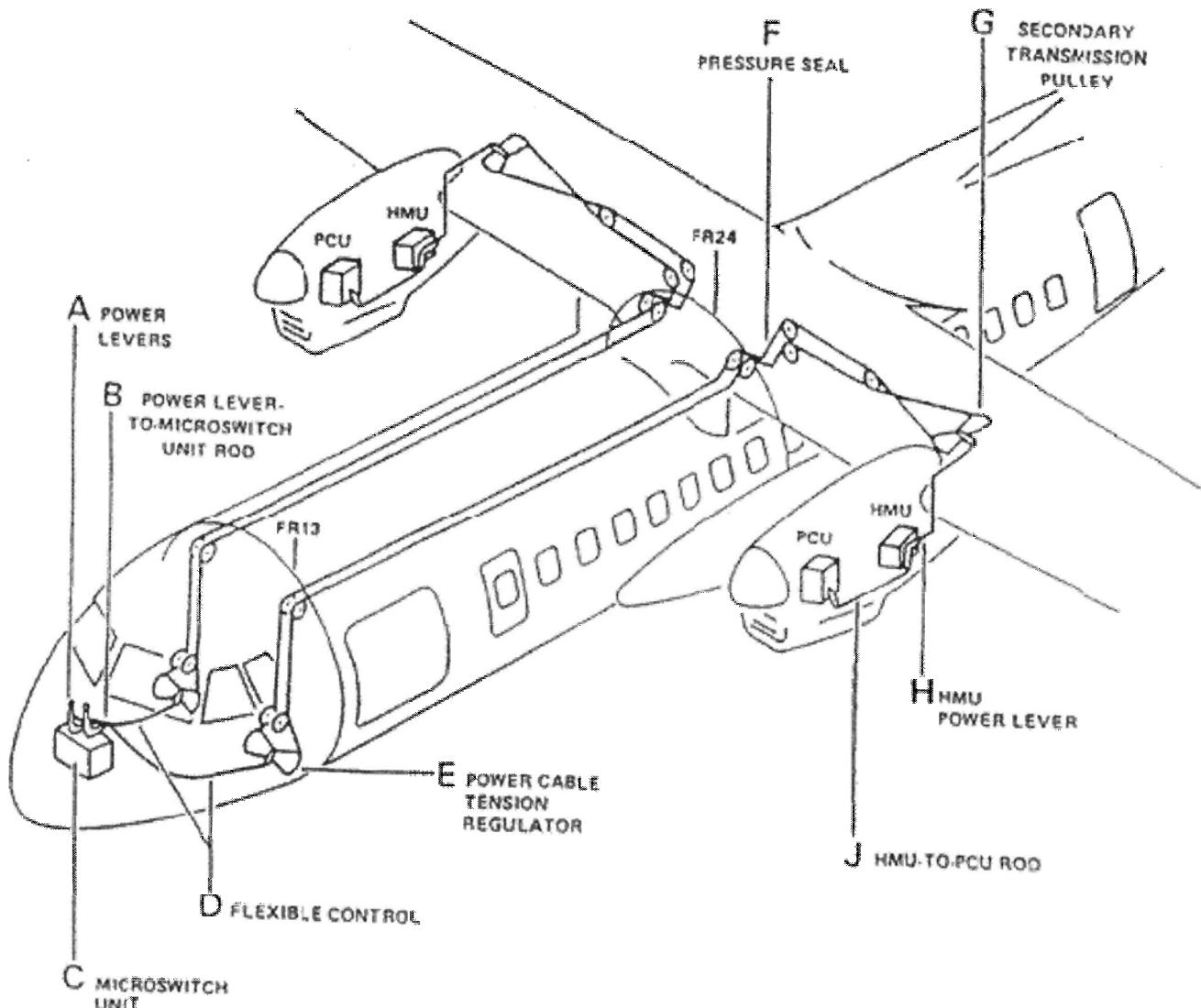


Figure 19.25: Turboprop power control system – cable routing

Power Controls

The power lever controls, via the Hydromechanical Control Unit (HMU), the full flow from “MAX” (maximum power) to “REV” (reverse) (Figure 19.25). Power lever movement is transmitted to the HMU via a series of push/pull rods and cables. A control rod between the HMU and the Propeller Control Unit (PCU) enables control of propeller blade angle in beta mode.

Propeller/HP Shutoff Cock Control

The “Condition Lever” controls via the PCU propeller speed from, “Min N_p ” (minimum propeller speed) to “Max N_p ” (maximum propeller speed). Condition lever movement is transmitted via a series of push/pull rods and cables, similar to the power lever controls. A second control rod (figure 19.25) between the PCU and HMU enables control of the HP fuel shutoff cock within the HMU by the condition lever. The condition lever also controls feathering of the propeller (figure 19.24)



Engine Build Unit

When an engine is delivered from manufacturer or overhaul it will not have all the equipment needed for its installation into the aircraft. This is because engines can be fitted into different types of aircraft and the accessories will be type specific.

Hydraulic pumps, electrical generators, starters, drains and mounts will have to be fitted during or prior to installation in the aircraft. Although the engines fitted to each wing are the same, the accessories and their fittings may well be handed for the different installations i.e. the BAe 146 has a generator on the outboard engines and a hydraulic pump on the inboard. These components are referred to as dress items, an engine that is dressed is ready for fitment. For some engines fitting the accessories prior to fit on the aircraft is impractical and the accessories are fitted once the engine is installed.

Examples of engine build units are shown in Figures 19.26 to 19.29 together with a list of items and components that must be fitted before the engine is considered ready for release to service prior to installation into the aircraft.

Turbofan Engine

The manufacturer delivers the engine to fit the no-2 (right) position.

Conversion from the no.2 (right) to the no.1 (left) position requires re-position of:

- The front engine mount adaptor.
- The trunion mount.
- The HP compressor 7th and 12th stage bleed air ducts.
- The electrical harness on the engine.
- The external igniter leads on top of the engine.
- The engine vibration transducer wiring.



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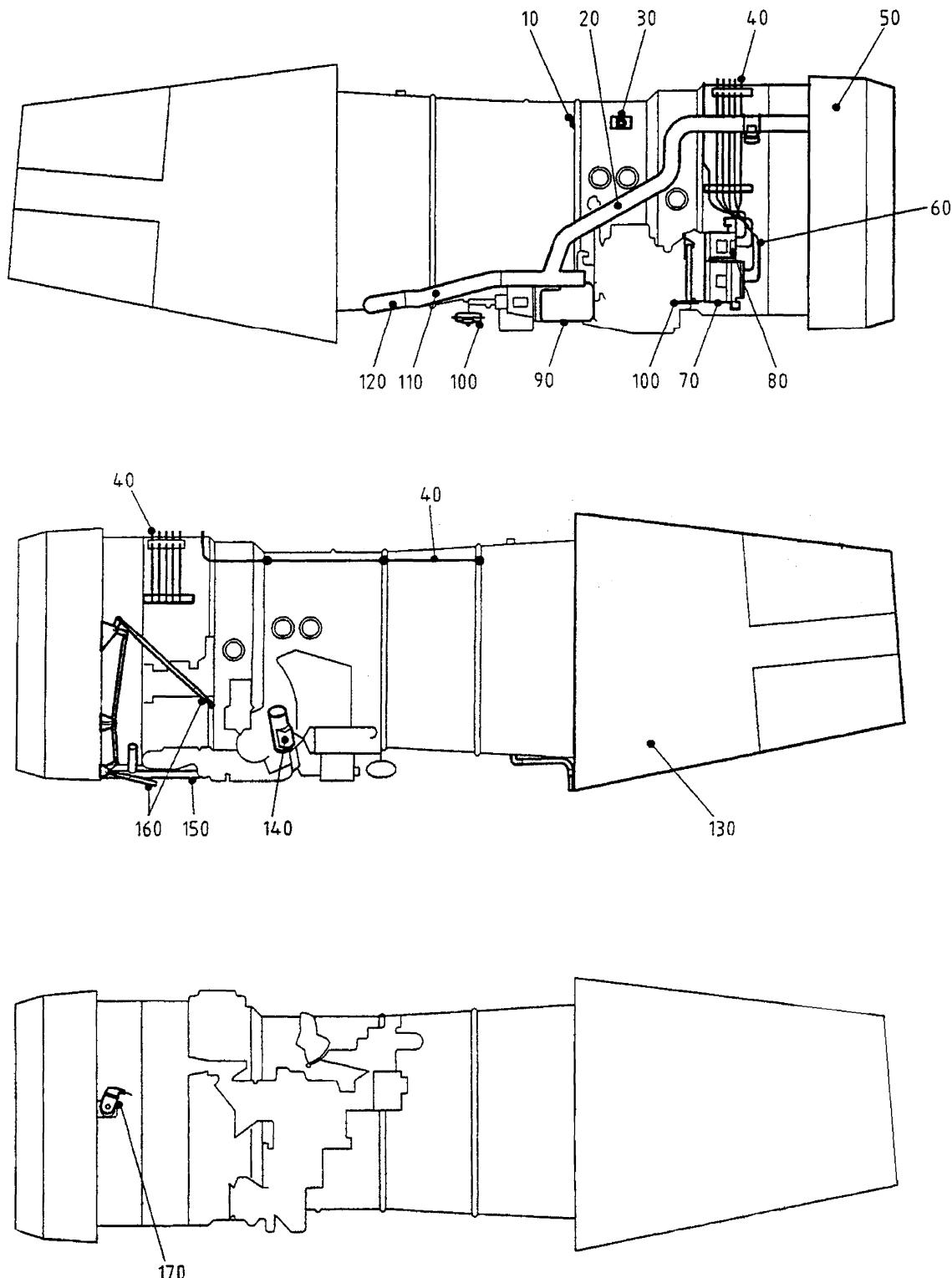


Figure 19.26: Power Plant Build Installation (Tay)



Number	Item
10	Front Mount Adapter
20	Anti-Icing System
30	Vibration Transducer
40	Hydraulic Lines
50	Inlet Cowling
60	Hydraulic Hoses
70	Hydraulic Pump No. 1
80	Hydraulic Pump No. 2
90	Integrated Drive Generator
100	Vent and Drain System
110	Starter System,
120	Air-Starter Duct,
120A	Air-Starter Duct
130	After Cowling
140	Fuel Flow Transmitter
150	Fuel Line
160	Engine Control Rods
170	Power Lever Angle Transmitter



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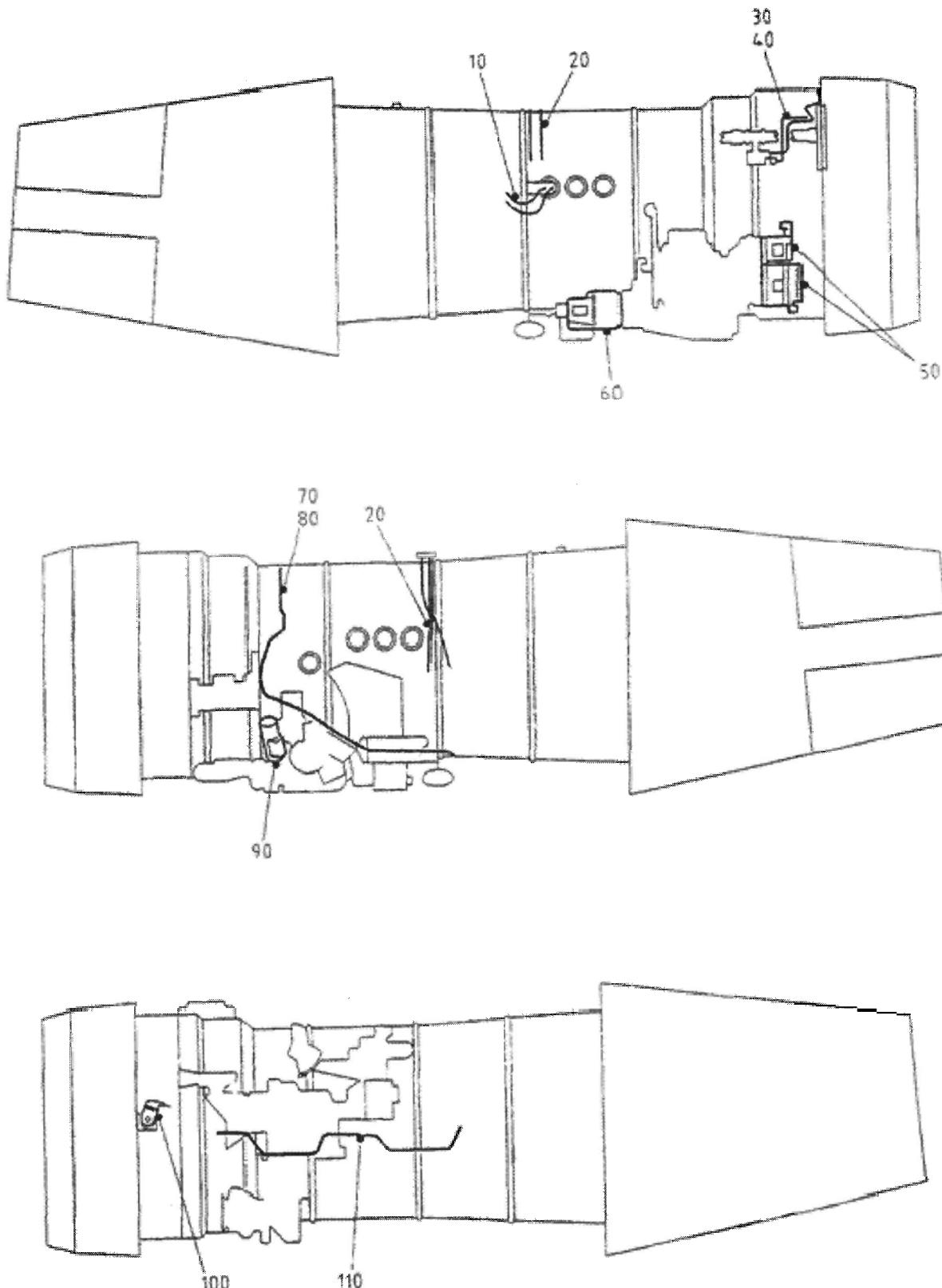


Figure 19.27: Electrical Harness Installation (Tay)



Number	Item
10	Igniter Leads
20	Igniter Leads
30	Anti-Ice Electrical Harness
40	Anti-Ice Electrical Harness
50	Electrical Harness on the Hydraulic Pumps No. 1 and 2
60	Electrical Harness on IDG and IDG Oil Temperature Switch
70	Vibration Transducer Electrical Harness, LH-Engine
80	Vibration Transducer Electrical Harness, RH-Engine
90	Electrical Harness on Fuel Flow Transmitter
100	Electrical Harness on PLA-Transducer
110	Fire Detection Element



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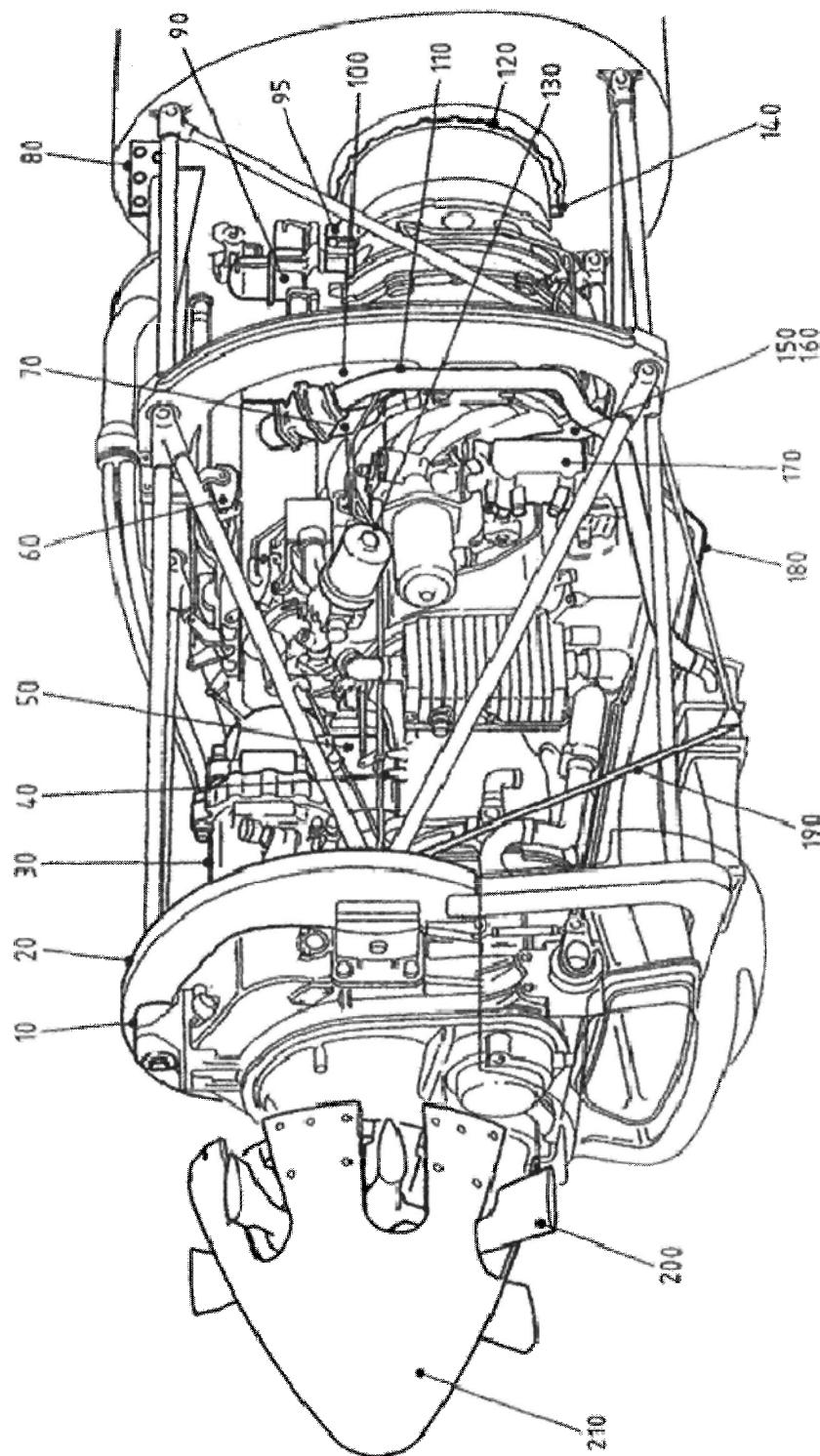


Figure 19.28: Turboprop Build Left Hand Side (PW125)



Number	Item
10.	Engine Mounts - Forward Isolators
20.	Engine Mounts - Forward Frame Assy
30.	IDG Assy
40.	IDG Support Bracket
50.	Pitch Control Unit and Control Rods
60.	Lever Bracket and Interconnection Rods
70.	Bleed Air - Low Pressure Check Valve
80.	Electrical Harness
90	Bleed Air, High Pressure Bleed Valve
95.	Heat Shield Installation
100	Back-up Firewall
110	Bleed Air - Low Pressure Off-Take
120.	Female Flange - Exhaust
130.	Main Fuel Supply Tube
140.	Drain Hoses
150	Pipe Lines Installation for Oil Pressure Transducer & Oil Pressure Switch
160	Oil-Pressure Transducer, Oil-Pressure Switch, Oil-Temperature Detector and Fuel-Temperature Detector
170	Heat Exchanger
180	Airduct and LHS & A-Frame
190	Oil-Cooler Assy
200	Propeller
210	Spinner



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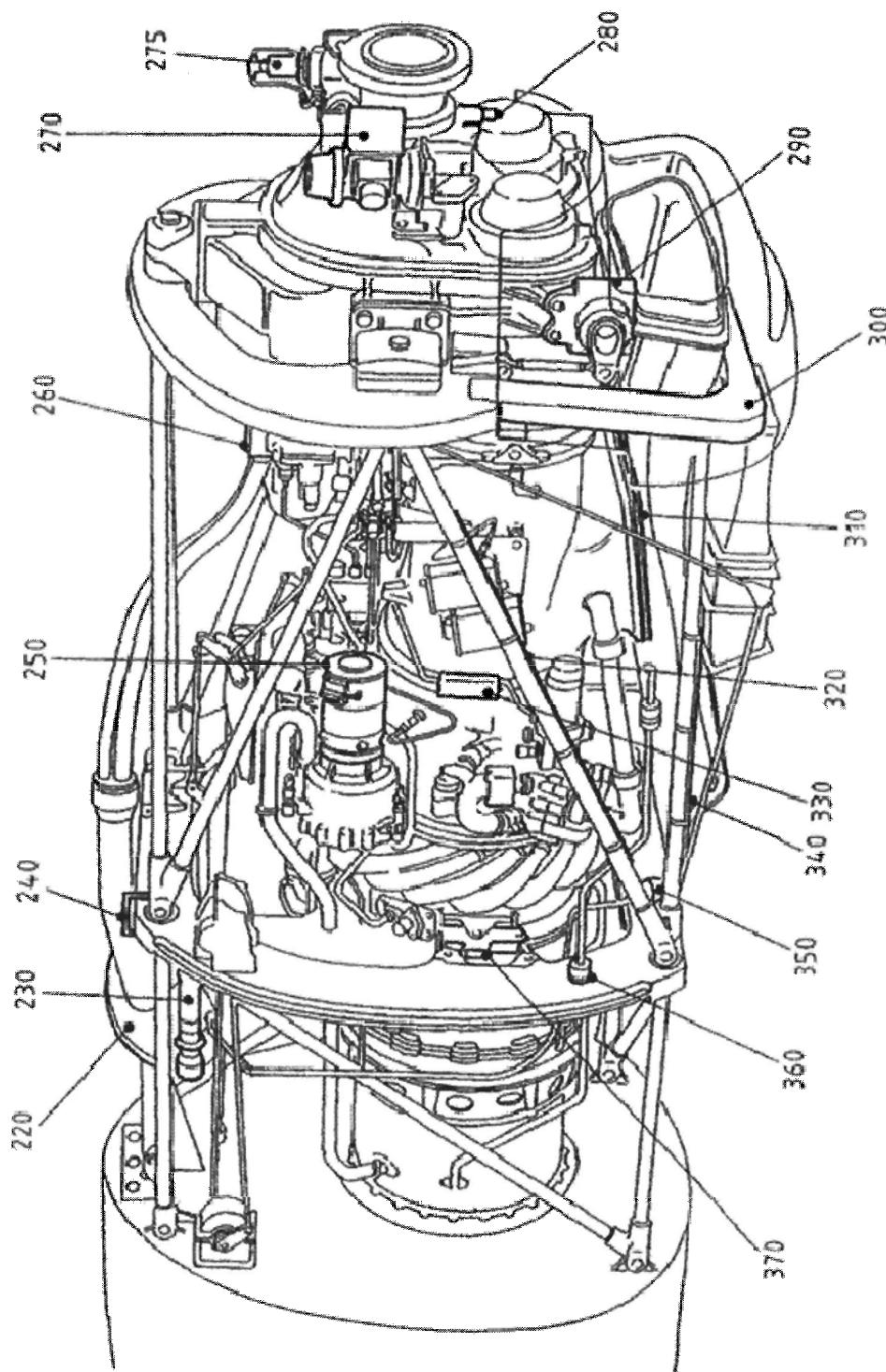


Figure 19.29: Turboprop Build Right Hand Side (PW125)



Number	Item
220	Vertical Firewall
230	Bleed Air - High Pressure and Low Pressure
240	Fire Extinguisher Tube
250	Starter Motor
260	Hydraulic Hose Assemblies and Hydraulic Pump
270	Feathering Pump
275	Brush Block
280	Drain Tubes
290	Torque Tube Isolator
300	Air Intake
310	Engine Seal Assy
320	Hydraulic Pump Seal Drain
330	Fuel Flow Transmitter
340	Oil Drains
350	Fuel Lines on the Engine
360	Spray Pipe for Air Intake
370	Engine Mounts
370A	Engine Mounts - Rear Isolators



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Intentionally Blank



Fire Prevention – Bays or Zones

To prevent the spread of a fire within an aircraft/engine nacelle, it is divided up into sections or zones, each being separated by a fireproof bulkhead. These are made of titanium or stainless steel and prevent the fire from spreading into adjacent areas.

The engine nacelle is split into two sections (UK).

Zone 1. The cool section contains the:

- Fan
- Compressor
- Fuel Control
- Air system supply
- Hydraulic pump
- AC generator
- Bleed valves and Variable Inlet Guide Vane (VIGV) systems

Zone 2. The hot section contains the:

- Fuel burners
- Combustion chamber
- Turbines LP & HP
- Exhaust

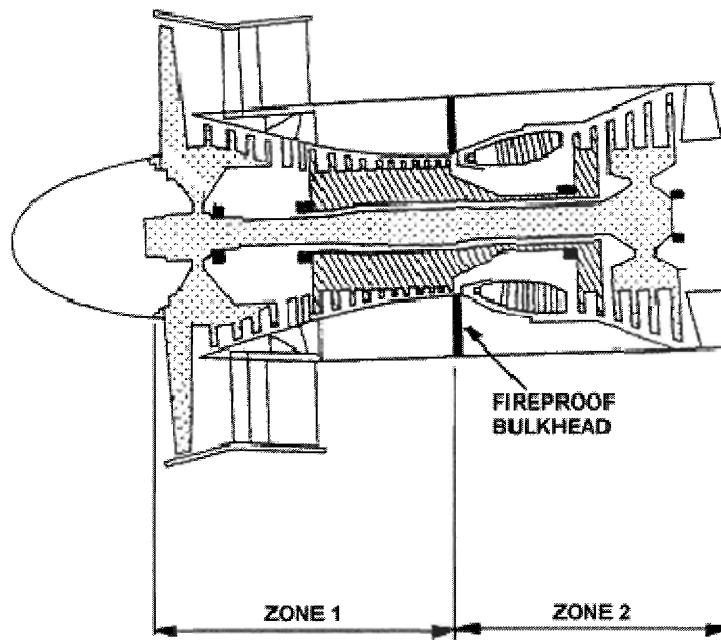


Figure 19.30: Fire zones



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All fire zones are sealed from adjacent areas. Fire resistant rubber seals are fitted to the edges of all doors, panels and bulkhead fittings to prevent fire spreading. Each of the zones will be ventilated to prevent the build up gases or pressure and to cool the outer casing of the engine and accessories. Fire break in panels will be built in to allow the use of external fire extinguishers, these may also operate as blow out doors to prevent pressure build up in the zone.



Installing and Removing Engines

The removal and installation of an aircraft engine follows basically the same principles. However there are differences between turboprop, turboshaft and other engines.

Because of the size and complexity of engine replacement there is usually a pre-printed job card to ensure the job is carried out correctly.

Removal

To prepare an aircraft for engine removal, check that the aircraft weight and balance will not be adversely effected when the engine is removed. Most engines weigh between 0.5 and 1 ton. Trestles may be required to stabilise the fore and aft axis of the aircraft.

The aircraft fuel system does not have to be drained, but the LP fuel valve must be closed and a label attached to the LP Cock handle, in the flightdeck, to prevent inadvertent operation. In addition, the aircraft should be made electrically safe which will entail isolation of the engine starting and ignition system.

Planning is an essential part of any engine removal activity. The Supervisor and personnel involved, should ensure that all necessary resources, such as sufficient manpower, special tools, lifting equipment and an engine transit / storage stand, are available.

The engine access doors and fairings will either have to be removed or supported clear of the engine.

Due to restricted access of some engine accessories and components, it is, in some cases, much easier to remove these items with the engine installed in the aircraft.

Once the engine has been initially prepared for removal (accessories removed etc) the procedure of disconnecting the engine systems, at the engine/ aircraft interface, can begin. Most engines employ quick release plugs and sockets for ease of disconnection of the electrical systems, however some electrical systems, with heavier duty cables, such as the starter and generator cables, may be bolted connections. Disconnect any cable cleats going across the engine / airframe interface.

The hydraulic pipes are usually quick release/self-sealing connections at both the hydraulic pump and the engine / airframe interface. Air supply connections will generally interface with a 'vee band' type of clamp or a bolted connection.

The engine LP fuel inlet pipe must be drained, before disconnection, into a suitable container and the waste fuel disposed off in an approved manner. With the exception of the main engine bearers, all mechanical links must be released and either removed or tied back to prevent fouling during the removal operation.



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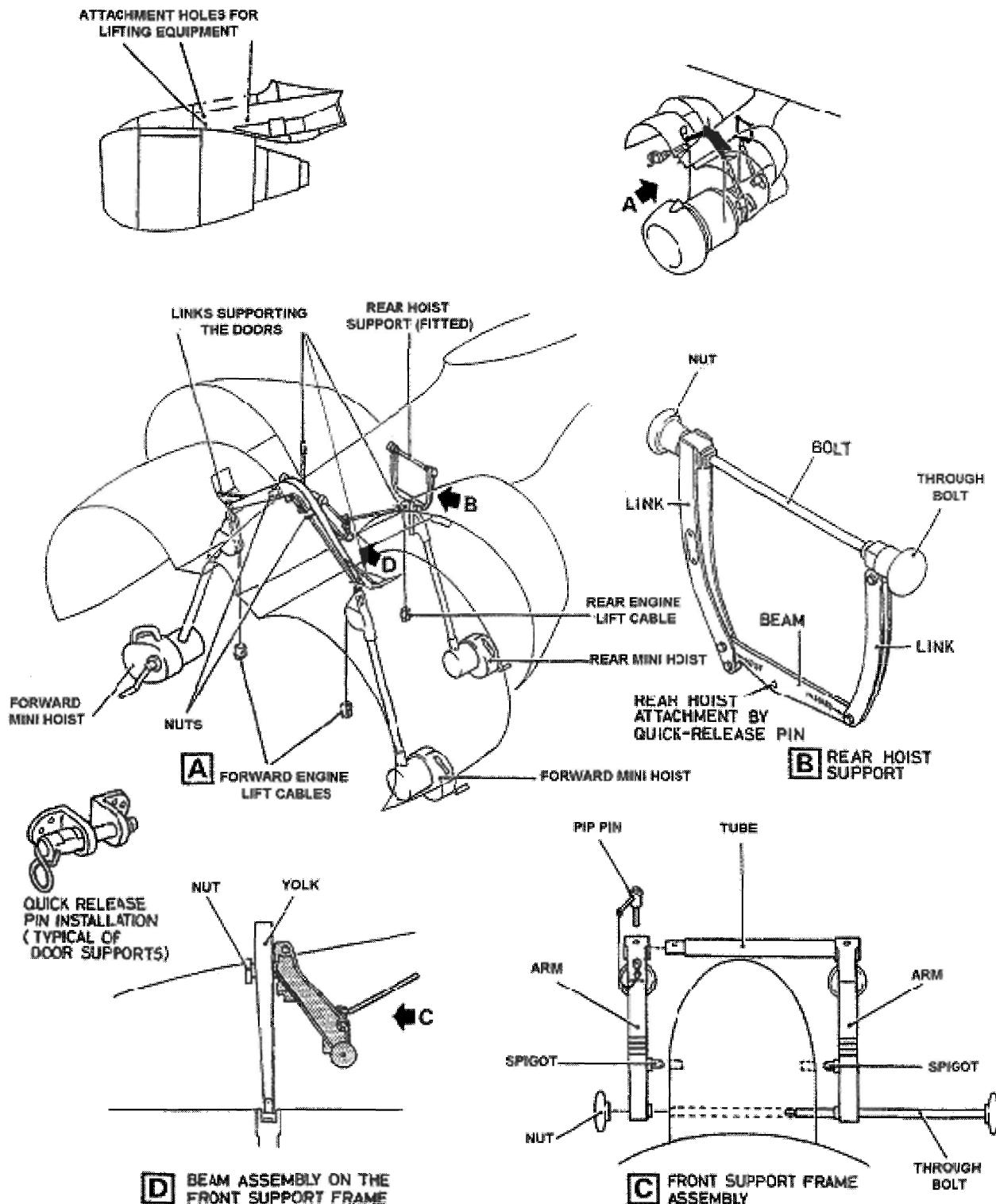


Figure 19.31: BAE Engine Lift Equipment.

Note. The Nose Cowling is attached to the Engine and is Removed Later.



If the engine is not being replaced or refitted immediately, all open pipes must be blanked off to prevent foreign particle ingress and all electrical plugs tied back and protected.

Once satisfied that the engine is ready for removal the lifting equipment can be fitted in accordance with the AMM. Jet engines are installed and removed utilising gantry cranes, mobile cranes or in many cases by use of 2, 3 or 4 mini hoists.

Whatever method is used the lifting equipment must be inspected before use. Particular attention should be paid to ensuring that the equipment has approval documentation and is of the correct 'safe working load' for the task. Cables should not show evidence of twisting or fraying and end fittings should be free of damage, corrosion etc. When mini hoists are used, the brake and clutch mechanisms of each hoist should be functionally checked and that the correct hoist is being used as similar units are rated at different settings.

Supervisors should double check that all the lifting equipment is serviceable and correctly fitted prior to commencing the removal process. The supervisor should also carry out a final check of the engine / airframe disconnect points to satisfy himself/herself that the engine and equipment is safe for removal.

Each winch / hoist is to be manned at all times during the removal process and at least one person who can check the engine to ensure it remains in a safe condition during removal. The supervisor must ensure that all team members are fully aware of the process and briefed on what is required of each individual. All instructions should be given in a clear and unambiguous manner and where hand signals are required, all members can see the supervisor and are aware of their meaning. Only the supervisor of the task should issue instructions during the process and unnecessary talk and noise (i.e. riveting operations in vicinity) minimised or stopped.

Immediately prior to removing the engine and finally releasing the engine mounts / attachments, the weight of the engine must be 'taken' by the lifting equipment. This will ensure that there is no unnecessary 'jerking' or 'snatching' of the cables. With mini hoists this is achieved by winching the cable in until the clutch in the handle breaks (Always re-engage the handle before progressing further). At this point the effectiveness of the brake unit in the mini hoist should be checked following the relevant manufacturers procedures. Once the supervisor is satisfied that all procedures have been followed correctly and that all resources are in place the engine mountings / bearers can be disconnected and the engine removed / lowered from its housing. At all stages of the removal procedure checks should be carried out to ensure that the engine does not become caught on the airframe structure or components.

WARNING

NEVER WALK UNDER A SUSPENDED LOAD. EVERY EFFORT SHOULD BE TAKEN TO MINIMISE THE TIME NECESSARY TO CARRY OUT ANY MAINTENANCE BENEATH A SUSPENDED LOAD

When lowering an engine using a mini hoist system, the weight of the engine should always be taken by the winding handle and the brake should be released and held off.

An engine stand should be positioned ready to accept the engine and any pins or mounts, between the engine and its stand, connected prior to allowing the weight to be removed from the winching system.



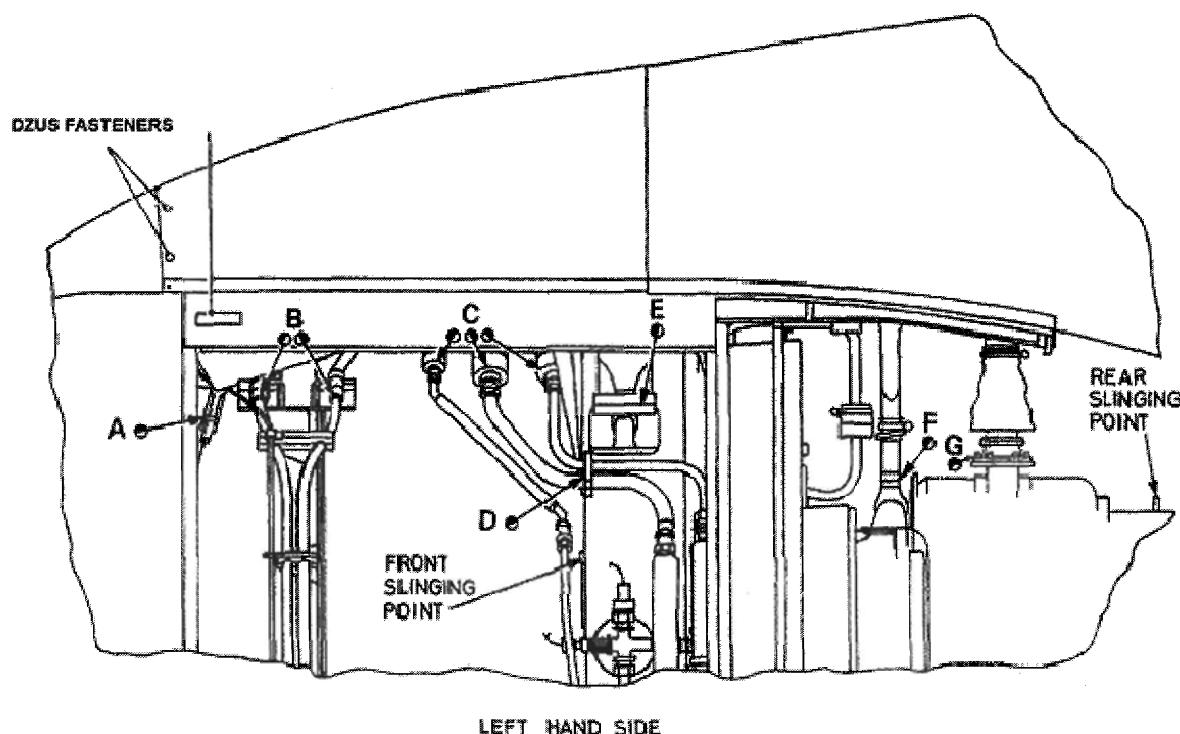
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If the engine is to be replaced remove any further dress items that have not already been removed. Complete and attach an equipment label to the engine detailing its condition, life used, etc.

To avoid or minimise deformation on the aircraft structure due to removal of the engine, it may be necessary to fit a component called a 'jury strut'. This requirement will be clearly stated in the relevant procedure of the AMM.

Once removed further inspections on the engine and the nacelle will be carried out. If the engine is to be returned to the manufacturer these will entail blanking of exposed pipes and protection of exposed cables and components. If the engine is to be refitted to the same aircraft then these checks, often referred to as 'bay checks' are more involved and are designed to ensure that the condition of the hard to see areas of the engine and engine bay are thoroughly checked.



● DISCONNECT/CONNECT POINTS

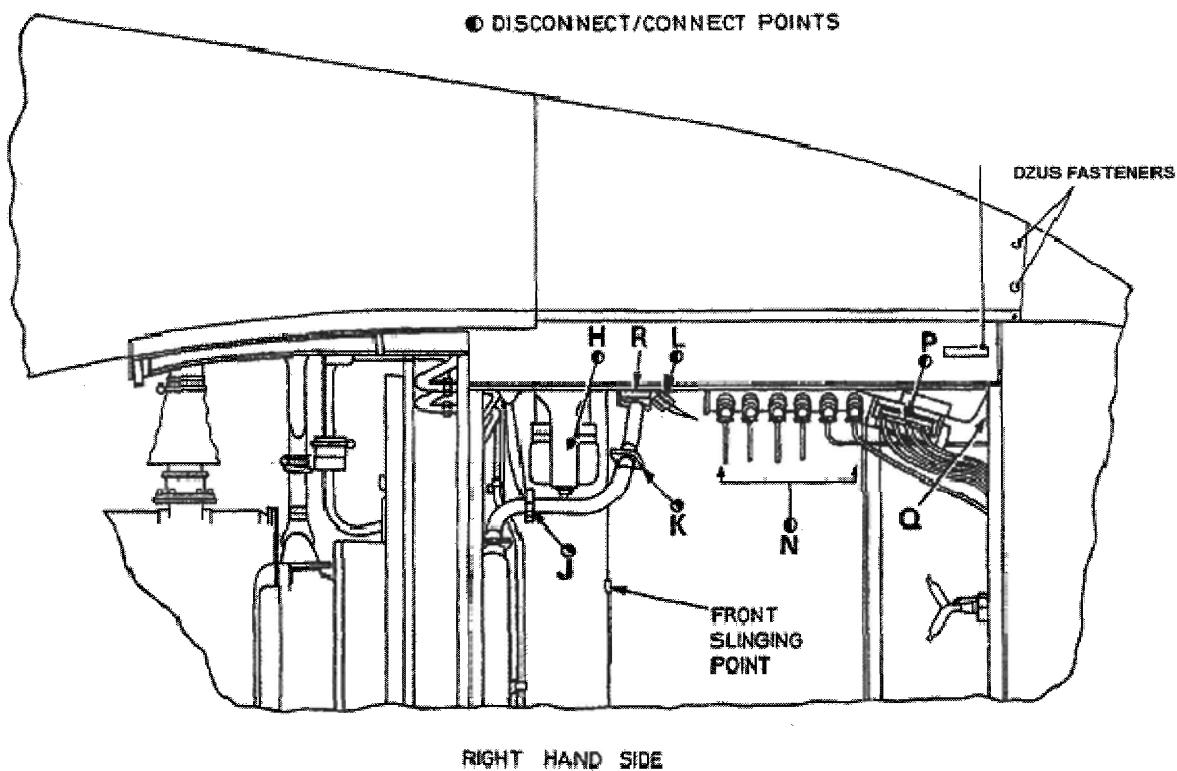


Figure 19.32 (a): Interface disconnect points

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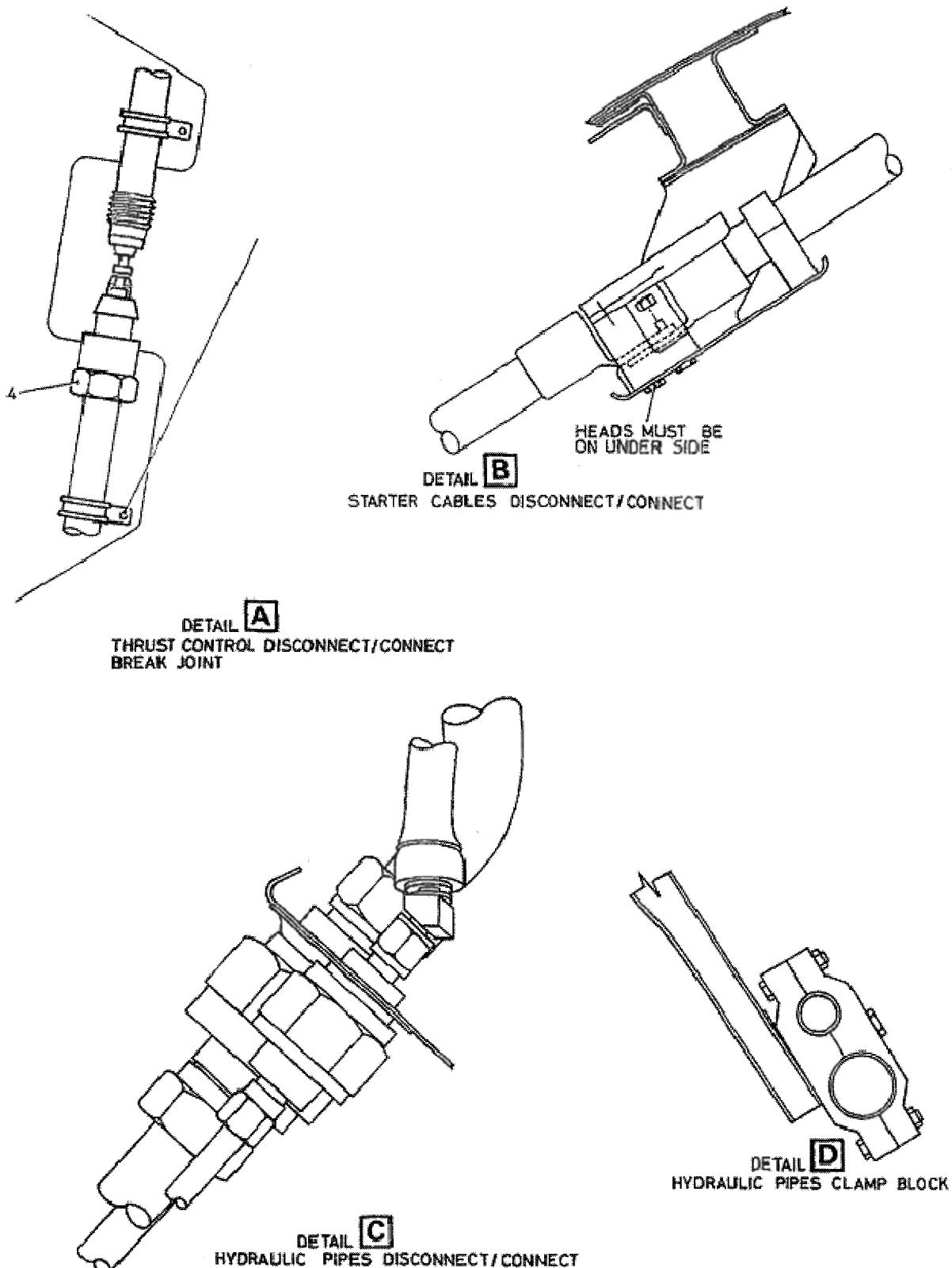


Figure 19.32 (b): Interface disconnect points

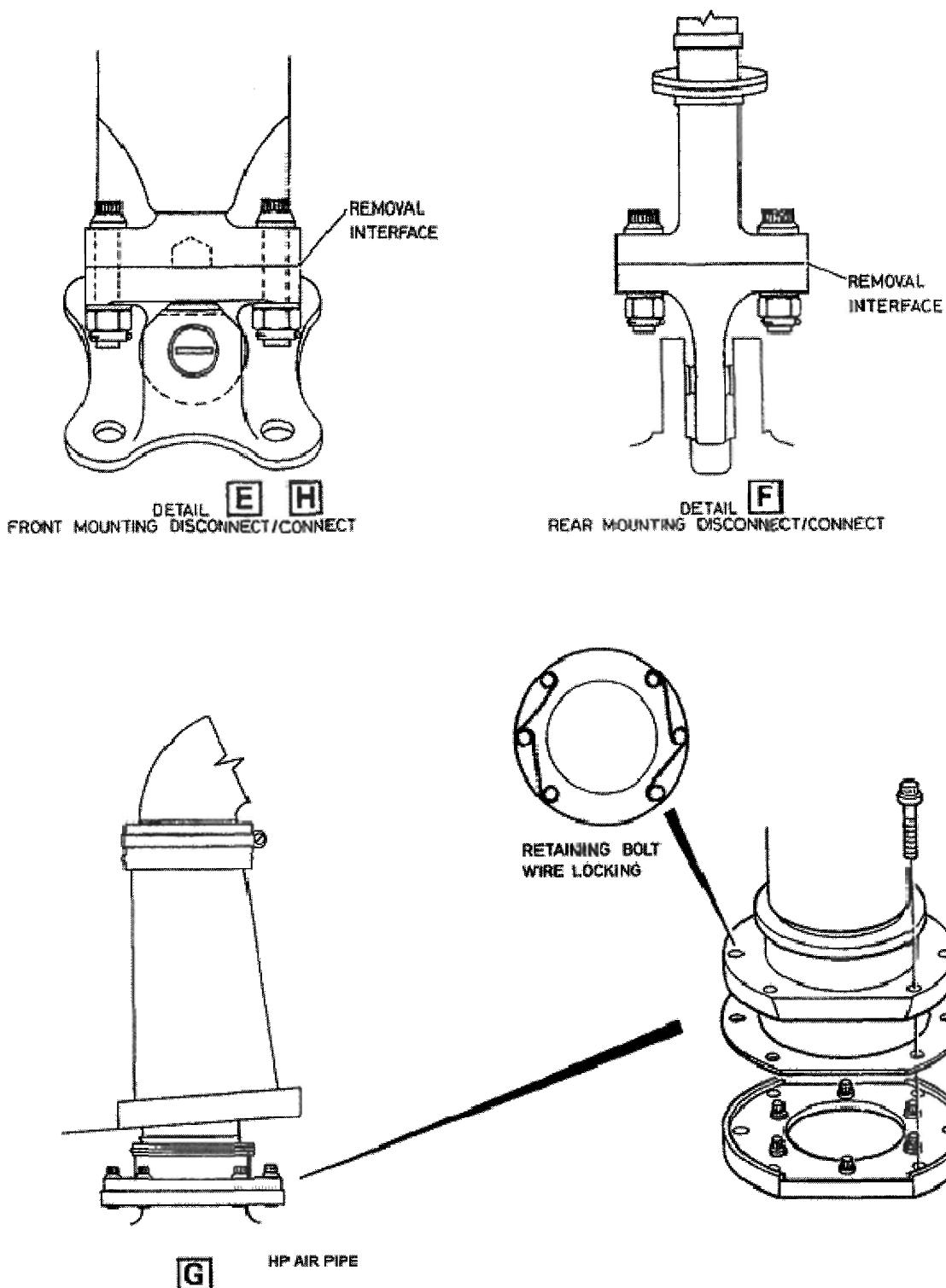
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Figure 19.32 (c): Interface disconnect points



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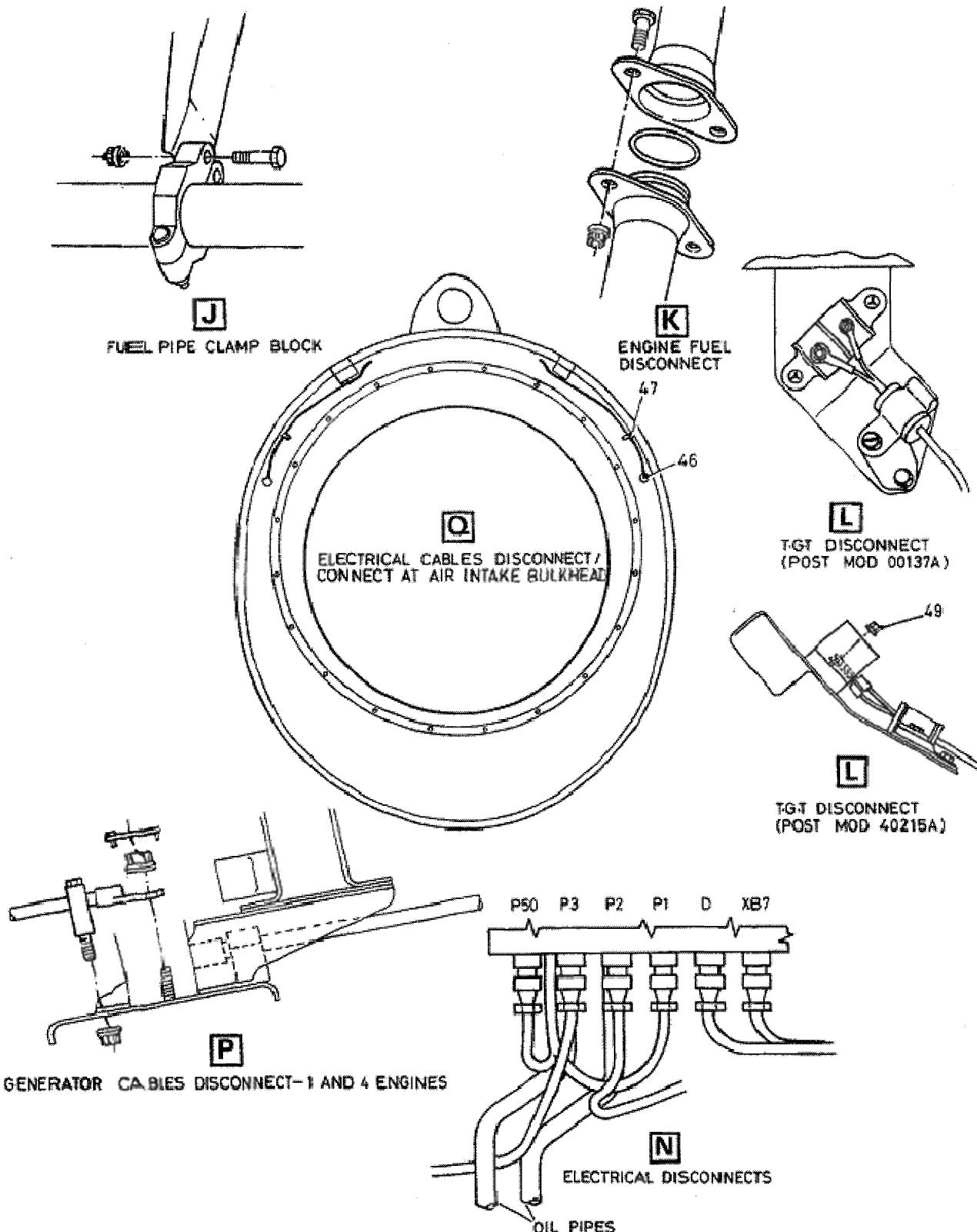


Figure 19.32 (d): Interface disconnect points



Fitting

Prior to fit remove the label from the engine and attach it to the paperwork for safekeeping. Check the engine over to ensure it is complete and check the label for any tasks required before fit. Fit any dress items that need to be fitted prior to fit.

Check round the bay to ensure it is clear to fit the engine and remove the jury strut if fitted. Check the lift gear is correctly installed and that it is serviceable.

Position the engine and correctly attach it to the lift gear (double check this).

Lifting the engine in follows the same basic rule as lowering. If using mini hoists there is no need to operate the brake when hoisting as it ratchets. When the engine nears the installed position the person in charge and his assistant will align the mounts and fit the pins or bolts, this is a critical time and may require very small movements on the lifting gear to allow the mounts to be connected. Great care and concentration is required to prevent damage or injury. Do not use your finger to check alignment as a very small movement of the engine could trap or sever it.

Once the mounts are made, and locked the lifting gear can be removed and the engine systems and accessories can be reconnected which is the reverse of the removal. Remember to fit new seals to the components.

After engine fit the electrical systems can be reset. The LP fuel valve opened and the engine fuel system bled to remove any air. The engine oil system is then checked and followed by an engine ground run. During the ground run leak and performance checks are carried out to ensure that the engine is satisfactory. After the run the chip detectors are checked and duplicate inspection is required on the engine controls.

Turbo Prop Engine Removal/Fitment

With a turboprop engine the prop would have to be removed prior to removal and fitted after the engine is mounted. The prop would also have to be bled and functioned prior to running to prevent damage.

Flight Transit

To allow an aircraft to return to a suitable base for an engine change, some multi engine aircraft can be flown with one engine shut down. In the case of the BAe 146 it has sufficient power to take off and fly on 3 engines. To prevent damage to the engine rotor locks are fitted to the LP and HP systems to prevent rotation. The starting and ignition systems must be inhibited for that engine to prevent damage by inadvertent election.



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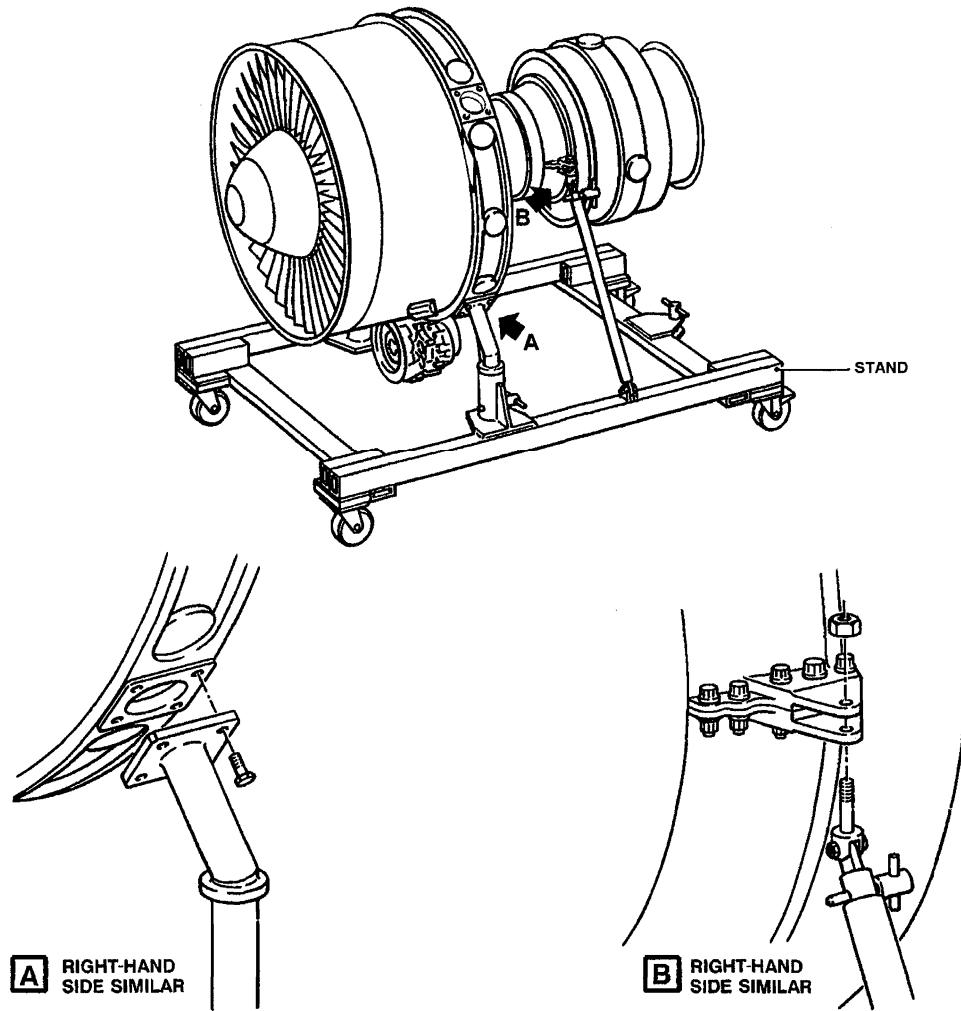


Figure 19.33: An ALF502 engine in its stand

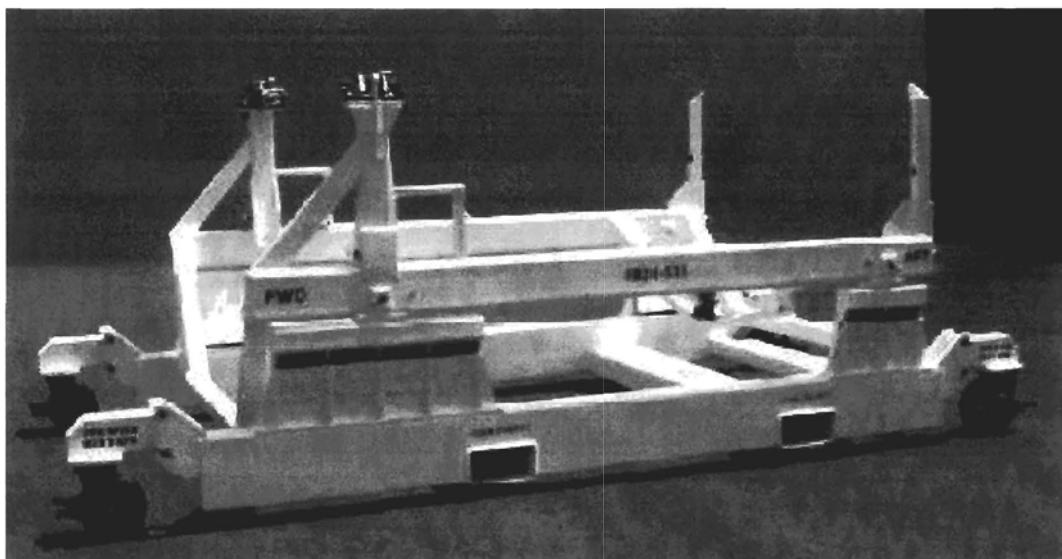


Figure 19.34: An RB211 stand



TTS Integrated Training System

Module 15 Licence Category B1

Gas Turbine Engine

15.20 Fire Protection Systems



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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.20 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.20 - Fire Protection Systems

Introduction

Because fire is one of the most dangerous threats to an aircraft the regulations regarding the design and specification of potentially hazardous areas are particularly stringent.

Requirements for Overheat and Fire Protection Systems

Overheat and fire protection systems on modern aircraft do not rely on observation by crew members as a primary method of fire detection. An ideal fire protection system will include as many as possible of the following features:

- A system which will not cause false warnings, under any flight or ground operating conditions.
- Rapid indication of a fire, and accurate location of the fire.
- Accurate indication that the fire is out.
- Indication that the fire has re-ignited.
- Continuous indication for the duration of the fire.
- Means for electrically testing the detector system from the aircraft cockpit.
- Detectors which resist exposure to oil, water, vibration, extreme temperatures, and maintenance handling.
- Detectors which are light in weight and easily adaptable to any mounting position.
- Detector circuitry which operates directly from the aircraft power system without inverters.
- Minimum electrical current requirements when not indicating a fire.
- Each detector system should actuate a cockpit light indicating the location of the fire, and an audible alarm system.
- A separate detection system for each engine.

There are a number of overheat and fire detection systems that satisfy these requirements, and a single aircraft may utilize more than one type.



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Fire Zones (EASA Part-25.1181)

For certification purposes and fire protection engines are classified with different fire zones separated by fireproof firewalls and shrouds.

The following are designated as fire zones:

- The engine power section
- The engine accessory section

Any complete powerplant compartment in which no isolation is provided between the engine power section and the accessory section.

- The compressor and accessory sections

- The combustor, turbine and tailpipe sections of turbine engine installations



Fire Detection Systems (EASA Part-25.1203)

Requirements

The following are listed as mandatory design characteristics:

- (a) There must be approved, quick acting fire or overheat detectors in each designated fire zone, and in the combustion, turbine, and tailpipe sections of turbine engine installations, in numbers and locations ensuring prompt detection of fire in those zones.
- (b) Each fire detector system must be constructed and installed so that
 - It will withstand the vibration, inertia, and other loads to which it may be subjected in operation;
 - There is a means to warn the crew in the event that the sensor or associated wiring within a designated fire zone is severed at one point, unless the system continues to function as a satisfactory detection system after the severing; and
 - There is a means to warn the crew in the event of a short circuit in the sensor or associated wiring within a designated fire zone, unless the system continues to function as a satisfactory detection system after the short circuit.
- (c) No fire or overheat detector may be affected by any oil, water, other fluids, or fumes that might be present.
- (d) There must be means to allow the crew to check, in flight, the functioning of each fire or overheat detector electric circuit.
- (e) Wiring and other components of each fire or overheat detector system in a fire zone must be at least fire-resistant.
- (f) No fire or overheat detector system component for any fire zone may pass through another fire zone, unless:
 - It is protected against the possibility of false warnings resulting from fires in zones through which it passes; or
 - Each zone involved is simultaneously protected by the same detector and extinguishing system.
- (g) Each fire detector system must be constructed so that when it is in the configuration for installation it will not exceed the alarm activation time approved for the detectors using the response time criteria specified in the appropriate Technical Standard Order for the detector.



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Detector System Descriptions

A **fire detector** system warns the flight crew of the presence of a engine fire that raises the temperature of a particular location to a predetermined high value. Most of these detection systems turn on red lights and sound a fire-warning bell.

An **overheat detector** initiates a warning when there is a lesser increase in temperature over a larger area. Overheat is usually used bleed air ducting to the airframe. In the event of a detected leak this initiates a caution and 'overheat' warnings, rather than a full fire warning .

In general a fire detection system consists of:

- Detector circuit
- Alarm circuit
- Test circuit.

There are a number of fire detection systems that are able to detect the presence of a fire:

- Thermal Switch Type
- Thermocouple Type
- Continuous-Loop Detector Systems
- Pressure-Type Sensor Responder Types

Thermal Switch Type

The thermal switch fire detection system is a spot-type system that uses a number of thermally activated switches to warn of a fire. The switches are wired in parallel with each other, and the entire group of switches is connected in series with the indicator light. If any detector reaches the temperature to which it is adjusted, it will complete the circuit to ground and turn on the warning light and the fire warning bell will ring.

The spot detector sensors operate using a bimetallic thermoswitch that closes when heated to a high temperature. A detector may be adjusted by heating its case to the required temperature and turning the adjusting screw in or out until the contacts just close.

The entire circuit can be tested by closing the test switch that actuates the test relay and grounds the end of the conductor that ties all of the detectors together. This turns on the warning light and the fire warning bell rings.

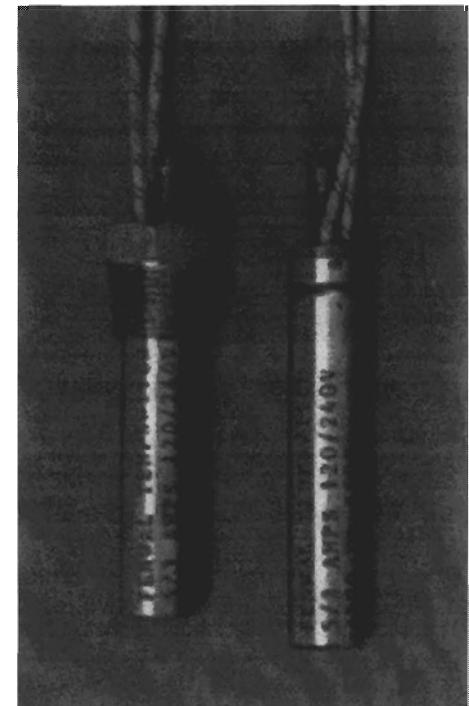


Figure 20.1: Thermal switches (spot detectors)

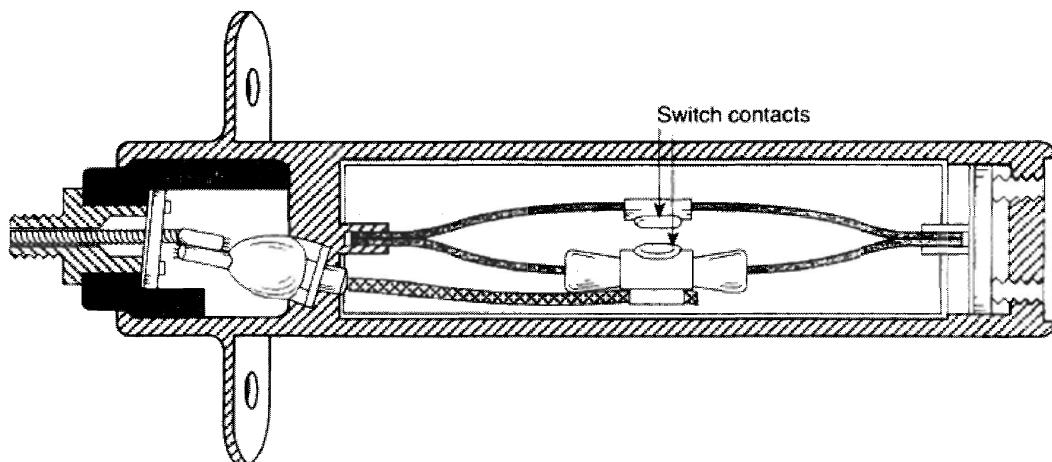


Figure 20.2: Bimetallic Thermal Switch

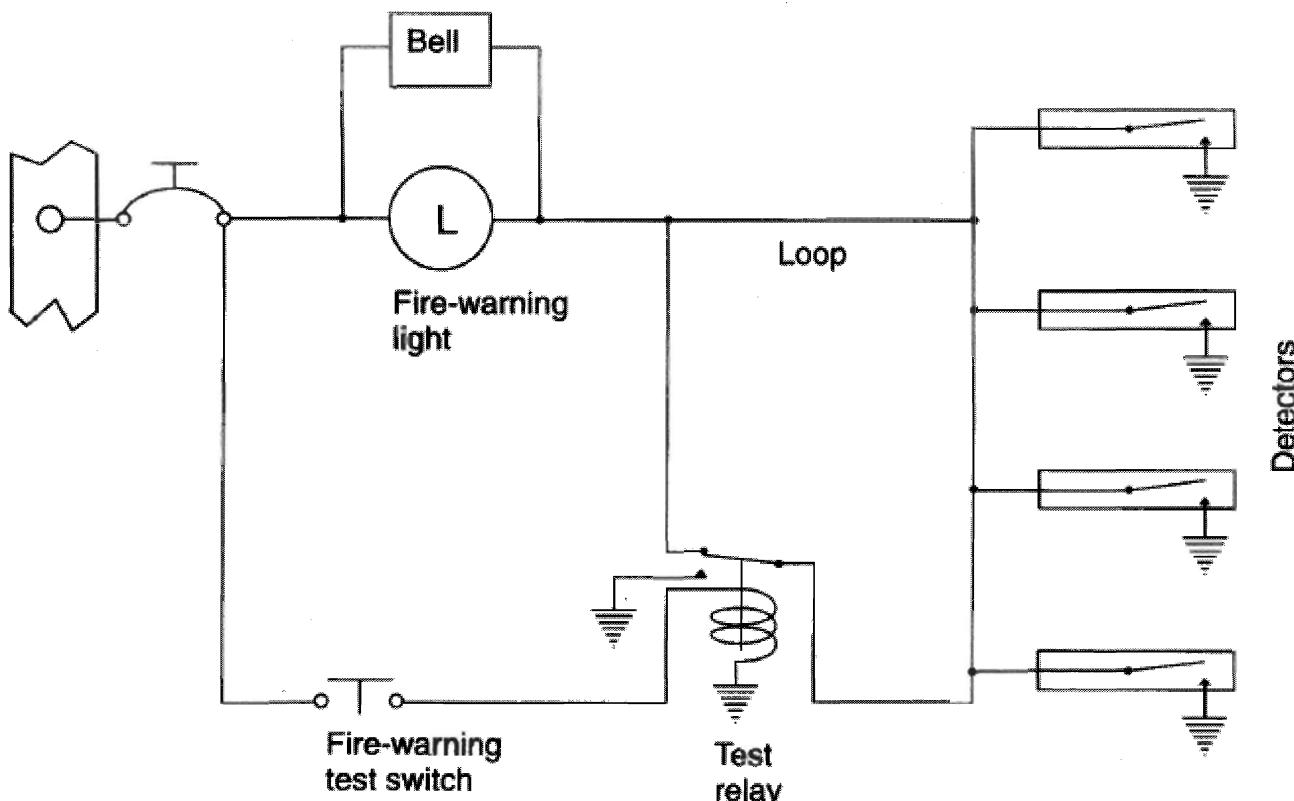


Figure 20.3: Single Loop Overheat I Fire Detection Circuit



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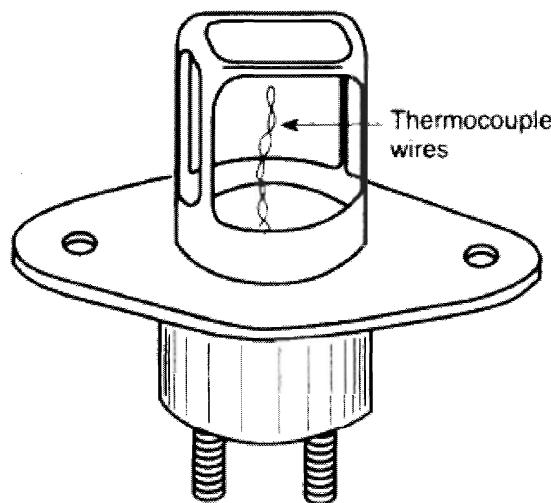


Figure 20.4: Thermo Couple Fire Sensor

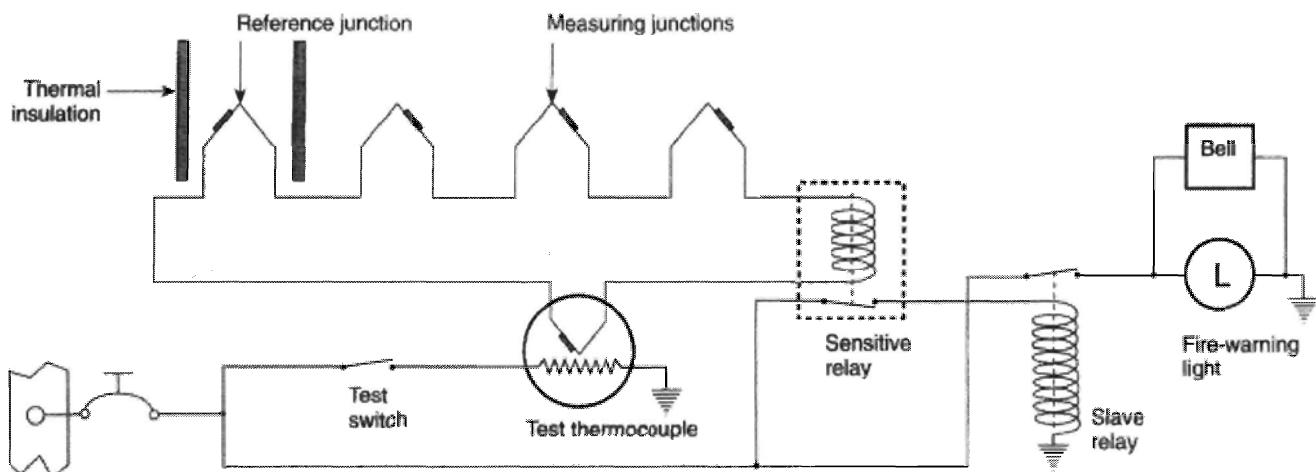


Figure 20.5: Overheat- Fire- Detection Circuit

This system operates on the rate-of-temperature-rise principle, rather than operating when a specific temperature is reached. This system will not give a warning when an engine overheats slowly, or a short circuit develops.

The thermocouple is constructed of two dissimilar metals such as chromel and alumel. The point where these metals are joined, and will be exposed to the heat of a fire, is called a hot junction. A metal cage surrounds each thermocouple to give mechanical protection without hindering free movement of air to the hot junction.

In a typical thermocouple system installation, the active thermocouples are placed in locations where fire is most likely to occur, and one thermocouple, called the reference thermocouple, is placed in a location that is relatively well protected from the initial flame. The temperature of the reference thermocouple will eventually reach that of the other thermocouples, and there will be



no fire warning if everything heats up uniformly as it does in normal operation.

If a fire should occur, the active thermocouples will get hot much sooner than the reference thermocouple, and the difference in temperature will produce a current in the thermocouple loop. This current flows through the coil of the sensitive relay. Anytime the current is greater than 4 milliamperes, the sensitive relay will close. The slave relay is energized by current through the contacts of the sensitive relay and the warning light is turned on.

A test circuit includes a special test thermocouple in the loop with the other thermocouples. This test thermocouple is equipped with an electric heater. When the test switch on the instrument panel is closed, current flows through the heater and heats up the test thermocouple. This causes current to flow to the thermocouple loop, and the fire warning light will illuminate.

The total number of thermocouples used in individual detector circuits depends on the size of the fire zone and the total circuit resistance. The total resistance usually does not exceed 5 ohms.



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Continuous-Loop Detector Systems

A continuous-loop detector or sensing system permits more complete coverage of a fire hazard area than any type of spot-type temperature detectors. The continuous-loop system works on the same basic principle as the spot-type fire detectors, except that instead of using individual thermal switches the continuous-loop system has sensors in the form of a long Inconel tube.

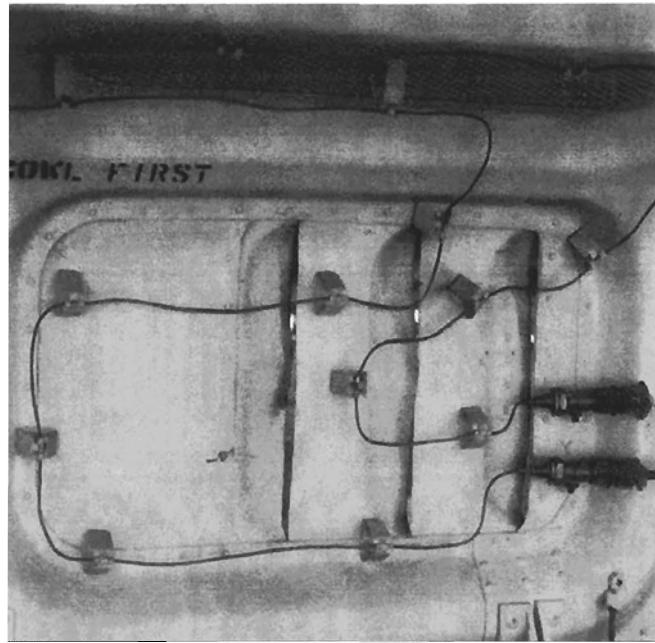


Figure 20.6: A continuous loop installation on an engine cowl

These are overheat systems, using heat sensitive units that complete an electrical circuit at a certain temperature. There is no rate-of-heat-rise sensitivity in a continuous-loop system. Three widely used types of continuous-loop systems are the Fenwall Kidde and Graviner systems.

Fenwall System

The Fenwall system uses a single wire surrounded by a continuous string of ceramic beads in an Inconel tube. The tube acts as the earth. The beads in this system are wetted with a eutectic salt which possesses the characteristics of suddenly lowering its electrical resistance as the sensing element reaches its alarm temperature.

At normal temperatures, the eutectic salt core material prevents electrical current from flowing. In case of fire or overheat condition, the core resistance drops and current flows between the signal wire and ground, energizing the alarm system.

The Fenwall system uses a magnetic amplifier control unit. This system is non-averaging but will sound an alarm when any portion of its sensing element reaches the alarm temperature.

Kidde System

In the Kidde continuous-loop system two wires are imbedded in a special ceramic core within an Inconel tube. One of the wires is welded to the case at each end and acts as an



internal ground. The second wire is a hot lead (above ground potential) that provides an electrical current signal when the ceramic core material changes its resistance with a change in temperature.

The Kidde sensing elements are connected to a relay control unit. This unit constantly measures the total resistance of the full sensing loop. The system senses the average temperature, as well as any hot spot.

Both systems continuously monitor temperatures in the affected compartments, and both will automatically reset following a fire or overheat alarm, after the overheat condition is removed or the fire is extinguished.

Note that both systems are purely resistive and are powered by 28V DC.

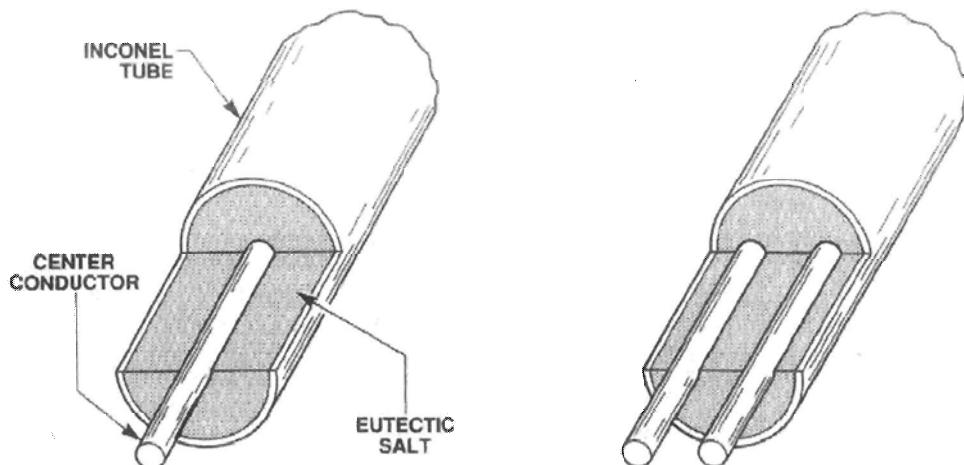


Figure 20.7: Sensing Elements (Fenwall and Kidde)

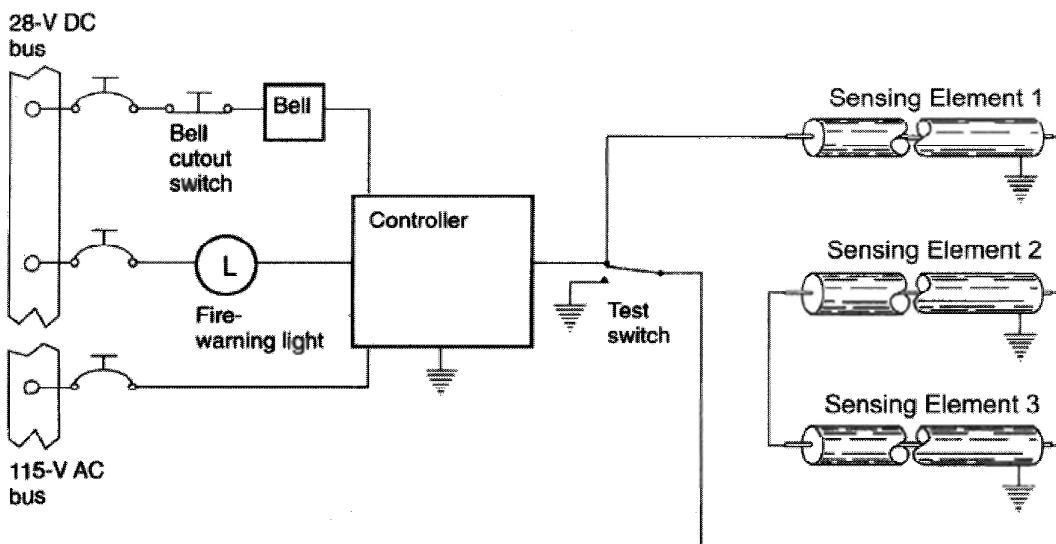


Figure 20.8: Electrical Circuit



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Graviner Continuous Fire Detectors (Resistive/Capacitive)

The Graviner system is a single wire continuous loop that looks identical to the earlier kiddie and fenwall detector wires, but works on a different principle. This system has been used on large commercial passenger transport aircraft with built in test facility.

A fire detector consists of two sensing elements which are attached to a support tube by quick-release mounting clamps. Each sensing element is a resistor-capacitor network, with resistance varying as a function of temperature.

At low temperatures, the impedance of the sensing element is mainly resistive. As temperature increases, the resistance drops, thus the impedance becomes more reactive. The detector senses the change as a fire signal. A pure resistance will not be sensed by the detector card as a fire, but as a fault.

As this system is capacitive a 400Hz oscillator converts 28Vdc to energize these detectors.

Systron Donner System

A Systron Donner detector consists of a sensor and a responder. The sensor tube contains a gas charged core material and helium under pressure. One end of the tube is sealed and the other end is mated through a ceramic isolator and hermetically sealed to the responder.

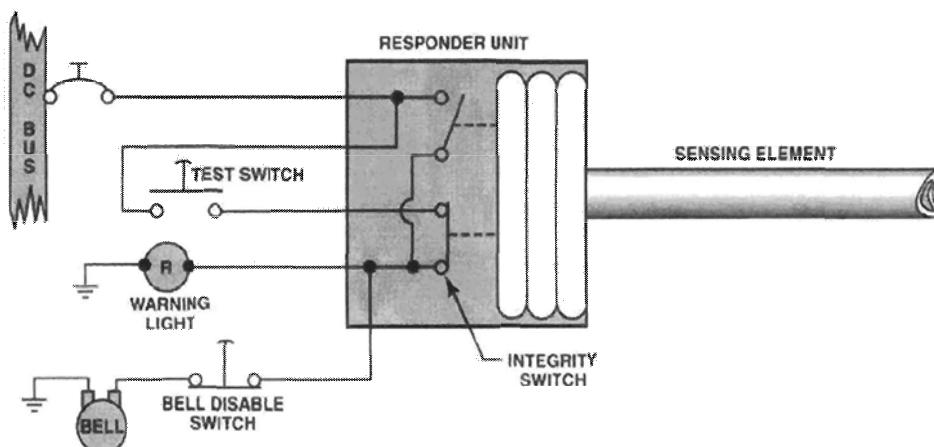


Figure 20.9: Systron Donner pressure sensing fire detectors

The responder contains 2 pressure switches and a resistor and is connected to airplanes wiring by two threaded studs. The two snap-over pressure switches are actuated independently by gas pressure in the sensor tube acting on small metal diaphragms within each switch. One switch, called the integrity switch is normally held closed by the helium pressure and serves as a monitor of the detector integrity. Should the sensor lose pressure, the diaphragm would snap-over, opening the integrity circuit. The other switch, called the alarm switch, closes when heat increases the gas pressure in the sensor to snap-over its diaphragm. The closed switch then signals an alarm to the system.

The sensors are able to respond in two modes: A localized flame or heat causes a “discrete” temperature rise which causes the core material to release gas to increase the pressure. The



central core material has the unique property of releasing an extremely large volume of gas whenever any finite section is heated above a certain temperature. The other mode is a general increase in temperature over a large area, causing an "average" temperature rise, increasing overall gas pressure. Either of these modes are completely reversible. Should the temperature decrease, the gas pressure will decrease and the system will return to normal.

Each detector assembly consists of a support tube assembly, Teflon liners, clamps and two detector elements. The support tube establishes routing configuration of the detector element and provides attach points to the airplane.

Testing of Continuous Loop Systems

The Systron Donner system is the current system of choice for Boeing and Airbus. Its great advantage is that if a detector loses pressure a fault will be instantly registered. The Graviner system can register a continuity fault in flight, but only if a test is carried out from the flight deck.

False warnings are an issue with the earlier systems largely due to chafing or cracking of the detector wires. Insulation testing of the elements is carried out during maintenance by using a 250V safety ohmmeter. Resistance values vary, therefore the AMM for each installation should be consulted.

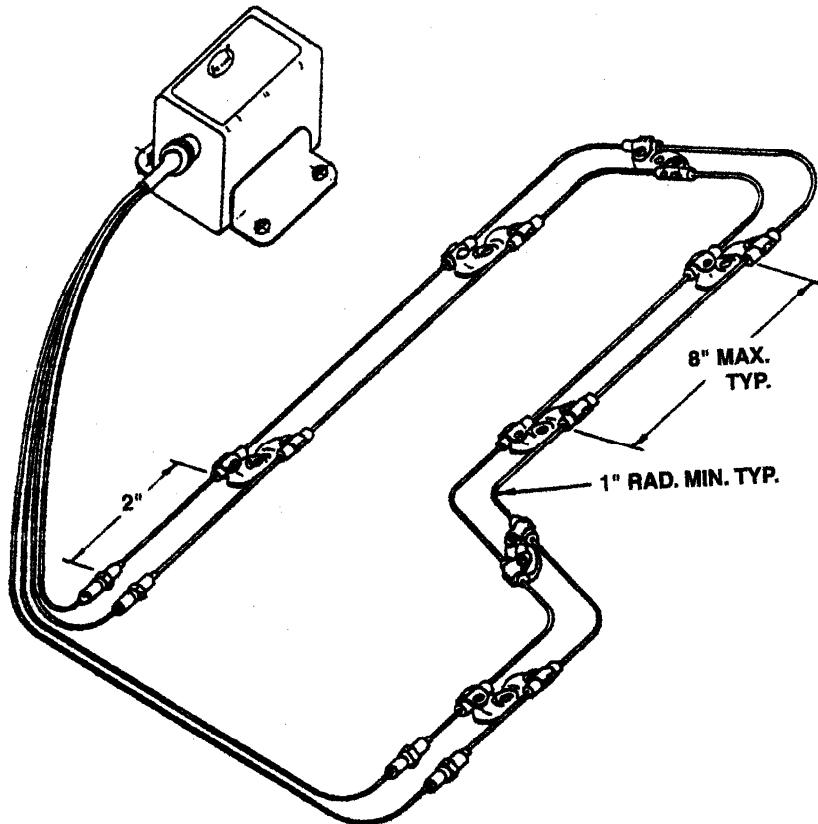


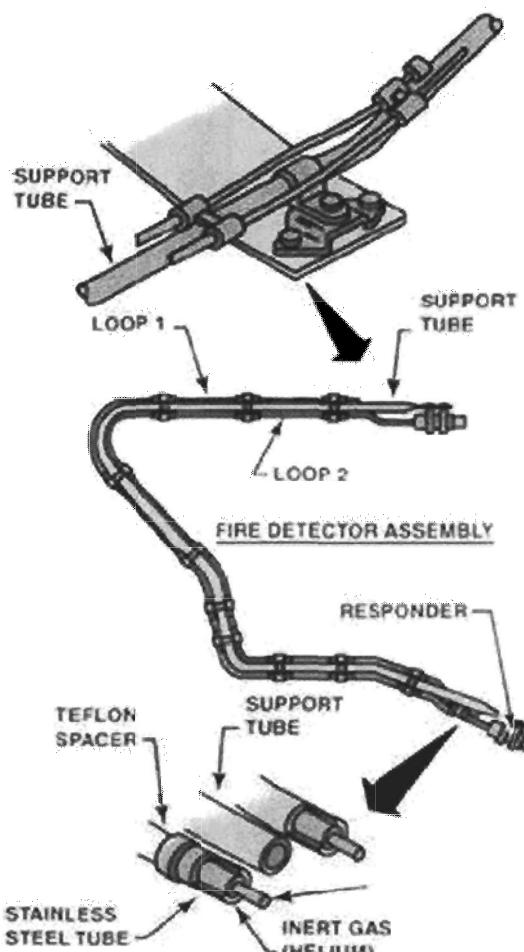
Figure 20.10: Installation of Continuous Loop Systems

Figure 20.10 shows an early dual loop system. In the event of one loop being faulty the other continues to function.



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Note the following:

- Minimum bend radius of 1" is a general standard.
- 8" between supports is a general standard

The clamps securing the wires to the nacelles or engine are used purely for support, **not** insulation.

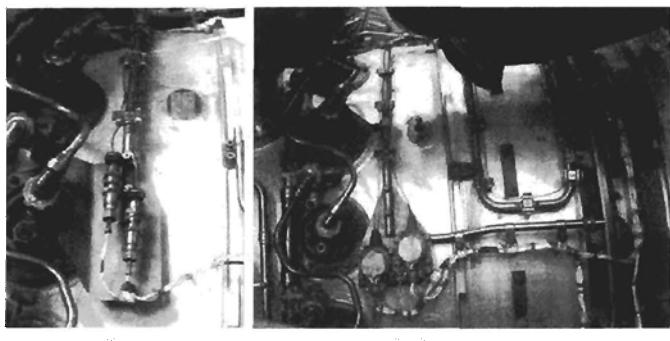


Figure 20.11: Typical fire wire installations

The photographs above show modern firewire rails in the 2 types. It should be noted that the detectors are supplied as a rail upon which the 2 detectors (dual loop) are mounted. The only physical difference between them is the connectors. (There is an alternative Systron Donner responder that is similar to the graviner, but three times the diameter.)

Note that the supporting clips mount the detectors to the rail, the rail being secured to the engine.

On an RB 211 engine there are 2 rails in zone 1 (Fan and Accessories) and 2 rails in zone 3 (Combustor and Turbine). each of the loop 1's are connected and each of the loop 2's are connected, thus forming a pair of continuous loops around the engine. Testing is automatic on power up and manually if the Eng/Fire/APU test switch in the cockpit is pressed.

The Fire Detector Unit requires a fire signal from both loops before it will signal a fire, if the loops are both serviceable. In the event of 1 loop being detected as unserviceable the control unit reconfigures to indicate a fire from a single loop.



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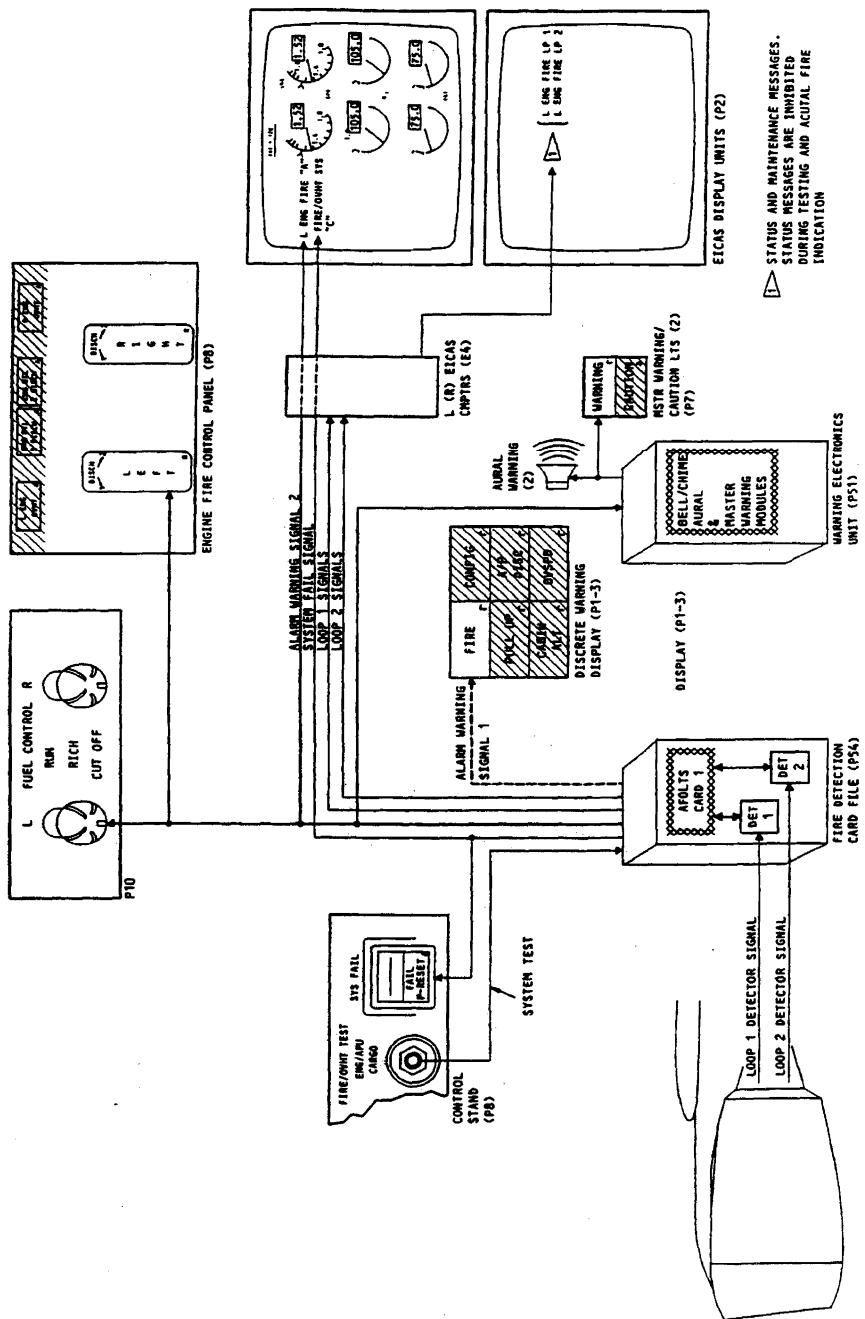


Figure 20.12: Typical Large Commercial Twin Turbo Jet (Boeing 757/767) Fire Warning System

Note: The detector loops can be Systron Donner or Graviner. Therefore if an engine is changed that swaps types of firewire the only action required is to replace the detector cards with the appropriate type.



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Fire Extinguishing Systems

These systems are provided for power plants, APUs, and in some types of aircraft, for landing gear wheel bays, baggage compartments and combustion heater installations. A system generally consists of a number of metal containers or bottles, containing an extinguishant which is pressurized with an inert gas and sealed by means of a discharge or operating head. When operated, either by selector switches in the cockpit or crash switches, an electrically fired cartridge ruptures a metal diaphragm within the discharge head and the extinguishant is released to flow through spray pipes, spray rings or discharge nozzles into the appropriate fire zone. Electrical power is 28 volts d.c. and is supplied from an essential services busbar.



Figure 20.13: Typical fire extinguisher panel (B737)

Two extinguishing methods are used for power plants. In the first method, which is employed in the majority of older types of aircraft, an individual system is provided for each power plant. The second method, known generally as the 'two-shot system', is the one most widely used and comprises connections between the individual power plant systems, so permitting two separate discharges of extinguishant into any one power plant.

In several types of aircraft, indication that a fire extinguishing circuit has been operated, is provided either by, warning lights or, indicating fuses connected in the circuit. The fuses contain a small charge and are enclosed within a domed cover which is normally transparent. When current flows in the relevant extinguishing circuit the charge is fired, and this causes a red powder to be spattered on the inside of the domed cover, thus furnishing a clear and lasting indication of the operation of an extinguisher.

In some installations special switches are incorporated to automatically operate the extinguishers in the event of a crash. These switches also connect cabin emergency lights to the aircraft battery power supply. Two types of crash switch are in common use: the inertia control type and the frangible type. An inertia controlled switch generally consists of a heavy piston supported on its own spring and so arranged that at the required degree of deceleration (a typical value is 3g), it compresses the spring and causes a bow spring to snap over thereby bridging contacts connected in the extinguishing system circuit. To allow resetting of the switch after operation or rough handling during transit, a reset plunger is incorporated.



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Typical Large Commercial Twin Jet Fire Extinguishing System

The fire extinguishing system includes a cockpit control switch, fire extinguishing agent containers, and an agent distribution system.

Figure 20.11 shows a typical container which houses the extinguishing agent. An engine can be protected with one bottle only or a cross-feed system with two or more bottles.

The bottle is pressurized with the extinguishing agent, in the range of 500 to 600 PSI. The gauge indicates the correct charge. The relief valve is a fusible (frangible) disk which will rupture if the bottle were to overheat. To discharge the bottle from the cockpit, an electrical current is applied to the contactor that detonates an explosive cartridge (commonly called a squib). This shatters a disk located in the bottle outlet. From there the agent flows to the engine.

Figure 20.12 illustrates a twin engine extinguisher system with a cross-feed. A number one engine fire can be extinguished with a number one fire bottle and also number two fire bottle. The same is true for number two engine through the distribution system.

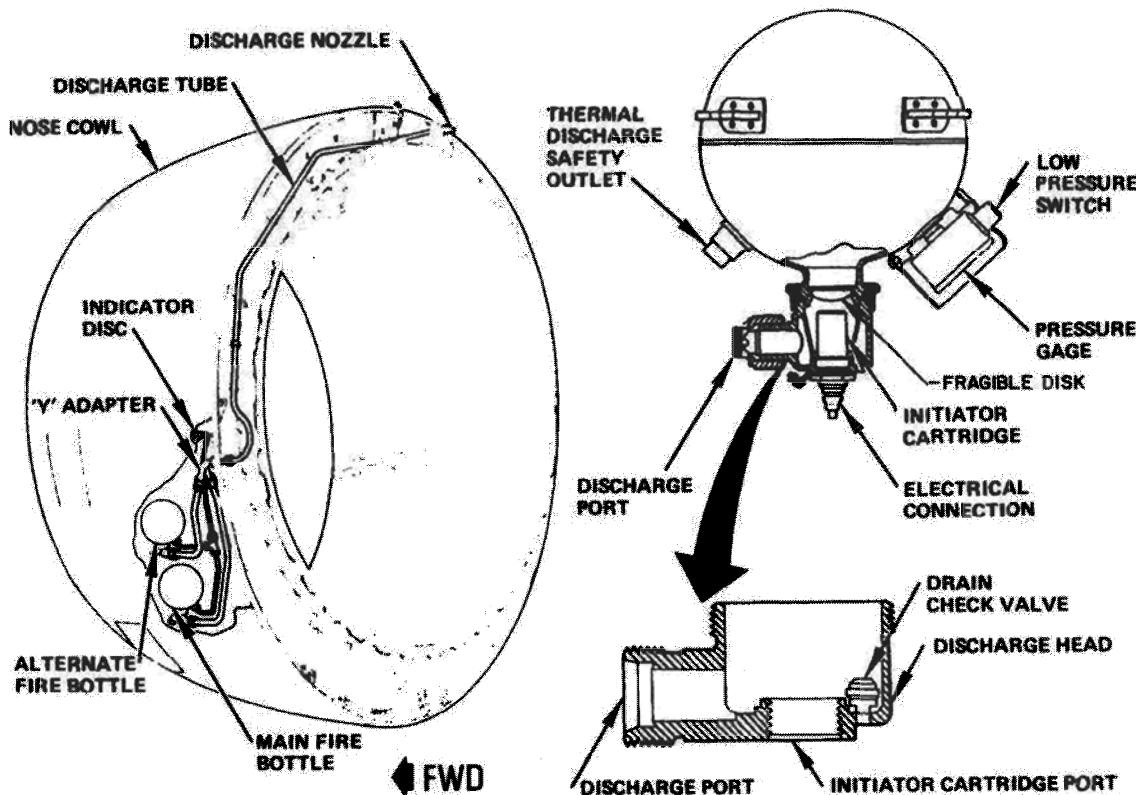


Figure 20.11: Fire extinguisher installation

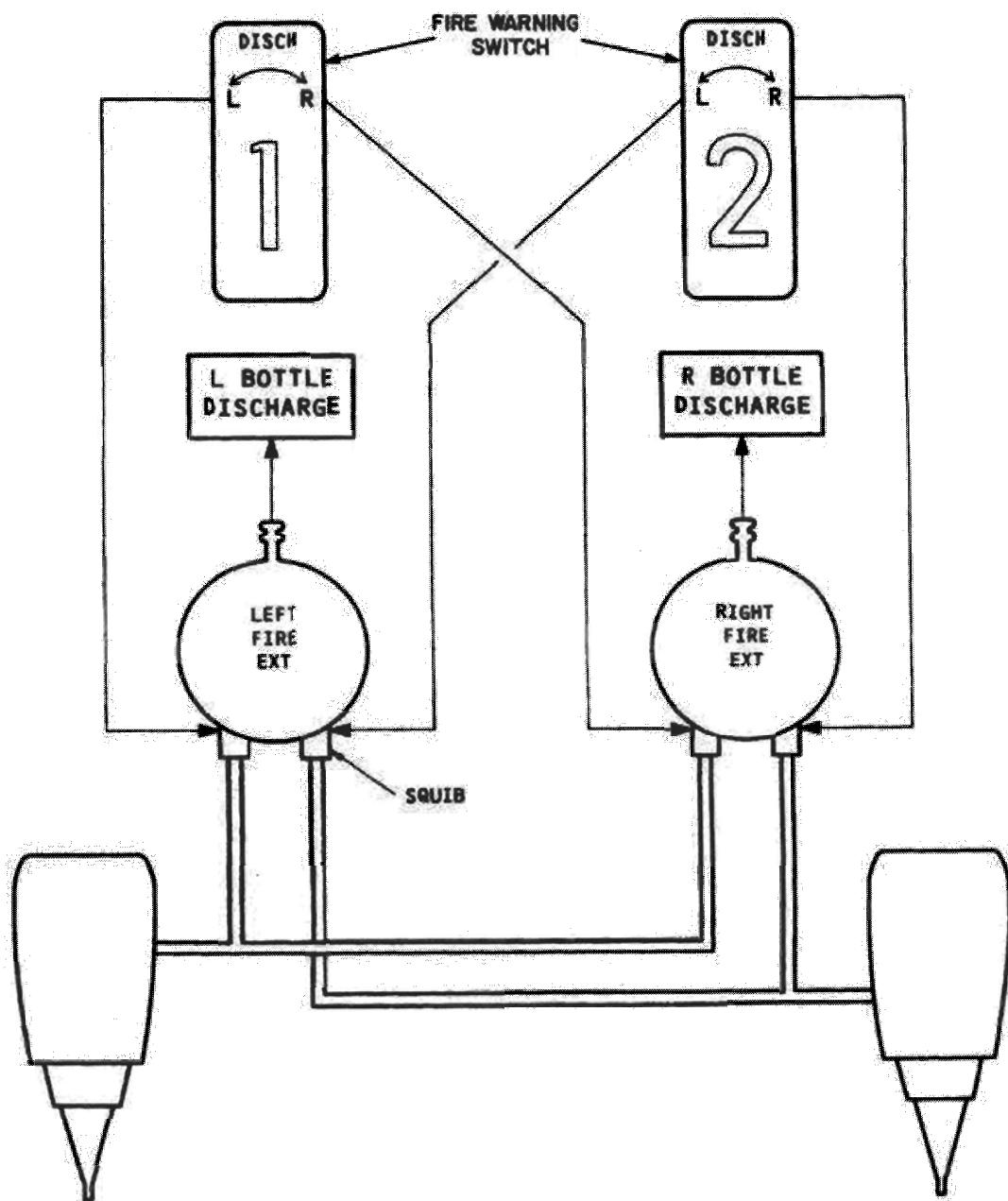


Figure 20.12: Two-shot system



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Common Extinguishing Agents, Approved for Aircraft Use

- **Carbon Dioxide (CO₂)** — The oldest type agent used in aviation. It is non-corrosive to metal parts but can cause shock to hot running parts of the engine if used in great quantity. Extinguishes by dissipating oxygen. CO₂ is considered toxic.
- **Bromochlorodifluoromethane (Halon 1211) (CBrClF₂)** — It is colorless, non-corrosive and evaporates rapidly leaving no residue whatever. It does not freeze or cause cold burns and will not harm fabrics, metals, or other materials it contacts. Halon 1211 acts rapidly on fires by producing a heavy blanketing mist that eliminates air from the fire source, but more importantly interferes chemically with the combustion process. It has outstanding properties in preventing reflash after the fire has been extinguished.
- **Bromotrifluoromethane (Halon 1301) (CF₃Br)** — An expensive nontoxic, non-corrosive agent which is very effective on engine fires. Also considered one of the safest agents from the standpoint of toxicity and corrosion. Halon 1301 has all the characteristics of Halon 1211, and it is less toxic.



Discharge Indicators

In fire extinguisher systems of the fixed type, provision is made for positive indication of extinguisher discharge as a result of either (a) intentional firing, or (b) inadvertent loss of contents, i.e. pressure relief overboard or leakage. The methods adopted are generally mechanical and electrical in operation.

Mechanical Indicators - Mechanical indicators are, in many instances, fitted in the operating heads of extinguishers and take the form of a pin that under normal conditions is flush with the cap of the hollow junction box. When an extinguisher has been fired, and after the charge plug has been forced down the hollow junction box, the spigot of the plug strikes the indicator pin causing it to protrude from the cap, thereby providing a visual indication of extinguishant discharge.

Pressure gauges - In the extinguishers employed in some types of aircraft, mechanical type pressure gauges are embodied in the containers and these serve to indicate extinguishant discharge in terms of pressure changes and, in addition, serve as a maintenance check on leakage.

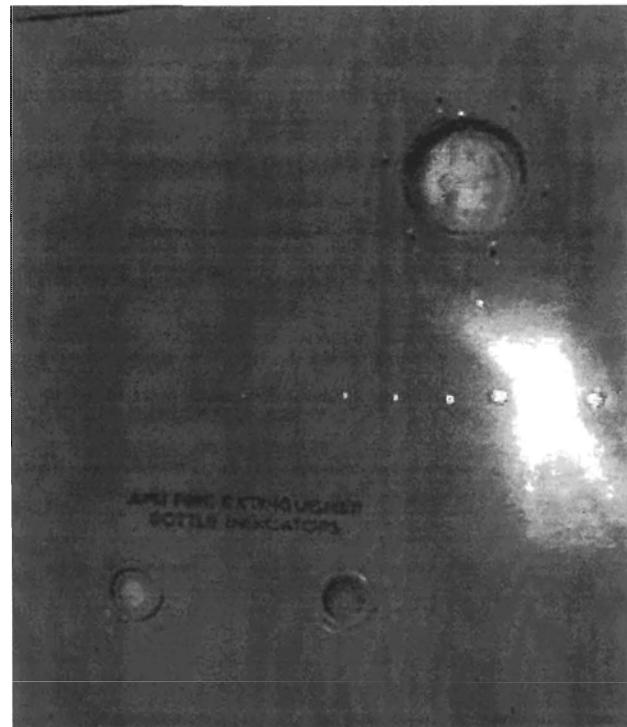


Figure 20.13: Fire extinguisher bottle indicators (B737)

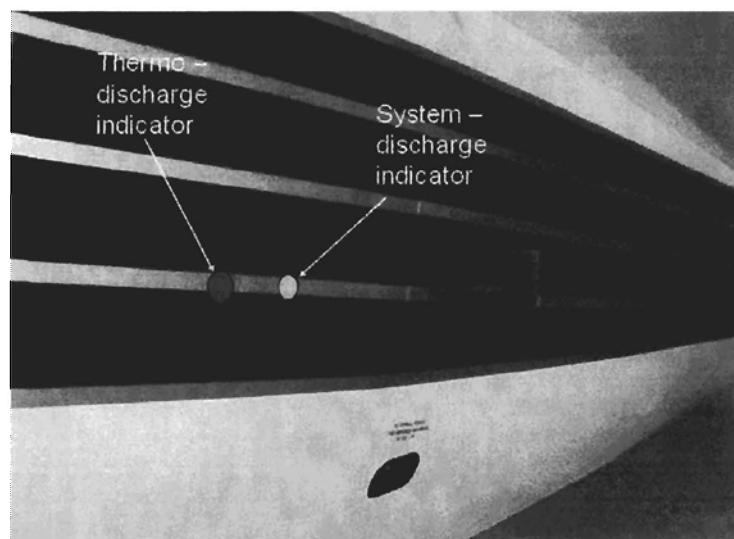


Figure 20.14: Fire extinguisher bottle indicators



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Bursting disc - Protection against bursting of a fire extinguisher as a result of build-up of internal pressure under high ambient temperature conditions, is provided by a disc which fuses at a specific temperature, or a disc which bursts when subjected to bottle over-pressure. The disc is located in the operating head and when operated, the extinguishant discharges overboard through a separate pressure relief line. In order to indicate that discharge has taken place, a disposable plastic, or metal, disc is blown out from a discharge indicator connected to the end of the relief line exposing the red interior of the indicator. Discs are generally coloured red, but in certain types of indicator, green discs are employed. Discharge indicators are mounted in a structural panel, e.g. a nacelle cowling, and in a position which facilitates inspection from outside the aircraft.

NOTE: In some aircraft, indicators of similar construction but incorporating a yellow disc, are provided to indicate discharge by normal firing.

Electrical Indicators Electrical indicators are used in several types of aircraft and consist of indicating fuses, magnetic indicators and warning lights. These are connected in the electrical circuits of each extinguisher so that when the circuits are energized, they provide a positive indication that the appropriate cartridge units have been fired. In some aircraft, pressure switches are mounted on the extinguishers and are connected to indicator lights which come on when the extinguisher pressure reduces to a predetermined value. Pressure switches may also be connected in the discharge lines to indicate actual discharge as opposed to discharge initiation at the extinguishers.

Extinguisher Weight and Pressure Checks

The fully charged weight of an extinguisher should be checked at the periods specified in the approved Maintenance Schedule, and before installation, to verify that no loss of extinguishant has occurred. The weight, including blanking caps and washers, but excluding cartridge units, is normally indicated on the container or operating head. For an extinguisher embodying a discharge indicator switch, the weight of the switch cable assembly is also excluded.

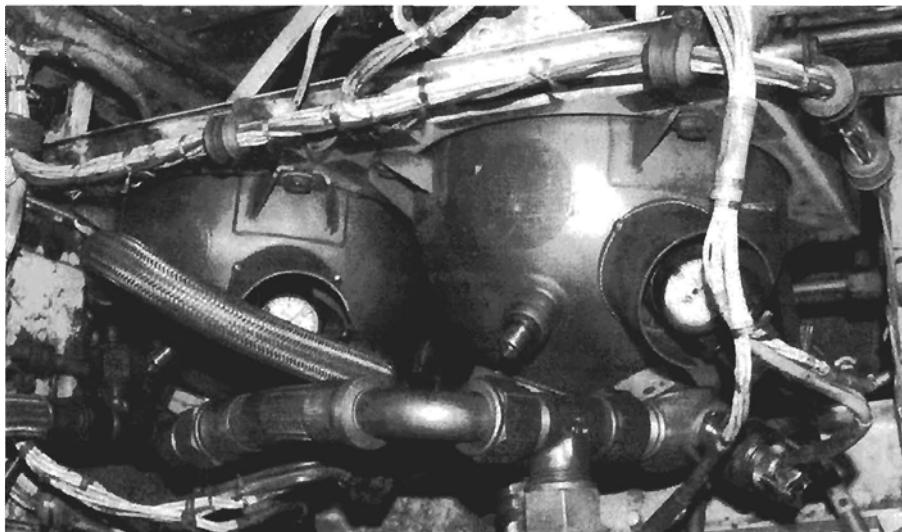


Figure 20.15: Engine fire bottles with pressure gauges (B737 NG)



NOTE: The provision of discharge indicators in fixed extinguisher systems does not alter the requirement for periodic weighing which is normally related to calendar time.

The date of weighing and the weight should, where specified, be recorded on record cards made out for each type of extinguisher, and also on labels for attachment to extinguishers. If the weight of an extinguisher is below the indicated value the extinguisher must be withdrawn from service for recharging.

For extinguishers fitted with pressure gauges, checks must be made to ensure that indicated pressures are within the permissible tolerances relevant to the temperature of the extinguishers. The relationship between pressures and temperatures is normally presented in the form of a graph contained within the appropriate aircraft Maintenance Manuals.

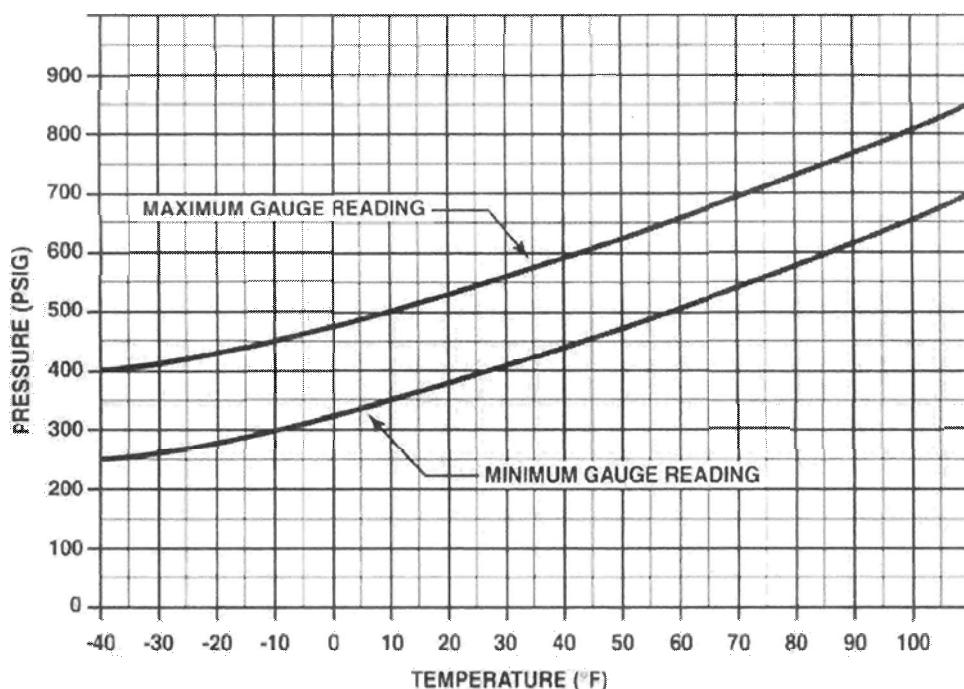


Figure 20.16: A temperature-pressure gauge reading chart

Storage

Extinguishers should be shielded from direct sunlight, stored in an atmosphere free from moisture and corrosive fumes and be located on shelves which allow free circulation of air. Transit caps, sealing plates and transit pins, where appropriate, must remain fitted during storage.

The weights of extinguishers should be checked annually during storage, which, in general, is limited to five years from the date of manufacture or last overhaul. Refer to the appropriate AMM for specific items. At the end of this period, extinguishers must be withdrawn for overhaul.

Cartridge units must be stored in sealed polythene bags in a moisture-free atmosphere and kept away from sources of heat. A label quoting the life expiry date which, in general, is five years from the date of manufacture or last overhaul, should be attached to each bag. If a cartridge unit



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is removed from its bag, the life expiry date is two years from the date of removal, provided the expiry is within the normal five year period.

Defective or time-expired cartridge units must be disposed of in accordance with explosive regulations.

Pipelines

Extinguishants are discharged through a pipeline system which, in general, is comprised of light-alloy pipes outside fire zones and stainless steel rings inside fire zones, which are perforated to provide a spray of extinguishant in the relevant zones. In some cases, extinguishant may be discharged through nozzles instead of spray rings. Flexible fireproof hoses are also used, e.g. between a nacelle firewall and spray rings secured to an engine.

Pipelines are colour coded for left and right engine. As an extra safety precaution there are also different pipe connection sizes to avoid cross connections.



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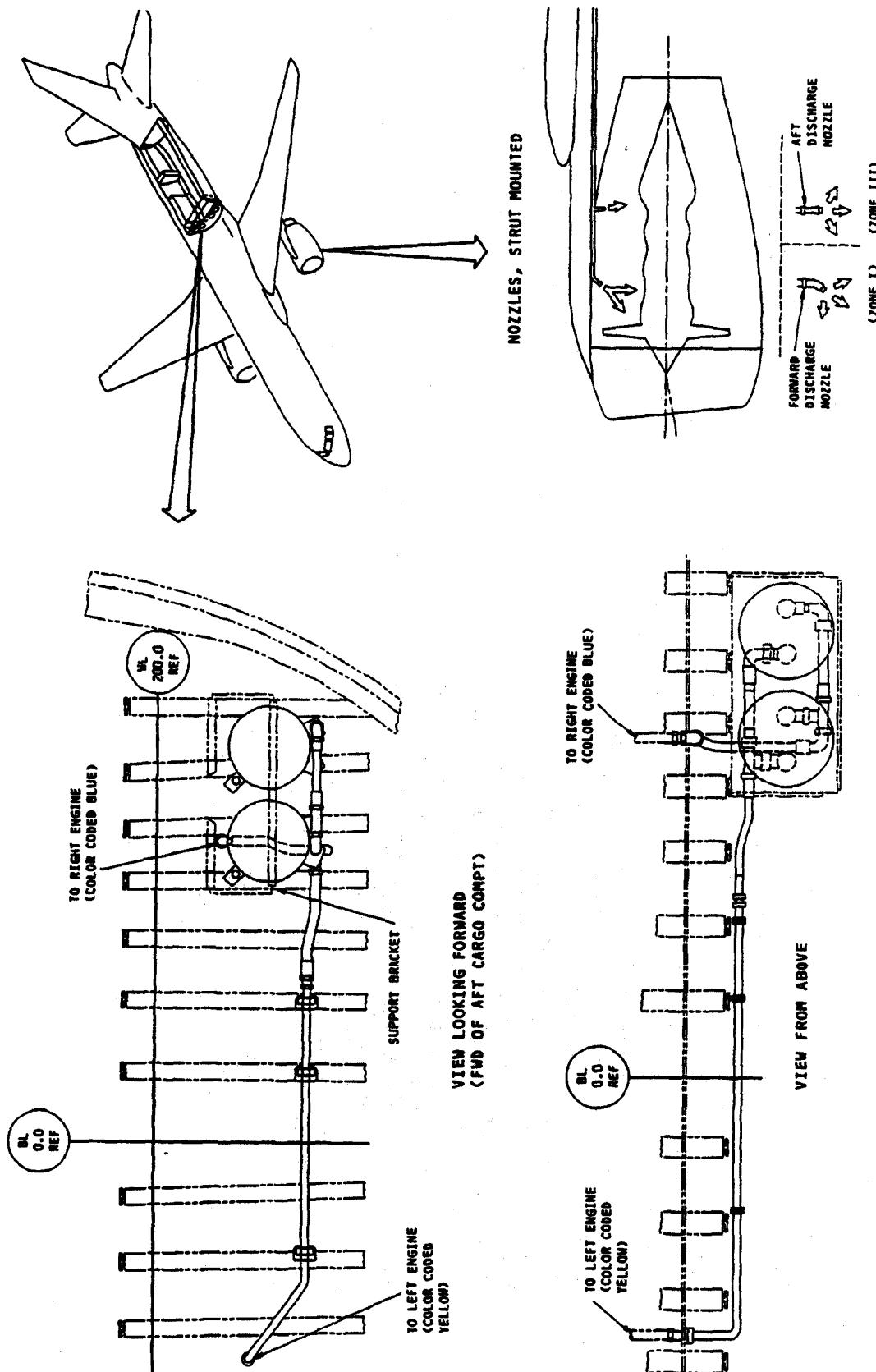


Figure 20.17: Boeing 757 engine fire bottle system



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TTS Integrated Training System

Module 15 Licence Category B1

Gas Turbine Engine

15.21 Engine Monitoring and Ground Operations



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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.21 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.21 - Engine Monitoring and Ground Operation

Ground Running

The life of a turbine engine is affected both by the number of temperature cycles to which it is subjected and by operation in a dusty or polluted atmosphere. Engine running on the ground should therefore be confined to the following occasions:

- After engine installation.
- To confirm a reported engine fault.
- To check an aircraft system.
- To prove an adjustment or component change.
- To prove the engine installation after a period of idleness.

Safety Precautions

Turbine engines ingest large quantities of air and eject gases at high temperature and high velocity, creating danger zones both in front of and behind the aircraft. The extent of these danger zones varies considerably with engine size and location and this information is given in the appropriate aircraft Maintenance Manual. The danger zones should be kept clear of personnel, loose debris and equipment whenever the engines are run. The aircraft should be positioned facing into wind so that the engine intakes and exhausts are over firm concrete with the jet efflux directed away from other aircraft and buildings. Silencers or blast fences should be used whenever possible for runs above idling power. Additional precautions, such as protective steel plates or deflectors, may be required when testing thrust reversers or jet lift engines, in order to prevent ground erosion.

Air intakes and jet pipes should be inspected for loose articles and debris before starting the engine and the aircraft main wheels chocked fore and aft. It may be necessary to tether vertical lift aircraft if a high power check is to be carried out.

Usually on large aircraft one member of the ground crew is stationed outside the aircraft and provided with a radio headset connected to the aircraft intercom system. This crew member is in direct communication with the flight deck and able to provide information and if necessary warnings on situations not visible from inside the aircraft. Due to the high noise level of turbine engines running at maximum power it is advisable for other ground crew members to wear ear muffs.

A suitable CO₂ or foam fire extinguisher must be located adjacent to the engine during all ground runs. The aircraft fire extinguishing system should only be used in the event of a fire in an engine which is fully cowled.

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Engine Preparation

It is usually not necessary to increase the temperature of a jet engine before you start it during cold weather operation. The normal engine starting procedure will usually be adequate.

Before you start the engine:

- Make sure the N1 rotor turns freely.
- Do a visual check for damage or ice on the fan inlet, fan blades, fan spinner, inlet temperature sensors, fan duct, and external cowl surfaces.
- If snow or ice holds the fan cowl panels, core cowl panels, or thrust reverser closed, apply heat as necessary to remove the snow and ice. Remove all melted snow and ice before you open the cowl panels.
- If ice has collected on the acoustic panels in the inlet cowl, or the fan and turbine exhaust ducts, apply heat to remove the ice.
- If there is ice in the sumps and strainers of the fuel system, apply heat to the drain area until the water has been removed.
- Make sure that all parts, tools, equipment and loose objects are removed from the engine air intake and the area around the intake. (Are all panels secure)
- Do a visual check of the core exhaust (LPT), exhaust duct, and exhaust nozzle for damage and unwanted material.
- Do a check of the drain ports for fuel, oil and hydraulic leaks. Also make sure that fuel drained from the engine does not cause a fire.
- Make sure that fire-fighting persons and/or equipment are present.
- Make sure that the parking brake is set to the on position.
- The landing-gear control-lever is in the DOWN position.
- The aircraft wheels should be chocked and all controls set according to the operations manual.
- Check that the aircraft is cleared of unnecessary persons and that there are no persons in the dangerous areas.

In the event that the ground personnel are required to carry out inspections or adjustment ensure that they are correctly briefed and have the tool to do the job.

Ensure that restrictions on ground running with certain cowlings open are adhered to.



Starting

There are many different types of turbine engine starters and starting systems, therefore it is not possible to give a sequence of operations exactly suited to all aircraft. The main requirements for starting are detailed in the following paragraphs.

Particular attention should be paid to the positioning of the aircraft and its ground support equipment (GSE). The aircraft should be facing into wind and securely chocked (possibly with the front and rear chocks tied together). The visual and free movement of both compressor and turbine should be checked, and the engine air intake examined for loose articles. The areas to the front and rear of the aircraft should be checked for loose articles and spilt fuel, which could cause a hazard to the aircraft during the run.

The technical log must be checked to ensure that no outstanding entries will jeopardise the operation or function of other aircraft systems. Other entries may require functional checks to be carried during the ground run, which may also require involvement in the run of other tradesmen. Ground support equipment should be positioned to ensure their safe operation and movement, if required, during the start and run.

Prior to starting the engines all personnel involved must be made aware of their responsibilities and role during the run. If hand signals are to be used (figure 21.1.) they should be agreed and understood by all concerned. All personnel outside the aircraft must wear ear-defenders, if possible one or more of the external team should have an intercom headset for direct communication with those inside.

The person(s) operating the controls during starting and running must be familiar with the controls, instruments and limitations associated with the engines. In particular they should be aware of the limitations imposed upon the engines turbine temperature during start.

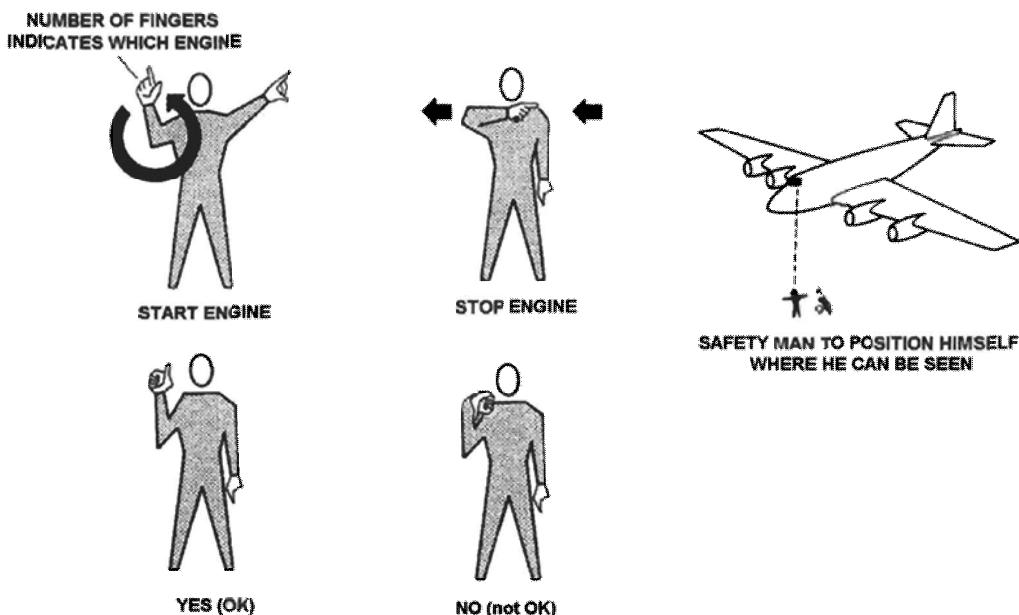


Figure 21.1: Commonly used hand signals for ground running



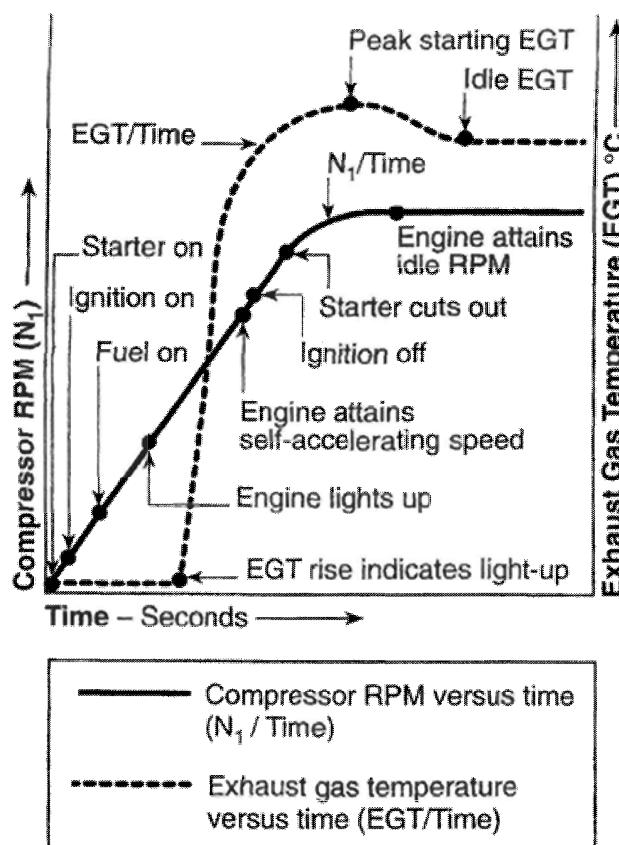
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An external electrical power supply is often required and should be connected before starting. Where a ground/flight switch is provided this must be set to 'ground' and all warning lights checked for correct operation.

Where an air supply is required for starting this should be connected and the pressure checked as being sufficient to ensure a start. If the electrical and air supplies are not adequate for starting purposes it is possible for a light-up to occur at insufficient speed for the engine to accelerate under its own power. This could result in excessive turbine temperatures and damage to the engine.

The controls and switches should be set for engine starting, a check made to ensure that the area both in front of and behind the engine is clear and the starter engaged. When turbine rotation becomes apparent the HP cock should be opened and the engine instruments monitored to ensure that the starting cycle is normal. When light-up occurs and the engine begins to accelerate under its own power, switch off the starter. If it appears from the rate of increase in exhaust or turbine gas temperature that starting limits will be exceeded the HP cock should be closed immediately and the cause investigated.



Once engine speed has stabilized at idling, a check should be made that all warning lights are out, the external power supplies disconnected and the ground/flight switch moved to 'flight'.



Testing

When a new engine has been installed a full ground test is necessary, but on other occasions only those parts of the test necessary to satisfy the purpose of the run need be carried out. The test should be as brief as possible and for this reason the aircraft Maintenance Manual specifies a sequence of operations which should always be observed. Records of the instrument readings obtained during each test should be kept to provide a basis for comparison when future engine runs become necessary.

Each aircraft system associated with engine operation should be operated and any warning devices or indicators in the cockpit checked against physical functioning. It may be necessary in certain atmospheric conditions to select engine anti-icing throughout the run and this should be ascertained from the minimum conditions quoted in the Maintenance Manual. Icing conditions are deemed to exist at less than +10°C with visible moisture.

The particular tests related to engine operation are idling speed, maximum speed, acceleration, and function of any compressor airflow controls which may be fitted. Adjustments to correct slight errors in engine operation are provided on the engine fuel pump, flow control unit, and airflow control units. Observed results of the tests must be corrected for ambient pressure and temperature, tables or graphs being provided for this purpose in the aircraft Maintenance Manual. Adjustments may usually be carried out with the engine idling unless it is necessary to disconnect a control. In this case the engine must be stopped and a duplicate inspection of the control carried out before starting it again. An entry must be made in the engine log book quoting any adjustments made and the ambient conditions at the time.

Stopping

After completion of the engine run the engine should be idled until temperatures stabilize and then the HP cock closed. The time taken for the engine to stop should be noted and compared with previous times, due allowance being made for wind velocity (e.g. a strong head wind will appreciably increase the run-down time). During the run-down fuel should be discharged from certain fuel component drains and this should be confirmed. A blocked drain pipe must be rectified. When the engine has stopped, all controls and switches used for the run must be turned off and the engine inspected for fuel, oil, fluid and gas leaks.

After a new engine has been tested the oil filters should be removed and inspected and after refitting these items the system should be replenished as necessary.



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Hazard Areas

General

Because aircrafts are equipped with engines of different power, it is impossible to make a rule. The only rule that can be made is: Never stay behind a running engine! The diagram on page 5 shows the hazard areas around operating turbojet engines. Pay particular attention to the area in front of the aircraft. Before starting the engine, check the area ahead of the inlet duct for loose objects that could possibly be ingested when the engine sucks in the tremendous amount of air that flows through it when it is operating. Rocks and loose bits of concrete can cause expensive damage. No one should approach within about 20-m of an inlet duct when the engine is operating in idle power, because the low-pressure area ahead of the engine is strong enough that a person could be sucked into the engine. For inspection purposes you can approach the engine through an entry corridor as shown in the following illustration.

If the engine operates above idle power, keep away from the engine in a safe distance.

At some time, when the engine is started, fuel which has not been burned in the combustion chamber can ignite in the exhaust area. This can cause long flames to blow out of the exhaust nozzle.

In the following example, keep in mind that distances and values vary from type to type.



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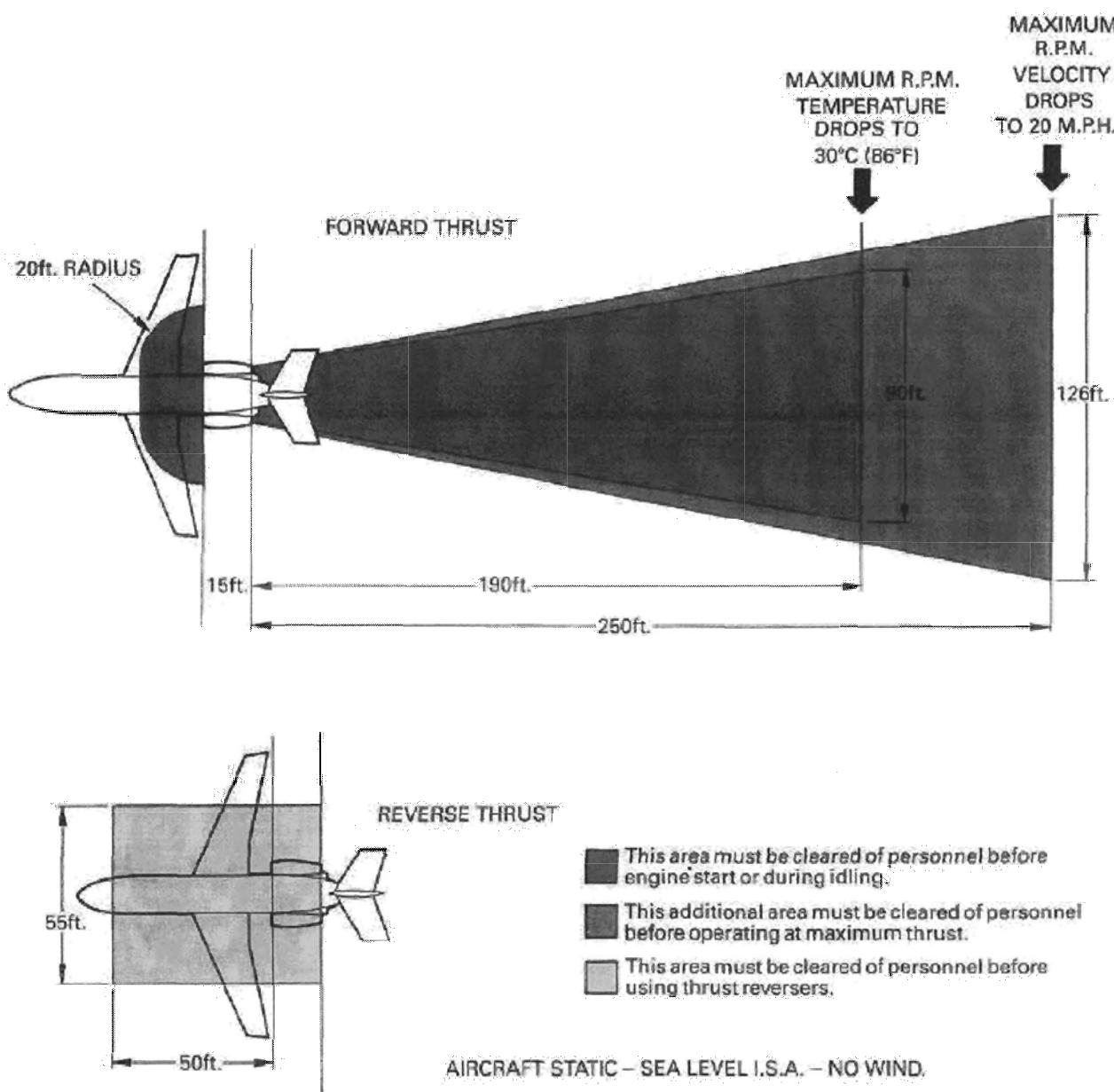


Figure 21.3: Fokker 100 Aircraft showing the engine running danger areas at idle and full power and during reverse thrust



Using the Thrust Reverser

The thrust reverser is usually used after the aircraft lands during roll out. It is possible (not recommended) to operate the thrust reverser at idle power when the aircraft is parked for test purposes. When the thrust reverser operates, the fan discharge air blows out the sides of the engine towards the front of the aircraft. Be aware of the extended hazard area in front of the engines as shown in the following illustration.

The reverse thrust air can go into the engine again with unwanted objects (from the ground) and cause gas path damage and a stall.

Wind Direction

Wind direction and velocity can change the stability of the engine. Where possible, the engine must be operated with the intake pointed into the wind as specified.

The wind velocities shown are for constant wind conditions only. You must reduce the maximum wind velocity limits shown for gusty wind velocities. Stop the test if the engine EPR or N1 speed are not stable. Stop the test if, at steady state, the inlet noise increases or changes to a blow torch sound or if vibration increases. To get information about wind speed and direction, contact the local meteorological office. You can find VHF frequencies on the airport approach or departure map.



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Turbine Engine Maintenance

The fundamental inspection of engine inlets, exhaust, and other exterior areas of built up engines is to visually look for tell-tale signs of air, fuel, and oil leaks and items that are loose, chafed, broken, or otherwise damaged.

Turbine engines have few moving parts that wear, and they are built in modules that can be exchanged without having to remove the engine from the aircraft.

Operating hours are not the only criteria used to determine when an overhaul is needed. Operating cycles are also important. One operating cycle consists of starting the engine, taking off, landing, and shutting the engine down. Engines installed on commuter airliners that make many short-duration flights will need to be overhauled with fewer total hours than engines on aircraft whose flights are all of long-duration.

On-Condition Maintenance

Turbine engines are not necessarily removed from the aircraft and overhauled when a specified number of operating hours or operating cycles have been-reached. Some engines are maintained according to an on-condition maintenance program.

On-condition maintenance is described in detail in the operations manual for the particular engine. It consists primarily of monitoring the engine performance at regular intervals and determining when maintenance is required, based on the deterioration of certain operating parameters.

Trend Monitoring

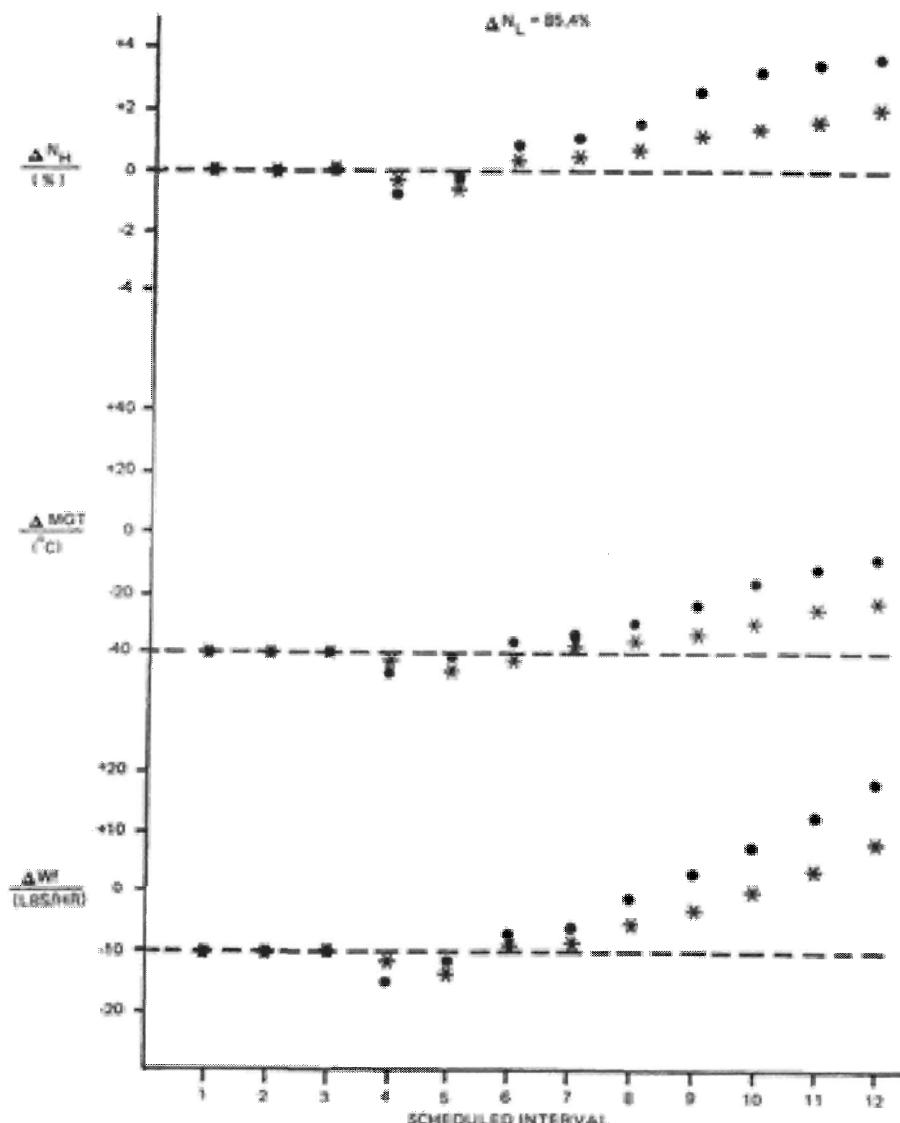
Trend monitoring is a system of routine comparison of engine performance parameters with a base line of these same parameters established when the engine was new or newly overhauled.

Graphs or curves are used to show trends in changing conditions, and trend monitoring curves reveal much about the internal condition of a gas turbine engine. The engine manufacturer or overhauler collects several datas such as N1, N2, EGT, fuel flow etc. when the engine is run in the test cell. This data is reduced to standard day conditions and used to create a series of standard reference baselines. Routinely, checks are made to compare the current performance of the engine with its test-cell performance. The same parameters are measured and reduced to standard day conditions, and the differences between the original and the new readings are plotted on a graph. One or two deviations from the baseline do not necessarily indicate an abnormal condition, but when the deviations in all the parameters are plotted over a number of operating hours or a given period of time, trends become apparent. These trends, when properly interpreted, are important maintenance tools that warn of impending problems before they could be detected by any other method.



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----- = Reference Baseline (Based on first 10 λ of new engine)

λ = N_L , MGT , W = Actual deltas

ζ = Average Deltas (Average of last 10 λ)

Figure 21.4: A trend analysis output



Aircraft Data Acquisition

The ADAS Aircraft Data Acquisition System is used to analyze flight crew performance as well as to monitor the aircraft systems and the health and condition of aircraft engines. Do not confuse the ADAS system with the DFDR (Digital Flight Data Recorder) or CVR (Cockpit Voice Recorder). The DFDR and CVR are mandatory recorders where the ADAS is an optional system.

Many hundreds or thousands of parameters are recorded during flight or during ground run-up. These data are usually stored on a mass storage device such as optical discs or magnetic tapes. The stored data are evaluated by using analysis programs. With such programs it is possible to visualize the data and plot graphical charts for better understanding.

With modern systems, parameter Exceedance events can be transmitted to the maintenance organization via ACARS (VHF/Satcom) transmission. Exceedance events are instances where the actual aircraft parameter exceeds what is recommended for a particular phase of flight. The maintenance organization is therefore in the position to monitor the aircraft in flight and if necessary, to prepare a maintenance action before the aircraft reaches its destination.

The following graphic shows the visualization of the vibration parameter of an engine.

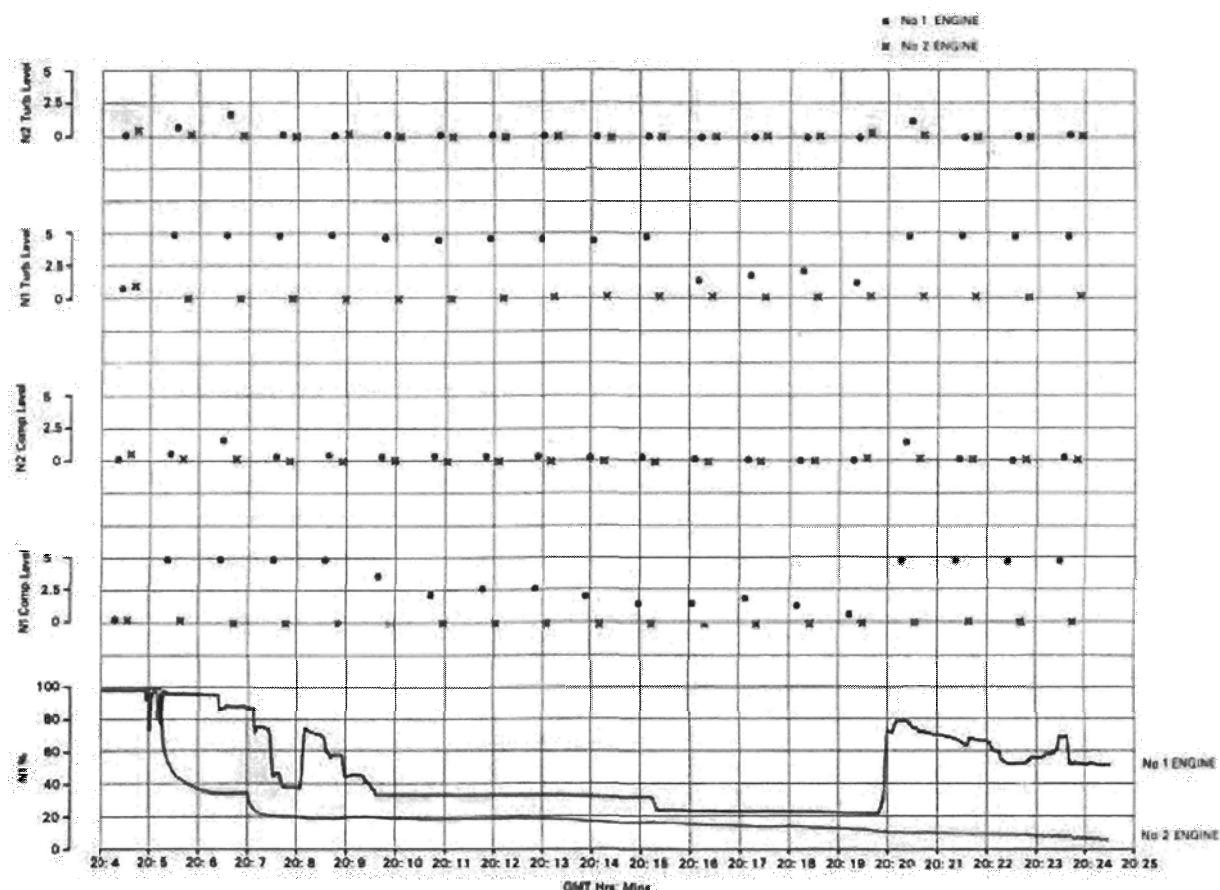


Figure 21.5: Vibration monitoring graph



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Special Inspections

Special Inspections are called for after certain incidents the following list is an example only.
The AMM is the only reference

Bird Strike

- Fan Visual Inspection
- Boroscope Inspection
- Vibration Survey

Engine Surge

- Fan Visual Inspection
- Boroscope Inspection
- Vibration Survey
- Full Power Check

Over Temping and Over Speeding

- The extent of the inspection will depend on the degree of exceedance. Ultimately an engine will be replaced for overhaul.
- Hot end inspection for damage and heat distress.
- Hot end inspection for damage and heat distress.

Heavy Landing

- Check engine controls for freedom of movement
- Examine mountings and pylons for damage and distortion
- Check freedom of rotation of rotating assemblies
- Examine cowlings for wrinkling, distortion and integrity of fasteners
- Check for oil fuel and hydraulic leaks
- Check Propeller shafts for shock loading IAW AMM
- Check oil system filters and MCDs
- Carry out engine run- check for leaks and on shutdown run down time.

Lightning Strikes

Examine engine and cowlings for signs of burning or pitting. If a lightning strike is evident tracking through the bearings may have occurred and oil filters and MCDs should be monitored for a specific number of running hours after the occurrence.



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Engine Gas Path Washing

The gradual accumulation of dirt and contaminants on the rotor and stator blades of a compressor will change the shape of and thus reduce the efficiency of each blade affected. Engine performance is thereby adversely affected.

All sorts of airborne contaminants pass through the engine. They could be dust from the airport taxiways, airborne pollution such as soot or smoke particles, salt or chemical emissions from industry. These contaminants will build up on the internal surfaces of an engine over a period of time.

Procedure

There are two recommended procedures to clean the engine gas path:

- pure water (without cleaning agent) for engine EGT recovery.
- a mixture of water and a cleaning solution for organic debris and oil deposits removal.

A gas path washing procedure could look as follows:

Always refer to the aircraft maintenance manual for the valid procedure.

- Dry motor the engine for two minutes while you inject water 360 degrees around the LPC inlet, through the fan blades.
- Let the engine soak for 5 minutes.
- Dry motor the engine again for two minutes, while you inject water 360 degrees around the LPC inlet, through the fan blades.
- Let the engine soak for 5 minutes.
- Dry motor the engine again for two minutes.
- During the first minute only, inject water 360 degrees around the LPC inlet, through the fan blades. The engine must be started within 30 minutes of the last wash cycle to purge the lube and sump system of any water ingestion.

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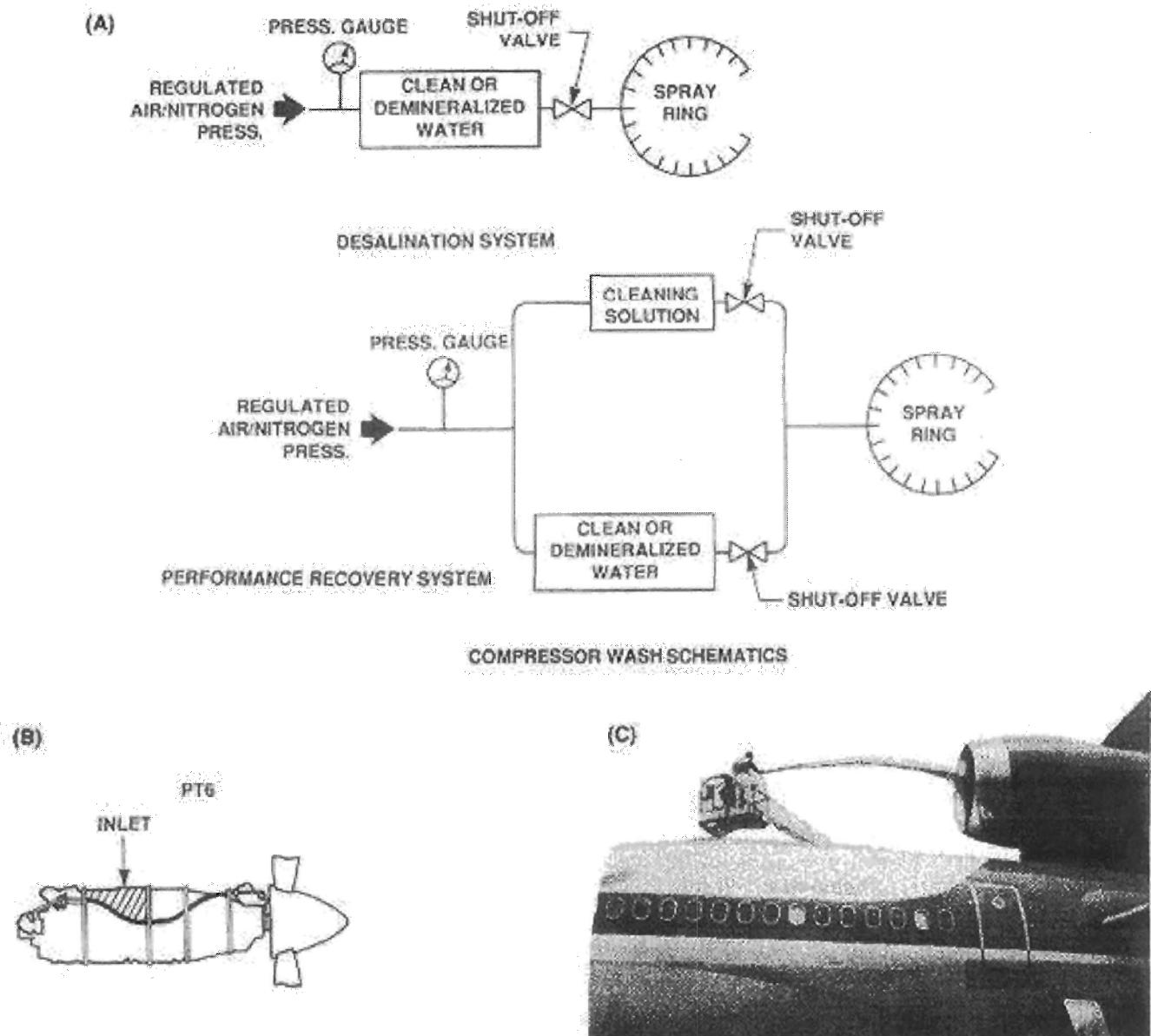
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(A)—Compressor wash schematics of the PT-6 for desalination and power recovery washes.

(B)—Water is Introduced into engine inlet. (C)—Large engine compressor wash.

Figure 21.13: Fluid cleaning

Water Properties

Do not use water with more than 100 parts per million total solids, water with more than 25 parts per million sodium plus potassium (Na + K), and with a pH of 6.8 - 8.0. Potable water usually meets these requirements.

Hot water of 60°C up to 90°C is more effective for cleaning.



Anti-freeze Mixtures

Anti-freeze mixtures must be used at temperatures below 50°C. Mixtures can be prepared as follows:

For temperatures of 50°C to -50°C, mix 25 percent of isopropyl alcohol to 75 percent of water.

For temperatures of -50°C to -10°C, mix 35 percent of isopropyl alcohol to 65 percent of water.

Do not wash the engine gas path at temperatures below -10°C.

Abrasive Grit

This method of cleaning involves injecting an abrasive grit into the engine at selected power settings (Figure 21.15) grit used may be ground walnut shell or apricot pits. The type and amount of material and the operational procedures will be described in the AMM. The main advantage of this procedure is that allows the time between cleaning to be extended because it produces a better result. However because the grit is mostly burned up in the combustion zone of the engine, it will not give an effective cleaning of the turbine blades and vanes as the fluid.

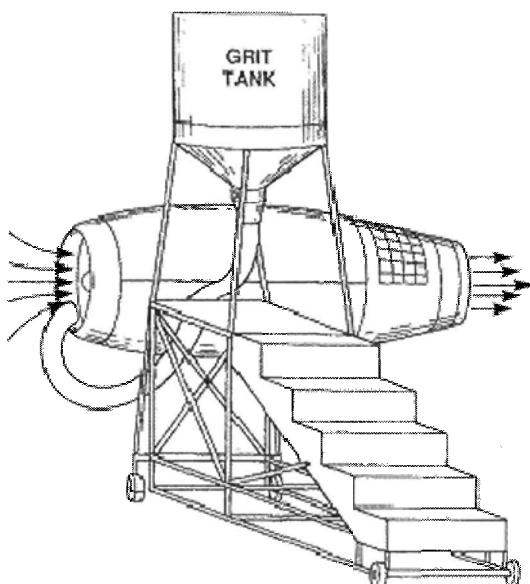


Figure 21.15: Abrasive grit compressor cleaning



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Oil Analysis

The oil analysis program for a turbine engine consists of the same two areas used for reciprocating engines: spectrometric analysis of the oil and an evaluation of the contents of the filter element. The laboratories used for the oil analysis program should be approved by the engine manufacturer. This assures recognition of any abnormal growth trends of a particular metal in the oil. The kit furnished by the lab includes containers for the oil taken from the oil tank and from the filter element, instructions for taking the samples, and forms for recording the results of the tests.

Normally, the sample of oil should be taken shortly after the engine has been run. A tube is inserted into the oil tank to get a sample of oil from the middle of the tank, and this oil is placed in the sample bottle furnished in the kit. The filter is back-flushed to remove entrapped metal particles, and any that are found are examined to determine where they came from. The sample sent to the laboratory must be identified with the type and serial number of the aircraft and engine, the number of hours on the filter since the last oil change, the number of hours since the last sample was taken, and the amount of oil added since the last sample. This information allows the laboratory to make a meaningful analysis of the engines gears, bearings and of course the oil itself.

Oil Filter Debris Analysis

Oil filters serve an important function within the lubrication system of a gas turbine engine in that they remove foreign particles that collect in the oil system. Filters are removed at regular intervals for cleaning, any particles present can then be analysed visually. If visual inspection reveals evidence of excessive debris this can be more accurately analysed via 'spectrometric analysis'.

Spectrometric Oil Analysis Programme (SOAP)

Under certain conditions and within certain limitations, the internal condition of any mechanical system can be evaluated by the spectrometric analysis of the lubricating oil. The components of mechanical systems contain aluminium, iron, chromium, silver, copper, tin magnesium, lead and nickel as the predominant alloying elements. The moving contact between metallic components will, despite lubrication create wear, the debris resulting from this wear being carried away by the lubricating oil. If the rate of wear of each kind of metal can be measured and be established as normal or abnormal, the rate of wear of the contacting surfaces will also be established as normal or abnormal.

At specified intervals samples of oil are removed from the engine for analysis. Spectrometric analysis is possible because metallic ions emit characteristic light spectra when vaporised in an electric arc or spark. The spectrum produced by each metal is unique to that particular metal and, the intensity of the light can be used to measure the quantity of metal in the sample. Again, information gained could be transferred onto a graph to show evidence of normal/abnormal trends.

In this process the oil is burnt which will also show on the analysis, but is ignored as a known substance. If we suspect that some or all of our fleet may have been contaminated by an



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incorrect oil, it is possible to sample the fleet using spectrometric analysis, to determine which components have the wrong oil in.

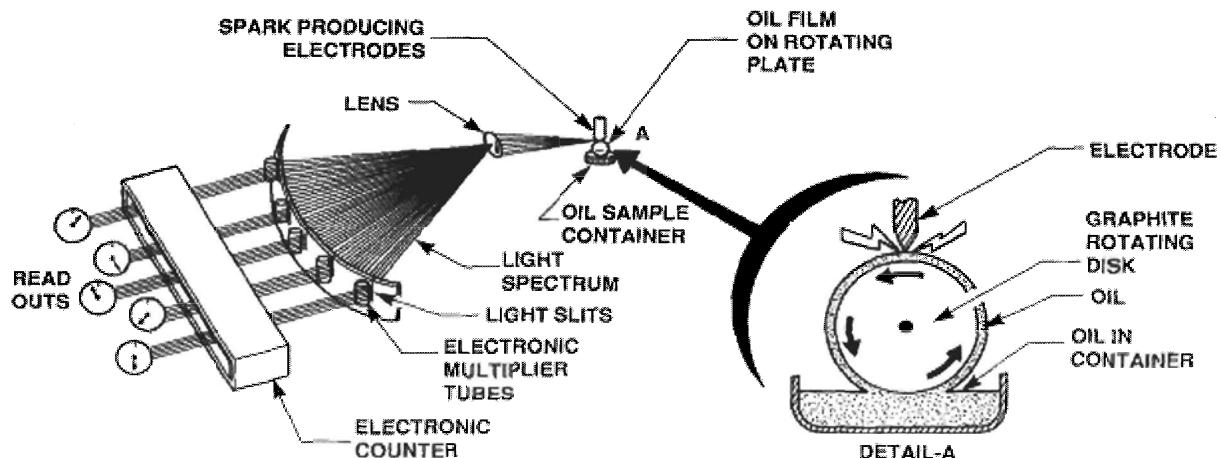


Figure 21.14: Spectrometric Oil Analysis Programme (SOAP)

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Engine Component Inspection

Boroscope Inspection

As mentioned before, turbine engines are designed for efficient maintenance with as little downtime as possible. One procedure that has improved efficiency is the built-in provision for inspecting the inside of the engine without disassembling it. This is done with a borescope or with one of its modern counterparts.

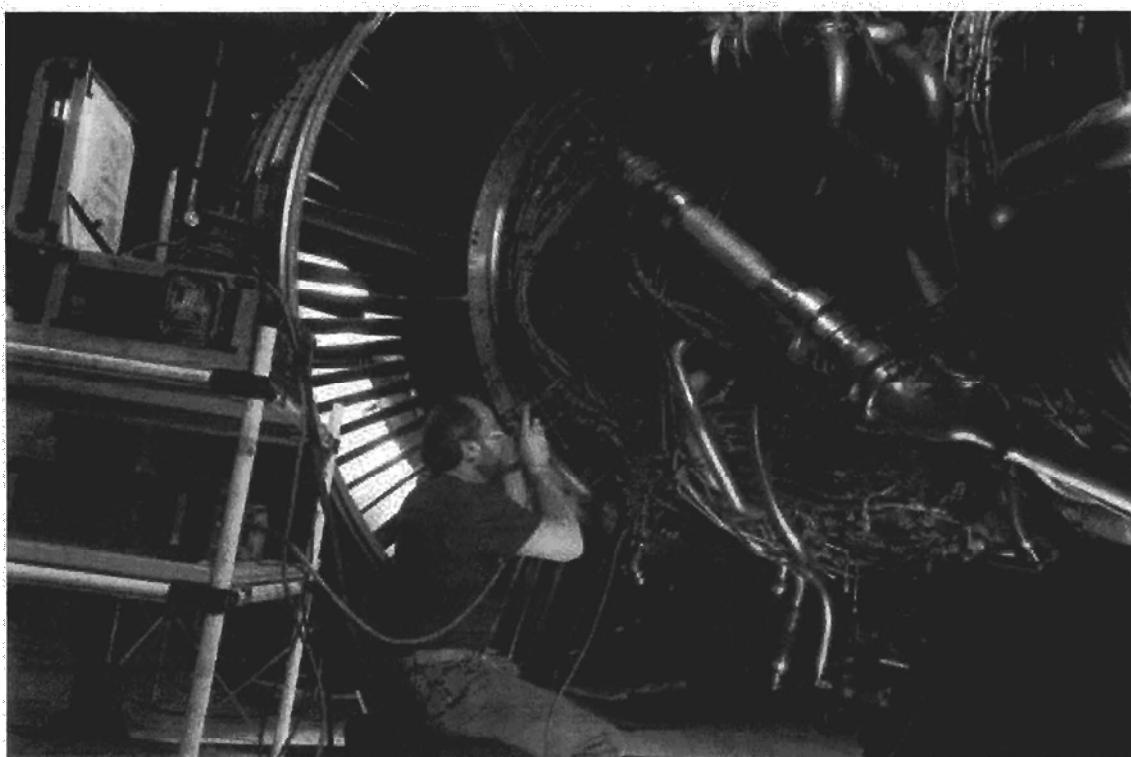


Figure 21.6: A borescope inspection

In recent years, boroscoping of inner parts of the engine has become another valuable inspection technique. The viewing eyepiece shown is lighted, capable of magnification, and is adaptable to photography.

It has long been the practice when inspecting reciprocating engines to disassemble them and examine the component parts. As engine output increased over the years, the susceptibility to detonation became a serious problem, and borescope inspection of the inside of installed cylinders becoming important maintenance tool. Turbine engines are lightweight for the amount of power or thrust they produce and are expensive to disassemble. Because of this, engine manufacturers have placed borescope ports at strategic locations, so that technicians can examine critical internal areas without disassembling the engine.



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There are three types of internal visual inspection instruments commonly used in turbine engine maintenance:

- rigid-tube scope
- flexible fiber optic scope
- video-imaging scope

Rigid-tube Scope

A rigid-tube borescope can be inserted into the engine through an inspection port, and a controllable power source allows you to regulate the intensity of the light produced by the lamp at the end of the scope tube. Insert the tube into the appropriate port and adjust the light. Aim the instrument at the area to be inspected and focus to get the sharpest image. Flexible-tube fiber optic scopes are more versatile than the rigid-tube scope.

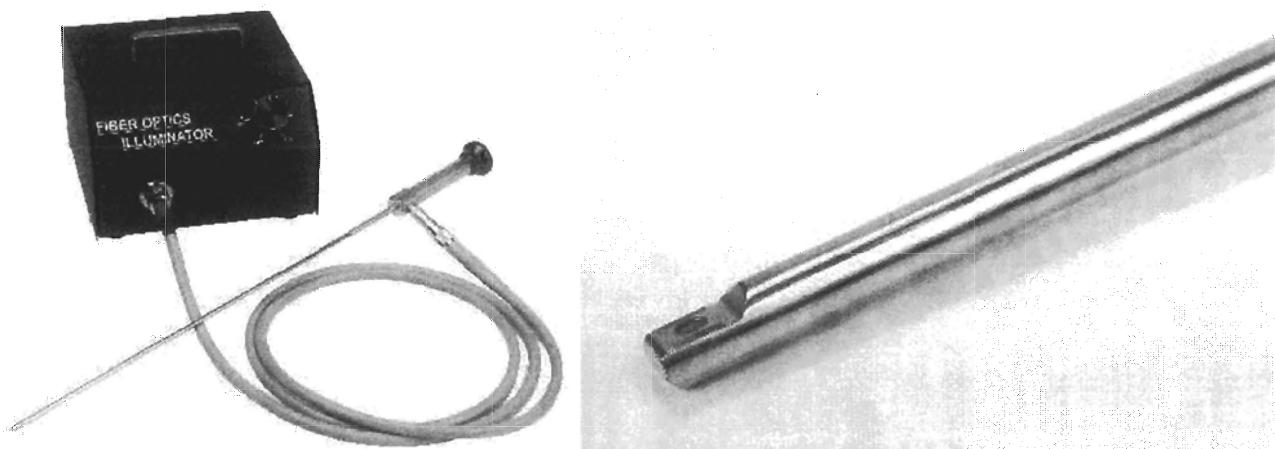


Figure 21.7: Rigid boroscope

Flexible Fiber-optic Scope

These instruments consist of a light guide and an image guide made of bundles of optical fibres enclosed inside a protective sheath. A power supply with a controllable light source is connected to the light guide, and an eyepiece lens is situated so it can view the end of the image guide.

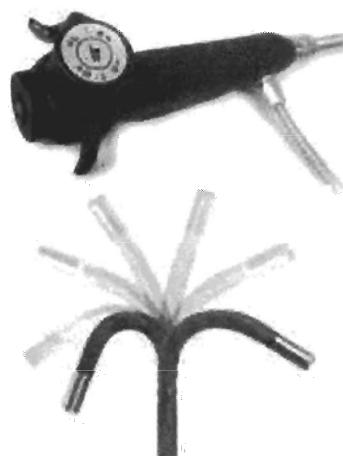
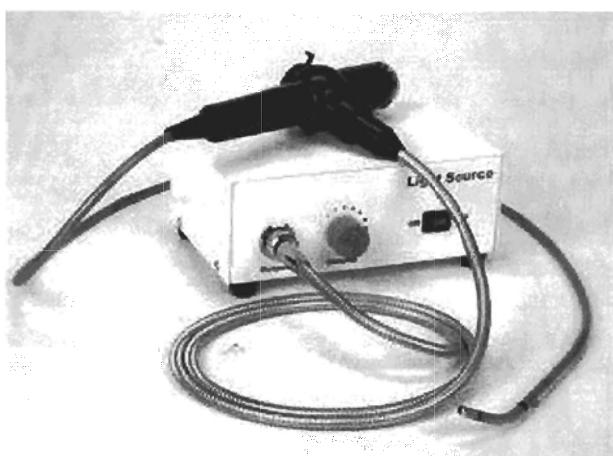


Figure 21.8: Flexible boroscope



Bending and focusing controls on the instrument housing allow you to guide the probe inside the engine and focus to get the clearest image of the area. Adapters are normally included that allow attachment of a still or video camera to the eyepiece, providing a permanent record of the interior of the engine.

Video Imaging Scope

The probe is inserted into the engine through one of the inspection ports, and the tip is guided to the area to be inspected. The sensor in the tip of the probe acts as a miniature camera and picks up an image of the area illuminated by the probe. This image is digitized, enhanced, and displayed on a video monitor. It can also be recorded on video tape.



Figure 21.9: Video Monitor and Video Recorder



Figure 21.10: Typical images from a borescope inspection

Boroscope Ports

Boroscope ports are located at strategic points around the engine. To turn the HP compressor it is normally necessary to connect an adapter to the High Speed (auxiliary) gear box, and using a ratchet rotate the gear box and hence the HP compressor. In this manner a complete stage of rotors can be inspected from a single position.



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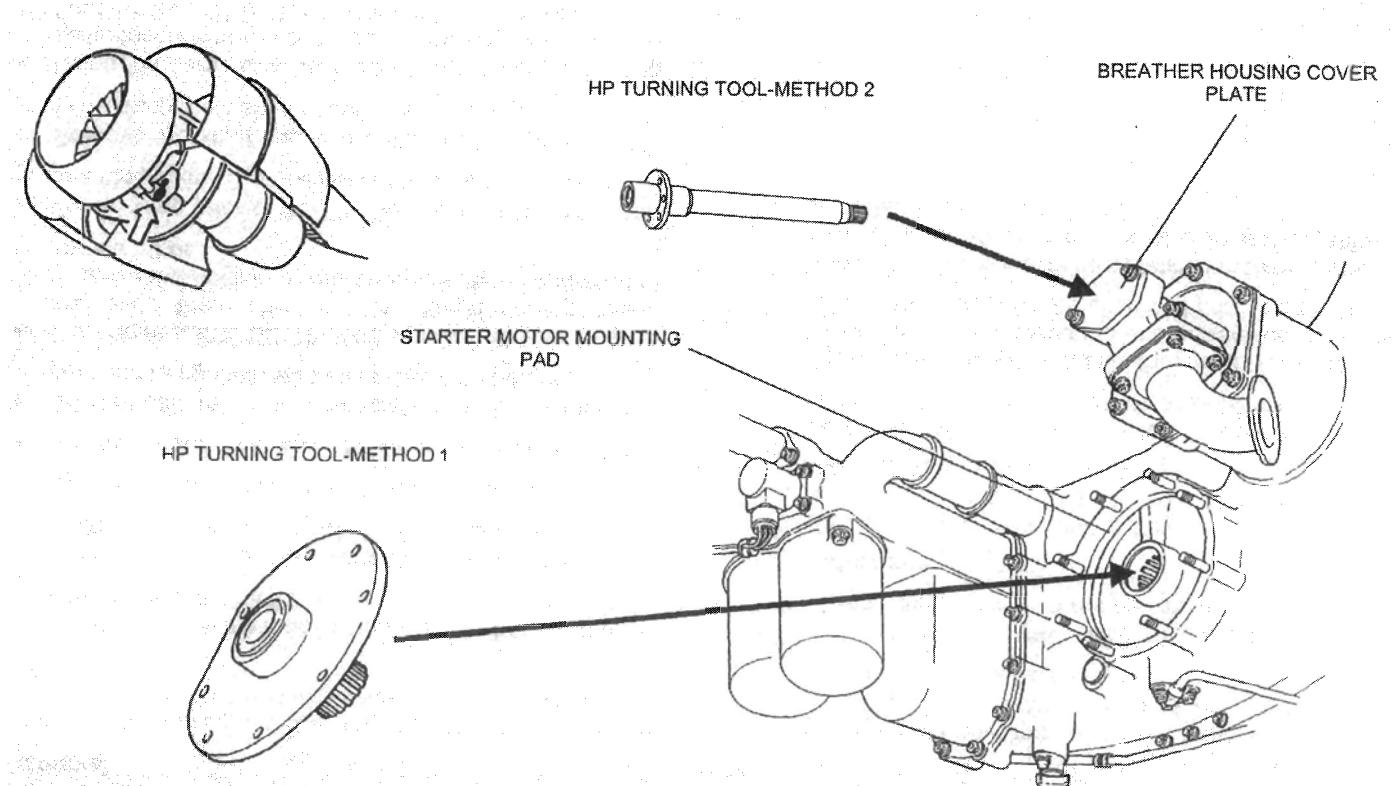


Figure 21.11: RB211-535 E4 – HP system hand turning points

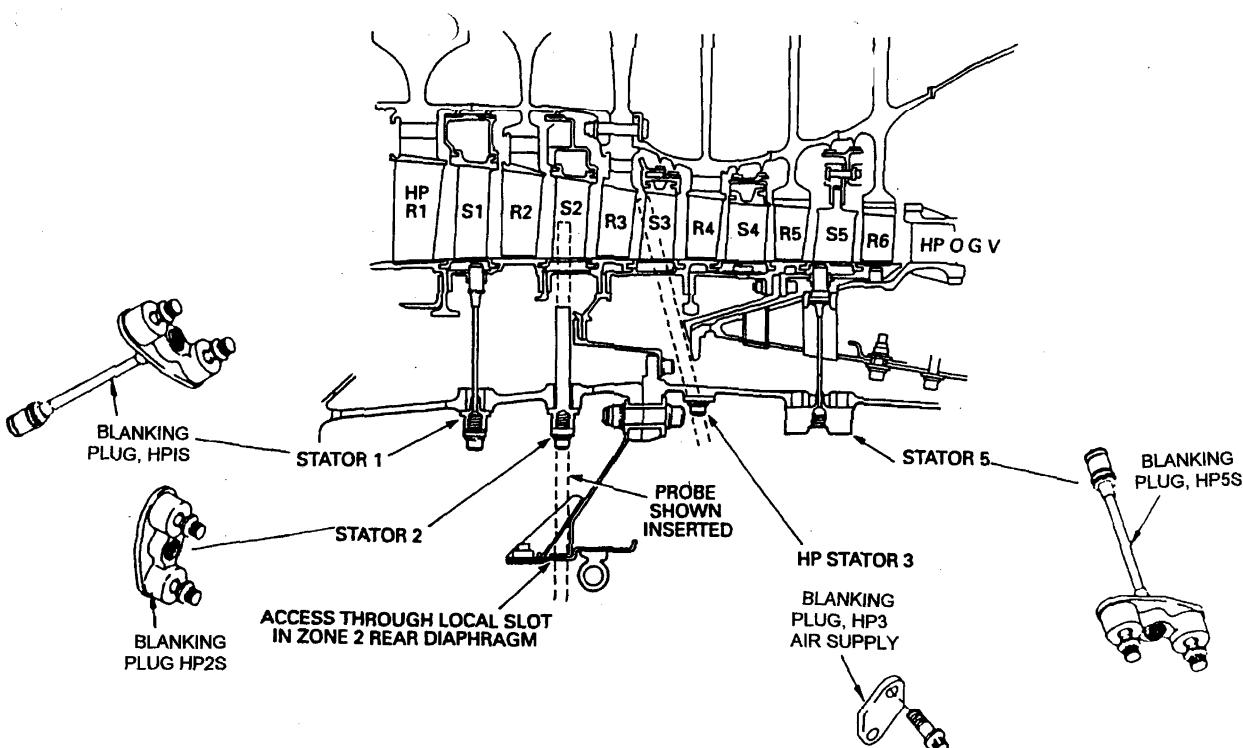


Figure 21.12: RB211-535 E4 HP compressor access ports



Compressor Damage

Foreign objects often enter engine air intakes either accidentally or through carelessness. Items such as pens, pencils cigarette lighters etc. can be drawn out of pockets and ingested by the engine. The compressor could be damaged beyond repair. Likewise, tools left in engine intakes could be drawn in causing damage. Prior to starting an engine therefore, the AME should ensure that all tools used in the vicinity of the intakes are free of any foreign objects and the area in front of intakes should be cleared of any loose stones or rubbish. Examples of the typical types of damage to be found on compressor blades is shown in Figure 21.16 and possible causes of damage and the terminology used in Figure 21.17.

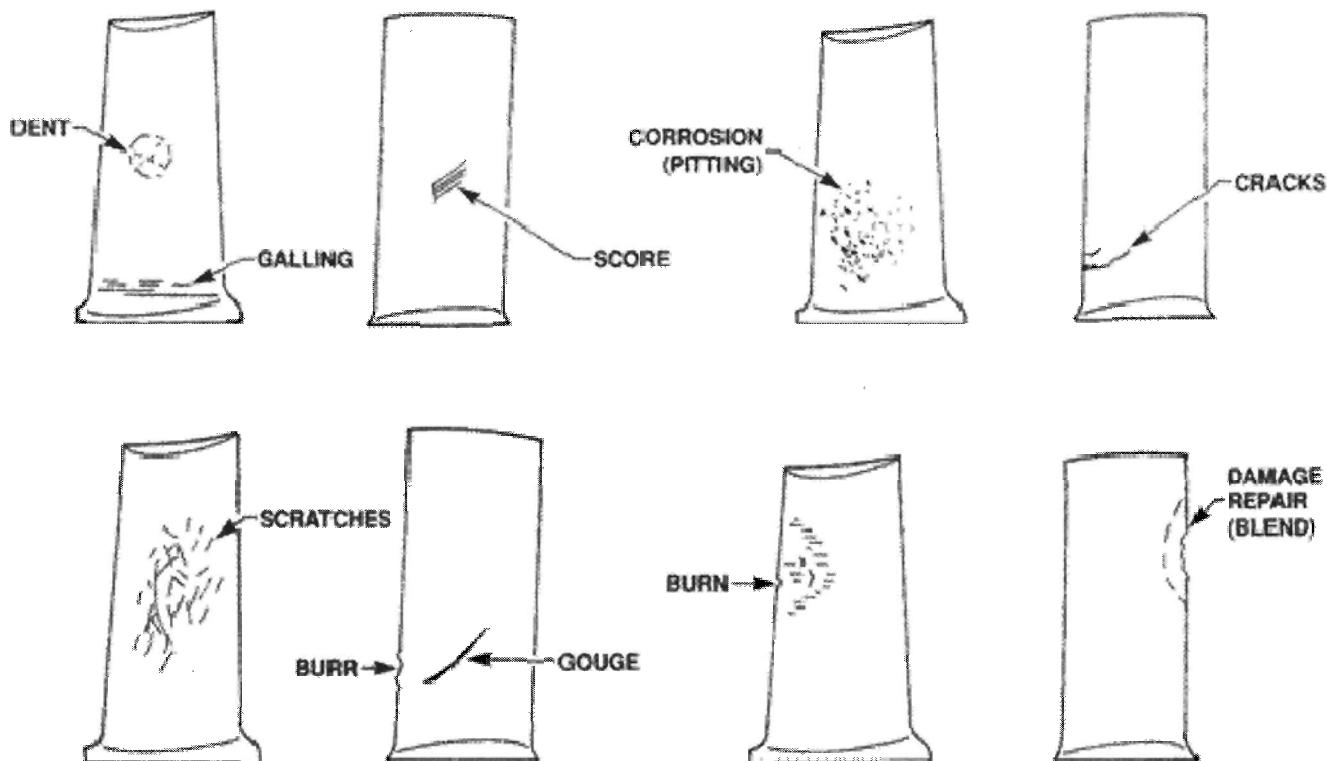


Figure 21.16: Compressor blade damage



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Term	Appearance	Usual Causes
Blend	Smooth repair of ragged edge or surface into the contour of surrounding area.	
Bow	Bent blade.	Foreign objects.
Burning	Damage to surfaces evidenced by discoloration or, in severe cases, by flow of material.	Excessive heat.
Burr	A ragged or turned out edge.	Grinding or cutting operation.
Corrosion (pits)	Breakdown of the surface; pitted appearance.	Corrosive agents - moisture, etc.
Cracks	A partial fracture (separation).	Excessive stress due to shock, over-loading, or faulty processing; defective materials; overheating.
Dent	Small, smoothly rounded hollow.	Striking of a part with a dull object.
Gall	A transfer of metal from one surface to another.	Severe rubbing.
Gouging	Displacement of material from a surface; a cutting or tearing effect.	Presence of a comparatively large foreign body between moving parts.
Growth	Elongation of blade.	Continued and/or excessive heat and centrifugal force.
Pit	See Corrosion.	
Profile	Contour of a blade or surface.	
Score	Deep scratches.	Presence of chips between surfaces.
Scratch	Narrow shallow marks.	Sand or fine foreign particles; careless handling.

Figure 21.17: Compressor blade damage –possible causes

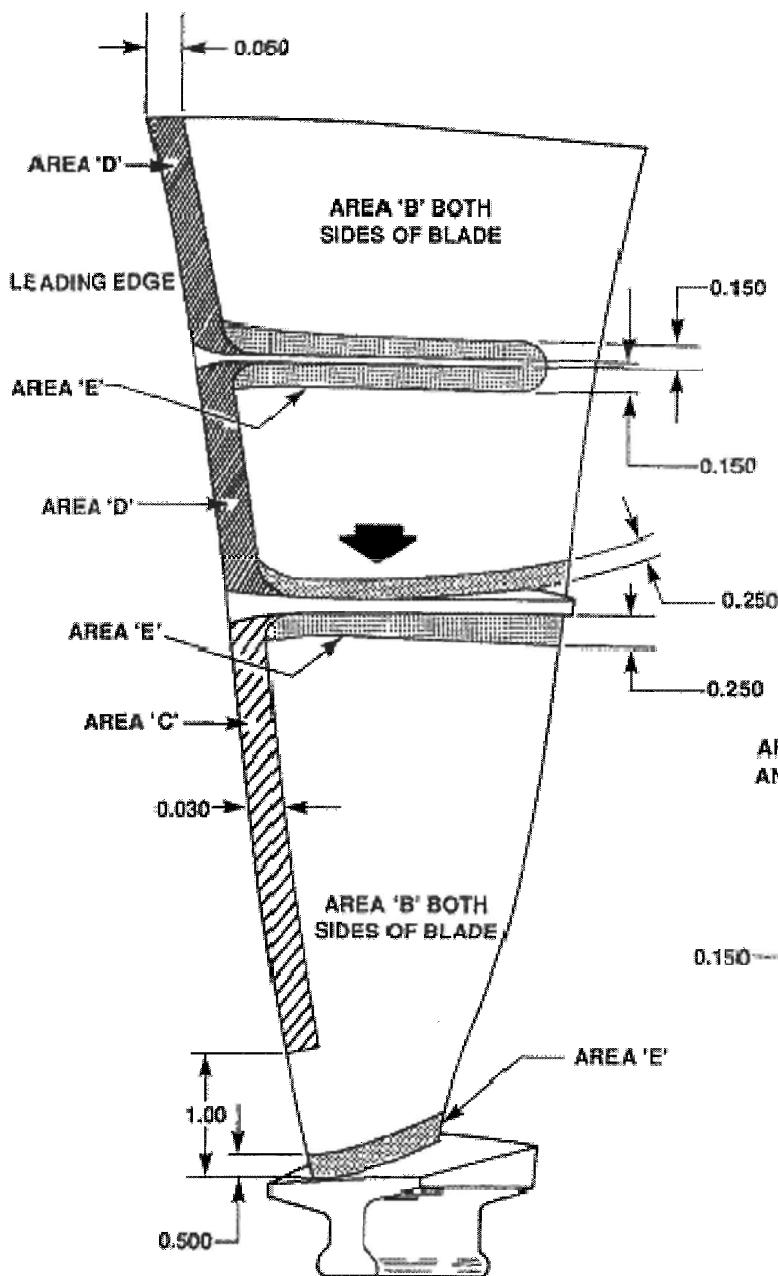
Damage Limits and Repair

Minor damage to compressor and fan blades may be repaired provided the damage is within the allowable limits established by the manufacturer in the AMM. Typical limits for fan blades are shown in Figure 21.18. All repairs must be well blended so that the finished surfaces are smooth.



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BLADE AREA	PERMISSIBLE DAMAGE (NO REPAIR REQUIRED)
Area B	Erosion, nicks, scoring or dents, maximum allowable depth 0.015"
Area C	Nicks, or dents, maximum allowable depth 0.030".
Area D	Nicks or dents, maximum allowable depth 0.060".
Area E	No damage permissible in fillet areas.

NOTES:

- (1) Blend-rework of damaged areas is required only in the instance of sharp bottomed damage. Damaged area must be removed and blended to a minimum radius 0.125".
- (2) Metal removal during blending operations must be carried out by hand filing and stoning methods only. Abrasive removal or grinding operations are not permitted.
- (3) In area 'C' and 'D', one blend repair only is permitted. Repaired areas are to be inspected with portable fluorescent penetrant or dye-check.
- (4) Cracks require rejection of blade.

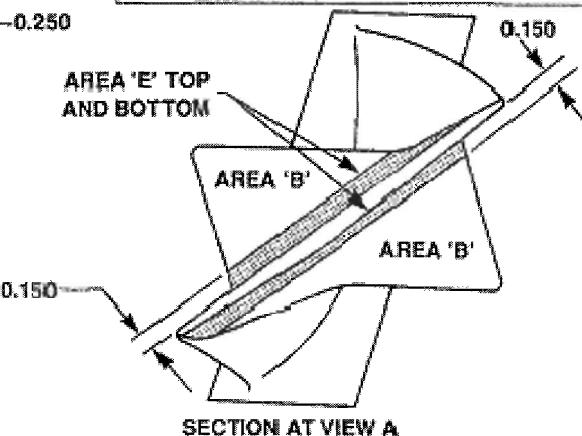


Figure 21.18: Typical fan blade damage limits

The majority of cold section inspections will require the use of a strong light source and sometimes a small mirror. If however doubt exists as regard the extent of damage, then a boroscope inspection would be instigated. Always observe the safety precautions associated with working in the intake. Ensure that the flightdeck is suitably placarded informing other personnel that you are in the intake. Tripping of CBs may be required by the manufacturer in



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order to isolate the starting and ignition circuits. A safety man may be required who's job it will be to look after your interest. Don't get sucked in!!!

Hot Section Inspections (HSIs)

The hot section includes all components in the combustion and turbine sections of the engine. Scheduled inspections may involve visual inspection of hot section components, and limited dimensional checks and fits and clearances as called up in the maintenance schedule and described in the AMM. The term 'hot section inspection' is usually interpreted to indicate a time related inspection of the hot section components. It may also be required following an over-temperature condition or hot start.

Some more in depth HSIs will require the removal of major components of the hot section. The modular construction of most modern gas turbine engine (Figure 21.19) will enable this removal element of the task to be carried out on the wing, thus reducing the down time. To reduce this down time figure even more, some operators maintain a stock of 'hot section' modules that are ready for immediate replacement, the removed item being returned for inspection to the operators overhaul facility.

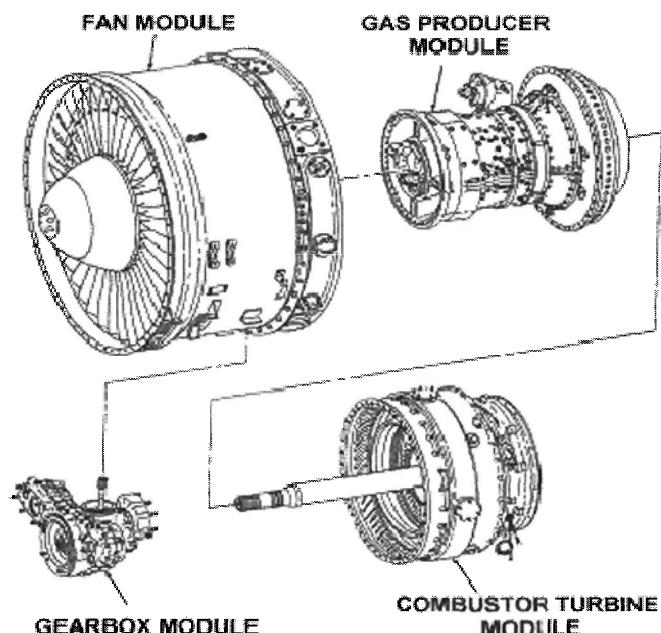


Figure 21.19: Engine modular construction (ALF 502)



Disassembly of Hot Section

The disassembly/reassembly process must ensure that component parts are reassembled in the same position they came apart from. This will require marking of components. *A note of caution here:* when marking any hot section component do not use a marker that will leave a carbon deposit. Hot metal will absorb carbon which can lead to intergranular stress and failure of the component.

Line Inspection of Combustor and Turbine Section

On wing inspection of the combustor and turbine section can be done visually through the jet pipe using a strong light source and a mirror and if required a magnifying glass. Boroscope inspection is also used as is, on occasion, non destructive methods of inspection such as dye-penetrant. As in other hot section inspections, the AME is most likely to see small cracks caused by compression and tension loads during heating and cooling. Other than on turbine blades and discs this type of distress is normally acceptable because after initial cracks relieve the stress, no elongation of crack normally occurs.

Erosion of blades and NGVs is also quite common, this brought about as a result of the wearing away of metal due to either the gas flow or impurities within the gas flow.

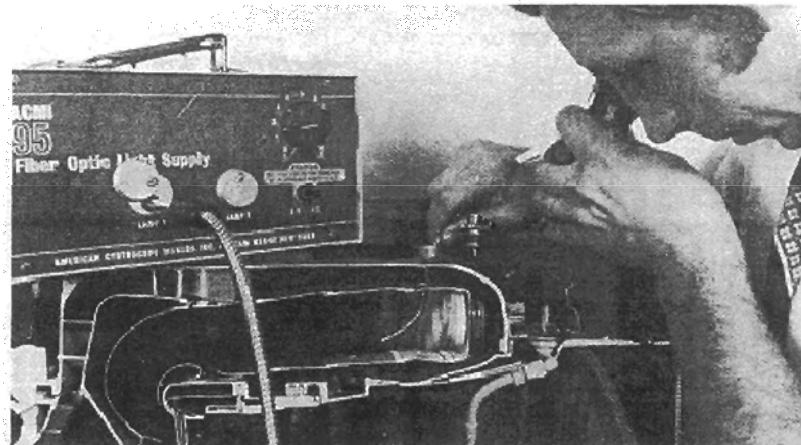


Figure 21.20: Combustion liner inspection

One of the most common faults found in the combustor section of a gas turbine engine is cracks. The combustion liner is made of a high temperature resistant steel that is subjected to high concentrations of heat. The most common methods of checking for faults is by boroscope (Figure 21.20). With this tool the AME can easily view the internal combustion liner and fuel nozzles, and determine their airworthiness. During the inspection the AME is looking for signs of cracking, warping, burning, erosion and hot spots which may have developed possibly as a result of burner misalignment. What is observed is then compared with the manufacturers' limitations.

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Turbine Discs and Blades

The inspection for cracks is of the utmost importance, most inspections are visual, the dye penetrant method of inspection being too impractical. Cracks on discs however small will necessitate removal of the module or engine for overhaul. Blade cracking also will invariably require removal of the module or engine. Some manufacturers' limitation allowance will permit repairs to be effected to damaged turbine blades. Figure 21.21 refers. Cracks however are not acceptable and will require blade replacement. In extreme cases part or whole blades may be missing due to severe overheating causing the blade to melt, on some engines this does not always show up on the vibration indicating system.

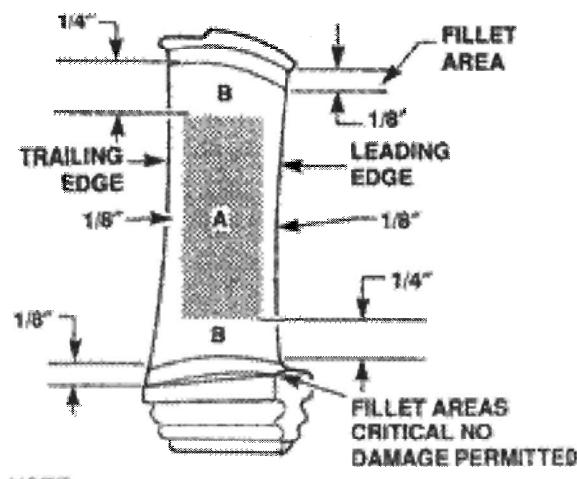
INSPECTION	MAXIMUM SERVICEABLE	MAXIMUM REPAIRABLE	CORRECTION ACTION
BLADE SHIFT	Protrusion of any blade root must be equal within 0.015" either side of disk.	Not repairable	Return bladed disk assembly to an overhaul facility.
AREA A Nicks (3 maximum.)	0.015" long by 0.005" deep	.015 long by 0.010" deep	Blend out damage area/ Replace blade
Dents and pits (3 maximum.)	0.010" deep	.015 long by 0.010" deep	Blend out damaged area/ Replace blade
Cracks	Not acceptable	Not repairable	Replace blade
AREA B Nicks, dents, and pits (No cracks allowed)	One 0.020" deep	Not repairable	Replace blade
LEADING AND TRAILING EDGES Nicks, dents, and pits	One 0.020" deep	Two 1/8" deep	Blend out damaged area/ Replace blade
Cracks	Not acceptable	Not repairable	Replace blade



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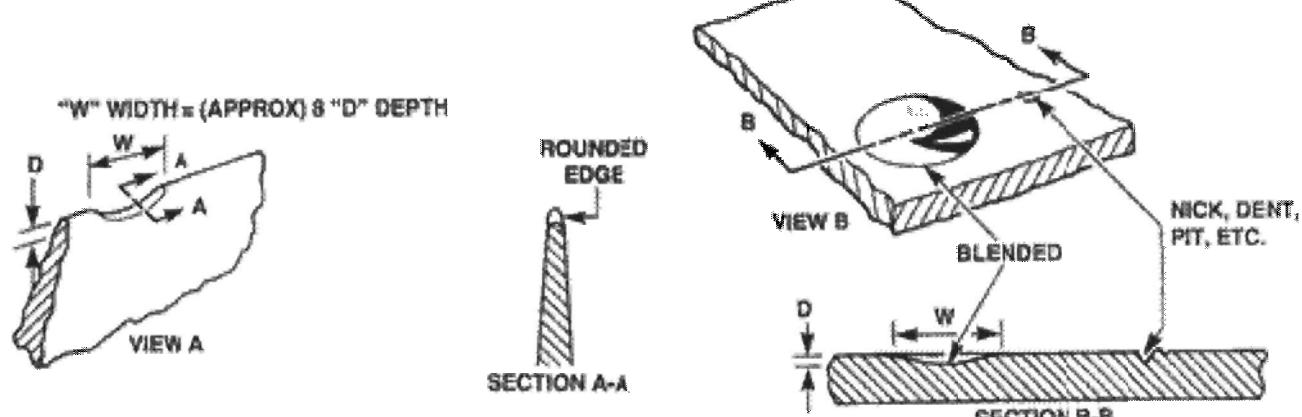
(A)



(B)



(C)



(A)—Power turbine blade repair limits. (B)—Repaired blade. (C)—Typical blending guides for turbine blade defects other than cracks.

Figure 21.21: Typical turbine blade damage limits.



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Turbine Blade Clearance

Creep is term used to describe the continuous and permanent stretching of turbine blades due to high temperatures and centrifugal forces acting on the blades. Each time a turbine is heated, rotated then stopped (referred to as an engine cycle) each blade will be slightly longer. At regular interval, specified intervals the AME will carry out a turbine tip clearance check (Figure 21.22). The AMM will stipulate what limitations must be observed and if these are exceeded then the engine or module will require replacing.

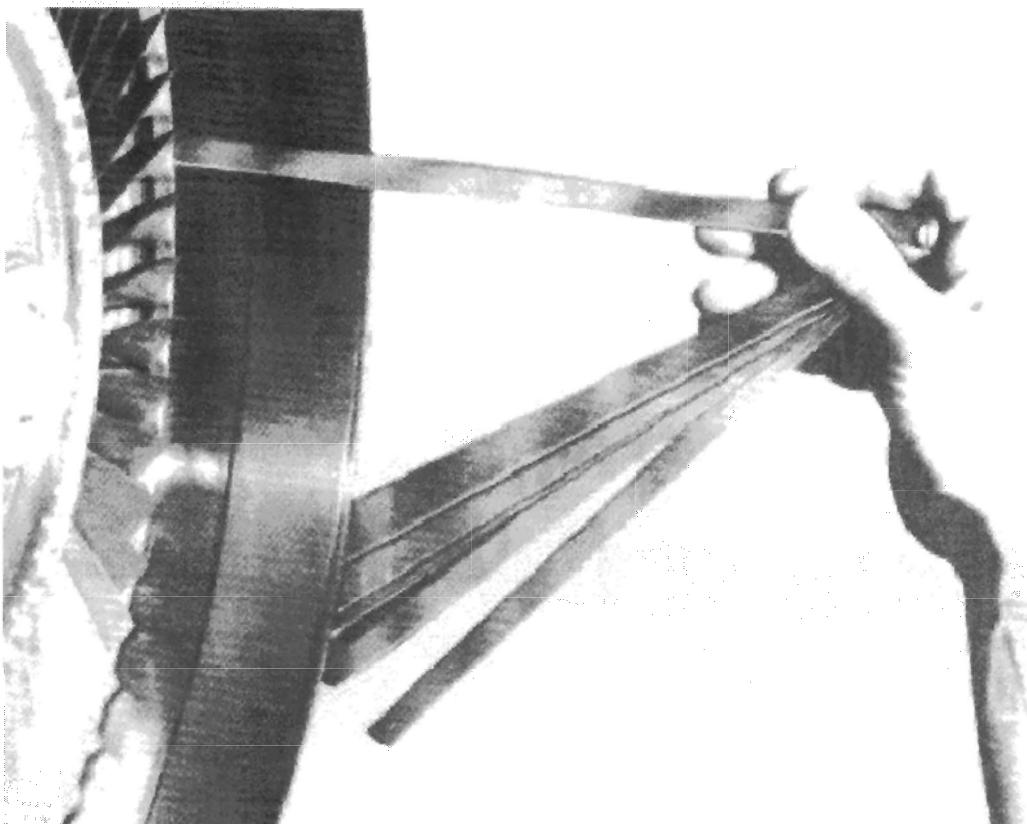


Figure 21.22: Turbine tip clearance check.



Turbine Blade Replacement

Some engine manufacturers will allow replacement of damaged turbine blades by an operators overhaul department. Blade replacement is generally accomplished by installing a new blade of equal moment weight. If the blade moment weight cannot be matched then the damaged blade, and the blade 180° out may be replaced with blades of equal moment weight or the damaged blade and the blades 120° from it may be replaced with blades of equal moment weight. Code letters representing the moment weight are stamped onto the blade to enable correct balancing of the turbine assembly undergoing blade replacement. Figure 21.23 refers.

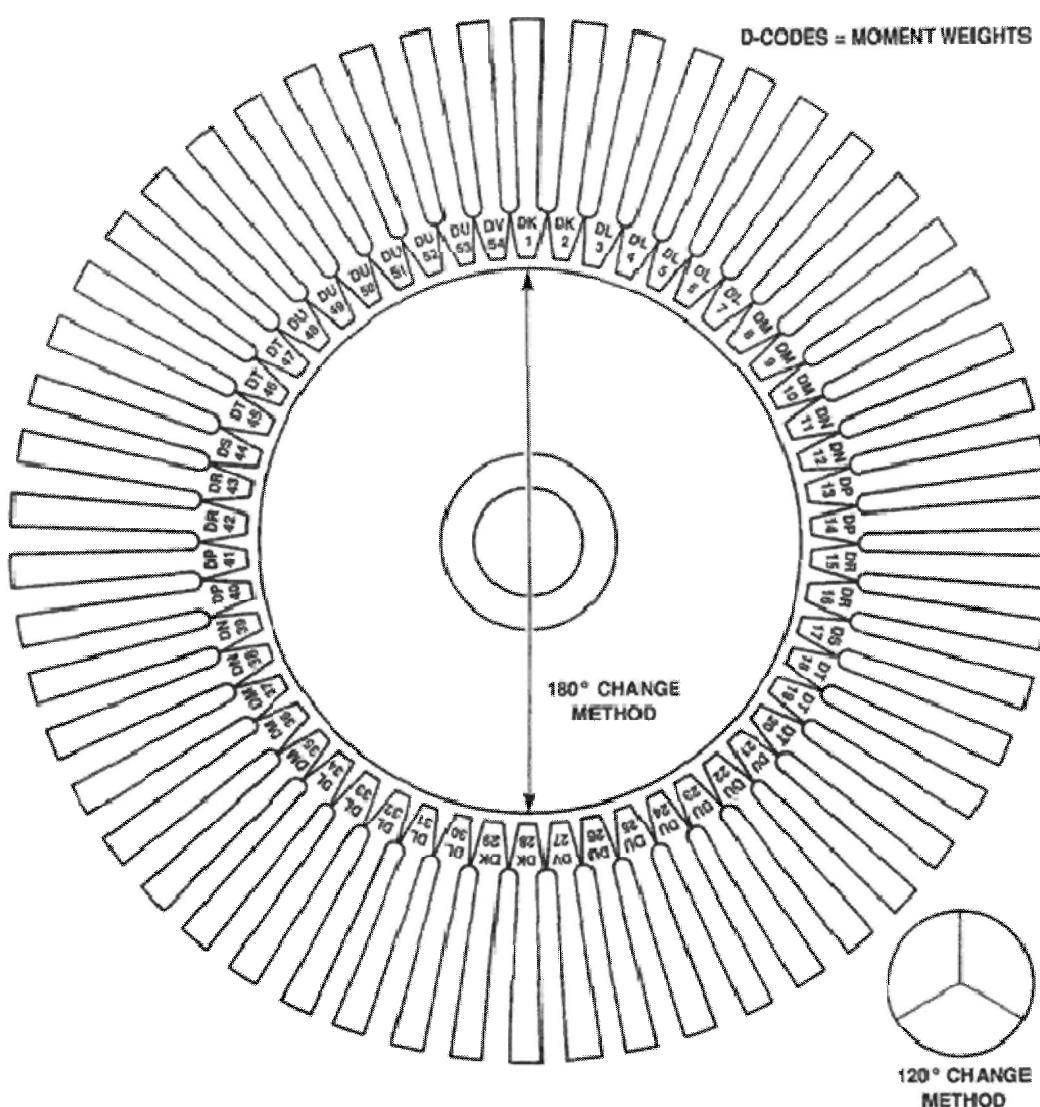


Figure 21.23: Typical turbine blade moment weight coding and change methods

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Nozzle Guide Vane Inspection

Inspection of the NGVs is possible using a strong light source and mirror, it is more probable however that a borescope inspection will be required. The NGVs are examined for signs of damage and or bowing on their trailing edges. Bowing may be an indication of a faulty fuel nozzle. Again the engine manufacturer will detail the damage/bowing tolerances which, if exceeded will result in module or engine replacement (Figure 21.25).

Inspection of the exhaust section of the engine can be done visually using an appropriate light source. The exhaust cone and jet pipe are examined for signs of cracking, weeping, buckling or hot spots. Hot spots identified on the exhaust cone may be the result of a defective fuel nozzle or combustion chamber resulting in the requirement for further investigation.

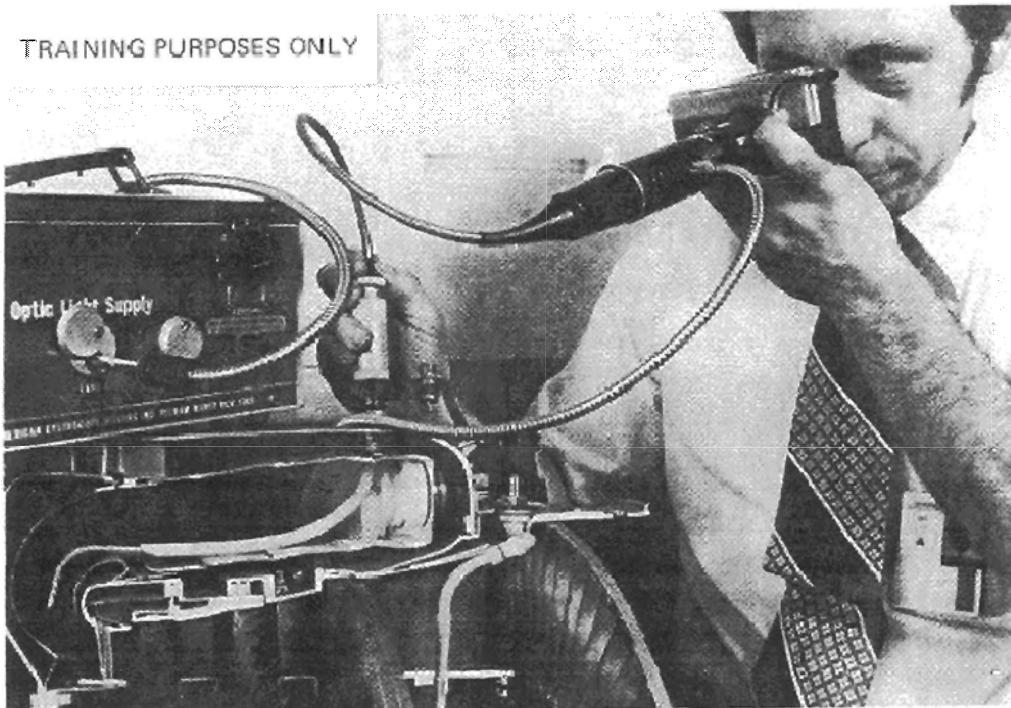
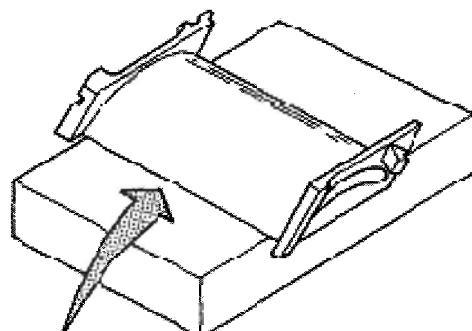


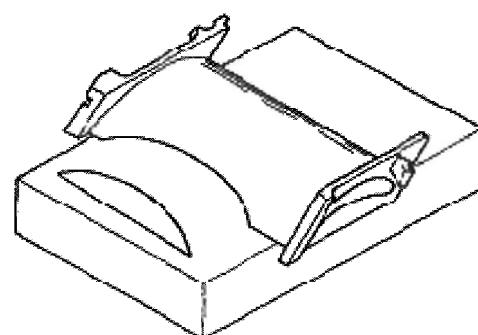
Figure 21.24: First nozzle inspection



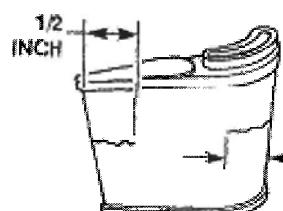
(A)



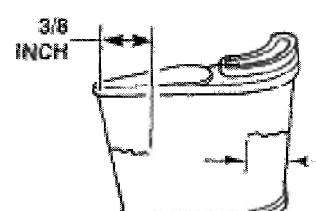
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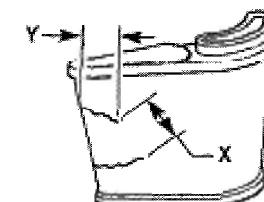
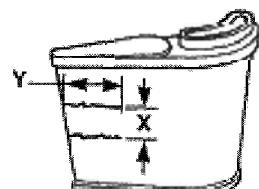
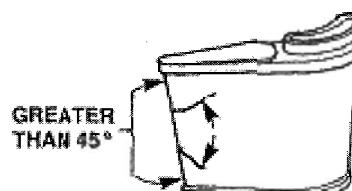
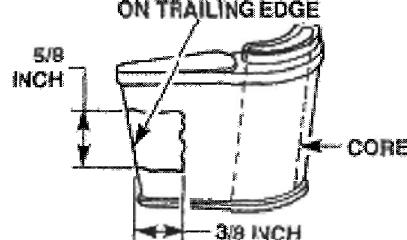
(C)



VANE WELDED TO OUTER SHROUD



VANE NOT WELDED TO OUTER SHROUD

CONVERGING CRACKS
ACCEPTABLE IF DISTANCE "X"
IS GREATER THAN LENGTH "Y"NON-CONVERGING CRACKS
DISTANCE "X" MAY BE LESS
THAN LENGTH "Y"DIVERGING
CRACKSCAN BE LOCATED ANYWHERE
ON TRAILING EDGEALLOWABLE
BURNINGCONVERGING CRACKS RADIATING
TOWARD EACH OTHER

(A)—Turbine nozzle vane bowing check. (B)—Vane repair by welding in a new segment. (C)—Vanes acceptable if they do not exceed these limits (dimensions typical of small engines).

Figure 21.25: Nozzle Guide Vane Inspection



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Exhaust Section Inspection

Inspection of the exhaust section of the engine can be done visually using an appropriate light source. The exhaust cone and jet pipe are examined for signs of cracking, warping, buckling or hot spots. Hot spots identified on the exhaust cone may be the result of a defective fuel nozzle or combustion chamber resulting in the requirement for further investigation.

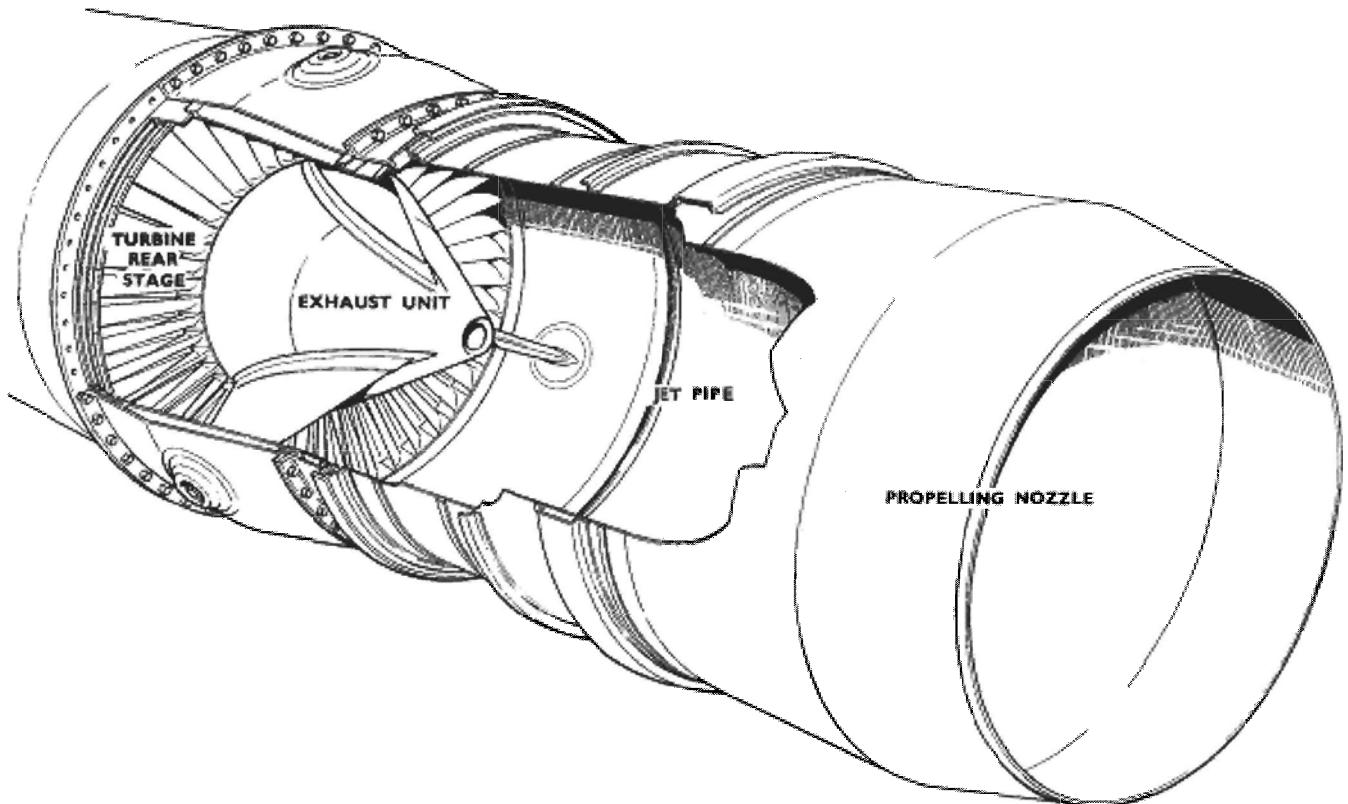


Figure 21.26: An exhaust system



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Gas Turbine Engine

15.22 Engine Storage and Preservation

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Knowledge Levels — Category A, B1, B2 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1 and B2 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each applicable subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

A familiarisation with the principal elements of the subject.

Objectives:

The applicant should be familiar with the basic elements of the subject.

The applicant should be able to give a simple description of the whole subject, using common words and examples.

The applicant should be able to use typical terms.

LEVEL 2

A general knowledge of the theoretical and practical aspects of the subject.

An ability to apply that knowledge.

Objectives:

The applicant should be able to understand the theoretical fundamentals of the subject.

The applicant should be able to give a general description of the subject using, as appropriate, typical examples.

The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.

The applicant should be able to read and understand sketches, drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

A detailed knowledge of the theoretical and practical aspects of the subject.

A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives:

The applicant should know the theory of the subject and interrelationships with other subjects.

The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.

The applicant should understand and be able to use mathematical formulae related to the subject.

The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.

The applicant should be able to apply his knowledge in a practical manner using manufacturer's instructions.

The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.



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Module 15.22 Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of EASA Regulation 2042/2003 Annex III (Part-66) Appendix I, and the associated Knowledge Levels as specified below:



Module 15.22 - Engine Storage and Preservation

Introduction

Under normal operating conditions the interior parts of an engine are protected against corrosion by the continuous application of lubricating oil and operating temperatures are sufficient to dispel any moisture which may tend to form; after shutdown the residual film of oil gives protection for a short period. When not in regular service, however, parts which have been exposed to the products of combustion and internal parts in contact with acidic oil, are prone to corrosion. If engines are expected to be out of use for an extended period they should be ground run periodically or some form of anti-corrosive treatment applied internally and externally to prevent deterioration.

The type of protection applied to an engine depends on how long it is expected to be out of service, if it is installed in an aircraft and if it can be turned.

This Leaflet gives guidance on the procedures which are generally adopted to prevent corrosion in engines but, if different procedures are specified in the approved Maintenance Manual for the particular engine, the manufacturer's recommendations should be followed.

The maximum storage times quoted in the Leaflet are generally applicable to storage under cover in temperate climates and vary considerably for different storage conditions. Times may also vary between different engines and reference must be made to the appropriate Maintenance Manual for details.



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Installed Engines

Installed turbine engines which are to be out of use for a period of up to seven days require no protection apart from fitting covers or blanks to the intake, exhaust and any other apertures, to prevent the ingress of dust, rain, snow, etc. A turbine engine should not normally be ground run solely for the purpose of preservation, since the number of temperature cycles to which it is subjected is a factor in limiting its life. For storage periods in excess of seven days additional precautions may be necessary to prevent corrosion.

Short-term Storage

The following procedure will normally be satisfactory for a storage period of up to one month.

Fuel System - The fuel lines and components mounted on the engine must be protected from the corrosion which may result from water held in suspension in the fuel. The methods used to inhibit the fuel system depend on the condition of the engine and whether it is installed in an aircraft or not and are fully described in the appropriate Maintenance Manual. On completion of inhibiting, the fuel cocks must be turned off.

Lubrication Systems - Some manufacturers recommend that all lubrication systems (engine oil, gearbox oil, starter oil, etc.) of an installed engine should be drained and any filters removed and cleaned, while others recommend that the systems should be filled to the normal level with clean system oil or storage oil. The method recommended for a particular engine should be ascertained from the appropriate Maintenance Manual.

External Treatment - Exterior surfaces should be cleaned as necessary to detect corrosion, then dried with compressed air. Any corrosion should be removed, affected areas re-treated and any damaged paintwork made good in accordance with the manufacturer's instructions. Desiccant or vapour phase inhibitor should be inserted in the intake and exhaust and all apertures should be fitted with approved covers or blanks.

Long-term Storage

For the protection of turbine engines which may be in storage for up to six months, the short-term preservation should be applied and, in addition, the following actions taken:-

Grease all control rods and fittings.

Blank-off all vents and apertures on the engine, wrap greaseproof paper round all rubber parts which may be affected by the preservative and spray a thin coat of external protective over the whole engine forward of the exhaust unit.

At the end of each successive six months storage period an installed engine should be re-preserved for a further period of storage. Alternatively, the engine may be removed from the aircraft and preserved in a moisture vapour proof envelope.

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Blanks

Approved blanks, covers or seals should be used whenever possible. These are normally supplied with a new or reconditioned engine and should be retained for future use. Pipe connections are usually sealed by means of a screw-type plug or cap such as AGS 3802 to 3807 and plain holes are sealed with plugs such as AGS 2108; these items are usually coloured for visual identification. Large openings such as air intakes are usually fitted with a specially designed blanking plate secured by the normal attachment nuts and the contact areas should be smeared with grease before fitting, to prevent the entry of moisture. Adhesive tape may be used to secure waxed paper where no other protection is provided, but should never be used as a means of blanking off by itself, since it may promote corrosion and clog small holes or threads.

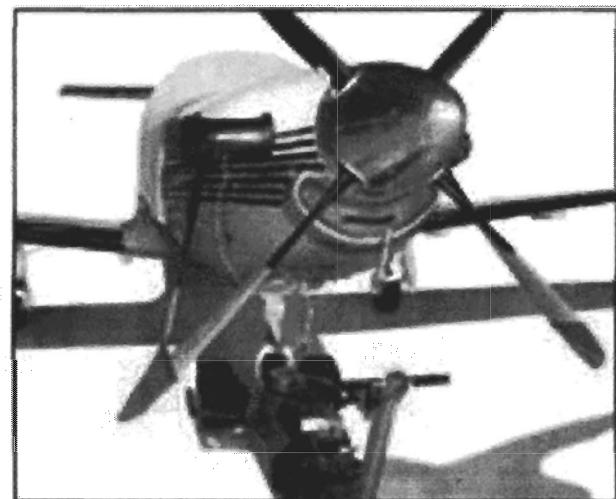
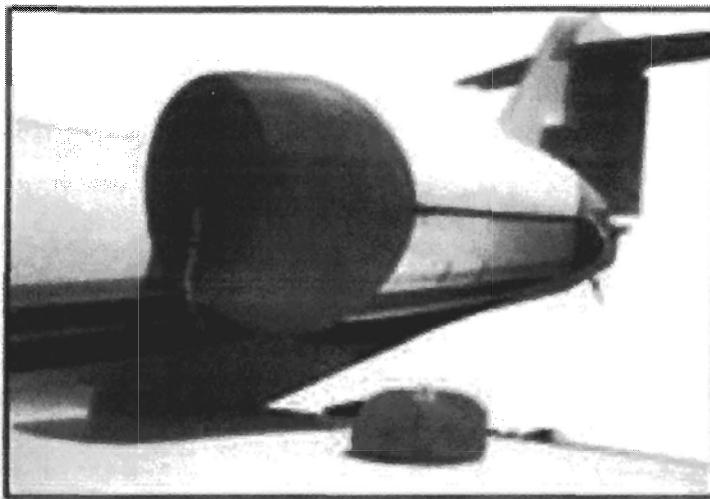


Figure 22.1: Covers and blanks fitted to a jet engine and a turboprop engine



Uninstalled Engines

Protection

Engines which have been removed from aircraft for storage, or uninstalled engines which are being returned for repair or overhaul, should be protected internally and sealed in moisture vapour proof (MVP) envelopes. This is the most satisfactory method of preventing corrosion and is essential when engines are to be transported overseas.

A turbine engine should be drained of all oil, fuel system inhibited, oil system treated as recommended by the manufacturer and blanks fitted to all openings.

Particular care should be taken to ensure that no fluids are leaking from the engine and that all sharp projections, such as locking wire ends, are suitably padded to prevent damage to the envelope.

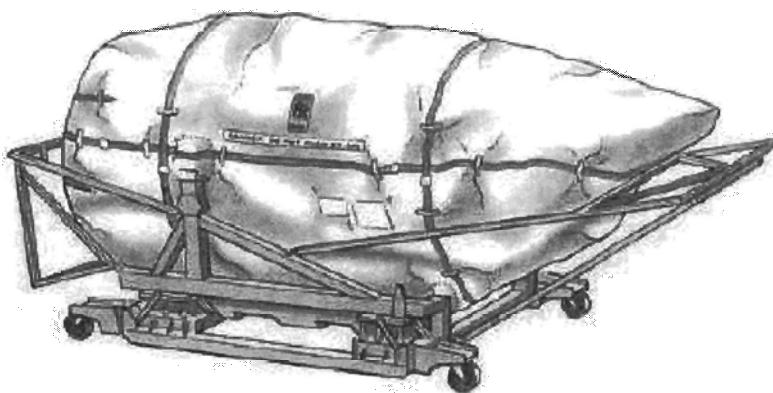


Figure 22.1: An engine prepared for storage

The MVP envelope should be inspected to ensure that it is undamaged and placed in position in the engine stand or around the engine, as appropriate. The engine should then be placed in the stand, care being taken not to damage the envelope at the points where the material is trapped between the engine attachment points and the stand bearers.

Vapour phase inhibitor or desiccant should be installed in the quantities and at the positions specified in the relevant Maintenance Manual and a humidity indicator should be located in an easily visible position in the envelope. The envelope should then be sealed (usually by adhesive) as soon as possible after exposure of the desiccant or vapour phase inhibitor.

The humidity indicator should be inspected after 24 hours to ensure that the humidity is within limits (i.e. the indicator has not turned pink). An unsafe reading would necessitate replacement of the desiccant and an examination of the MVP envelope for damage or deterioration.

After a period of three years storage in an envelope the engine should be inspected for corrosion and re-preserved.



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Engines in storage should be inspected periodically to ensure that no deterioration has taken place.

Engines which are not preserved in a sealed envelope should be inspected at approximately two-weekly intervals. Any corrosion patches should be removed and the protective treatment re-applied, but if external corrosion is extensive a thorough inspection may be necessary.

Envelopes on sealed engines should be inspected at approximately monthly intervals to ensure that humidity within the envelope is satisfactory. If the indicator has turned pink the envelope should be unsealed, the desiccant renewed and the envelope resealed.

Records

Appropriate entries must be made in the engine log book giving particulars of inhibiting procedures or periodic ground running. Such entries must be signed and dated by an appropriately licensed engineer or Approved Inspector.

Fuel System Inhibiting

The fuel used in turbine engines usually contains a small quantity of water which, if left in the system, could cause corrosion. All the fuel should therefore be removed and replaced with an approved inhibiting oil by one of the following methods:

Blanks

Approved blanks or seals should be used whenever possible. These are normally supplied with a new or reconditioned engine and should be retained for future use. Pipe connections are usually sealed by means of a screw-type plug or cap such as AGS 3802 to 3807 and plain holes are sealed with plugs such as AGS 2108; these items are usually coloured for visual identification. Large openings such as air intakes are usually fitted with a specially designed blanking plate secured by the normal attachment nuts and the contact areas should be smeared with grease before fitting, to prevent the entry of moisture. Adhesive tape may be used to secure waxed paper where no other protection is provided, but should never be used as a means of blanking off by itself, since it may promote corrosion and clog small holes or threads.



Equipment and Material

Equipment

The spraying equipment should be of a type approved by the engine manufacturer and should be operated in accordance with the instructions issued by the manufacturer of the equipment. For inhibiting cylinders a special nozzle is required and this should be checked immediately before use to ensure that the spray holes are unblocked. Correct operation of the spray gun may be checked by spraying a dummy cylinder and inspecting the resultant distribution of fluid.

Material

Only the types of storage and inhibiting oil recommended by the manufacturer should be used for preserving an engine. American manufacturers generally recommend oils and compounds to American specifications and British manufacturers generally recommend storage oil to DEF 2181, wax-thickened cylinder protective to DTD 791, turbine fuel system inhibiting oil to D. Eng. R.D. 2490 and external air drying varnish approved under a DTD 900 specification. Only approved alternatives should be used and any instructions supplied by the manufacturer in respect of thinning or mixing of oils should be carefully followed.



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Oil Circulation during Storage

Motoring Method

This should be used on all installed engines where it is convenient to turn the engine using the normal starting system. A header tank is used to supply inhibiting oil through a suitable pipe to the engine. A filter and an on/off cock are incorporated in the supply pipe, which should be connected to the low pressure inlet to the engine fuel system and the aircraft LP cock closed. After draining the engine fuel filter a motoring run should be carried out bleeding the high pressure pump and fuel control unit, and operating the HP cock several times while the engine is turning. Neat inhibiting oil will eventually be discharged through the fuel system and combustion chamber drains. When the motoring run is complete the bleeds should be locked, the oil supply pipe disconnected and all apertures sealed or blanked off.

Pressure Rig Method

This may be used on an engine which is installed either in the aircraft or in an engine stand. A special rig is used which circulates inhibiting oil through the engine fuel system at high pressure. The fuel filter should be drained and, where appropriate, the aircraft LP cock closed. The inlet and outlet pipes from the rig should be connected to the high pressure fuel pump pressure tapping and the system low pressure inlet respectively, and the rig pump turned on. While oil is flowing through the system the components should be bled and the HP cock operated several times. When neat inhibiting oil flows from the combustion chamber drains the rig should be switched off and disconnected, the bleed valves locked and all apertures sealed or blanked off.

Gravity Method

This is used when the engine cannot be turned. A header tank similar to the one used in the motoring method is required but in this case the feed pipe is provided with the fittings necessary for connection at several positions in the engine fuel system. The fuel filter should first be drained then the oil supply pipe connected to each of the following positions in turn, inhibiting oil being allowed to flow through the adjacent pipes and components until all fuel is expelled:

- High pressure fuel pump pressure tapping.
- Fuel control unit pressure tapping.
- Burner Manifold.
- Low pressure inlet pipe.

Components should be bled at the appropriate time and the HP cock operated several times when inhibiting the fuel control unit. All bleeds and apertures should be secured when the system is full of inhibiting oil.

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Removal from Storage

For an engine which was not installed in an aircraft during storage the installation procedure described in the appropriate Maintenance Manual should be carried out, followed by a thorough ground run and check of associated systems. For an engine which was installed in an aircraft during storage the following actions should be taken:-

- (a) Remove all masking, blanks and desiccant.
- (b) Clean the engine as necessary, e.g. remove excess external protective and surplus grease from controls.
- (c) Ensure fire extinguisher spray pipe holes are clear.
- (d) Replace any components which were removed for individual storage, de-inhibiting as necessary.
- (e) Drain out all storage oil, clean oil filters and refill with normal operating oil.
- (f) Prime the fuel system in accordance with the manufacturer's requirements.
- (g) Prime the engine lubricating oil system.
- (h) Start the engine and carry out a check of the engine and associated systems.

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Module 15 Appendix

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Module 15 Appendix

Colour Diagrams

The following diagrams from the main chapters of these notes have been reproduced here in full colour due to the essential nature of the colour-code information.

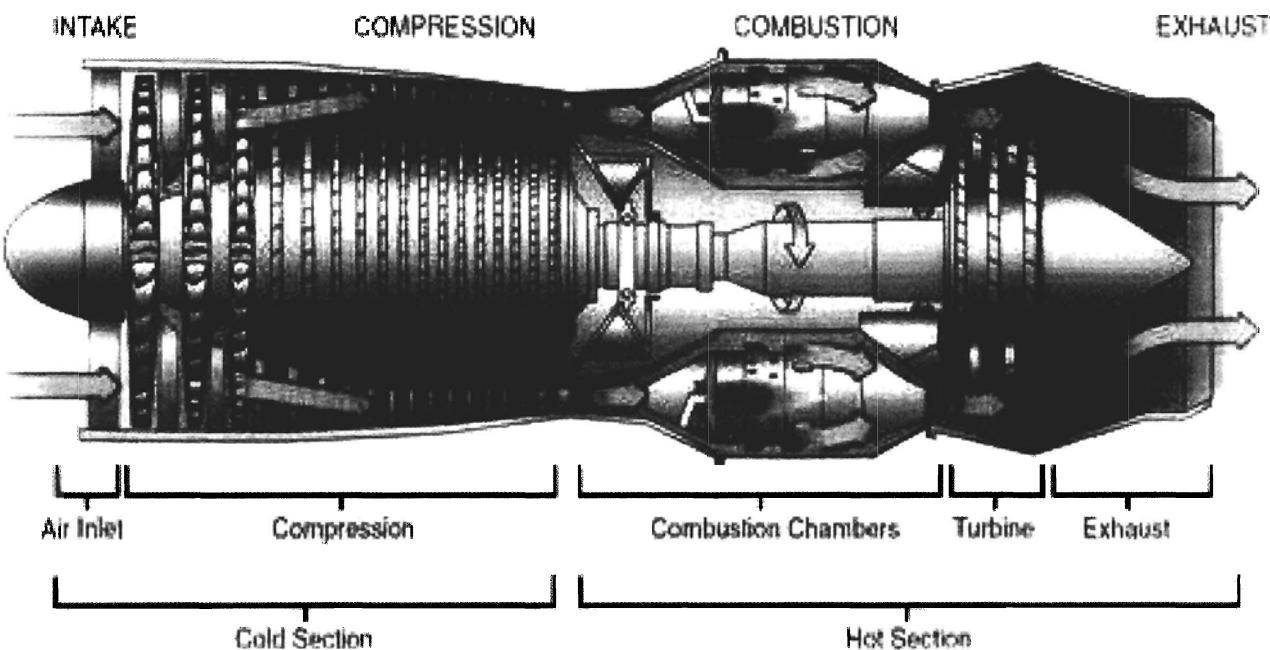


Figure 1.8: A single spool axial flow engine

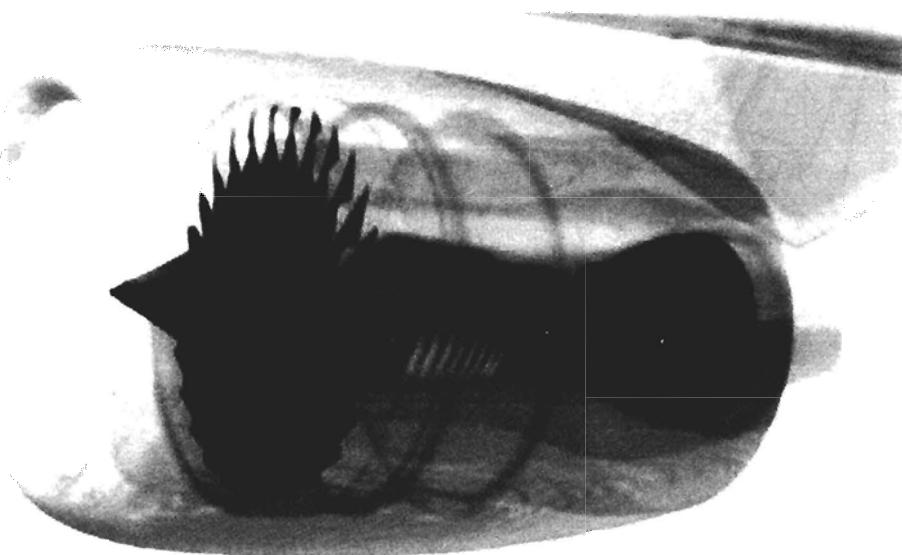


Figure 1.18: The triple spool high-bypass engine



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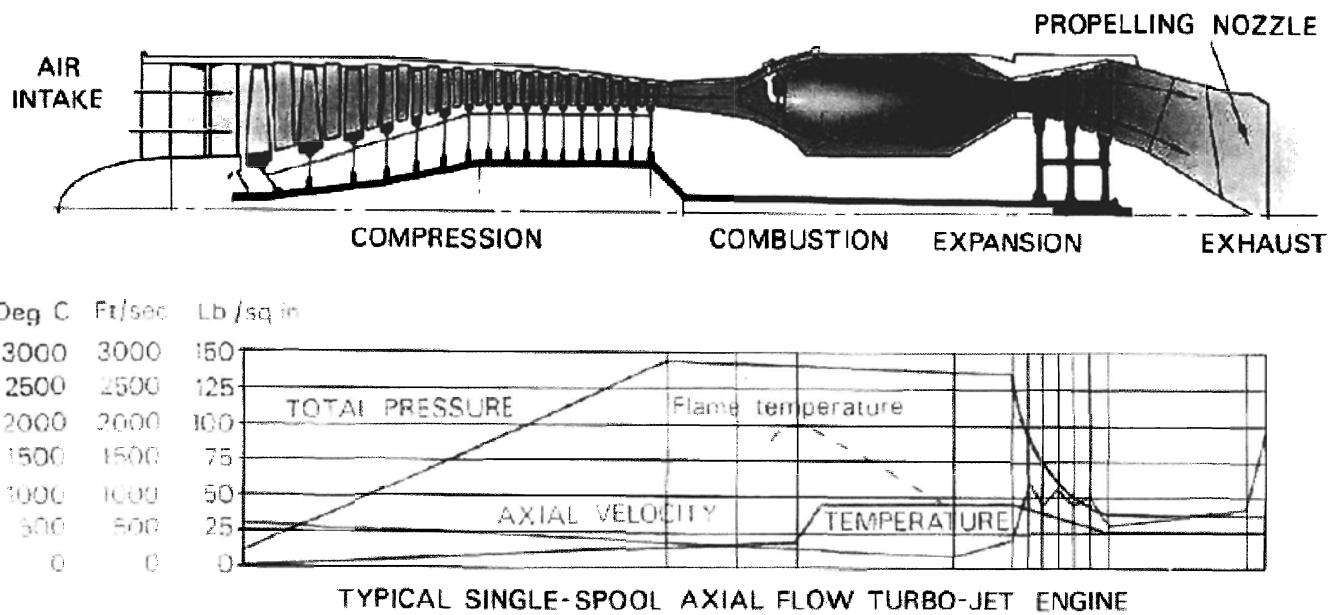


Figure 2.2: Pressure, temperature and velocity distributions through a turbo-jet engine

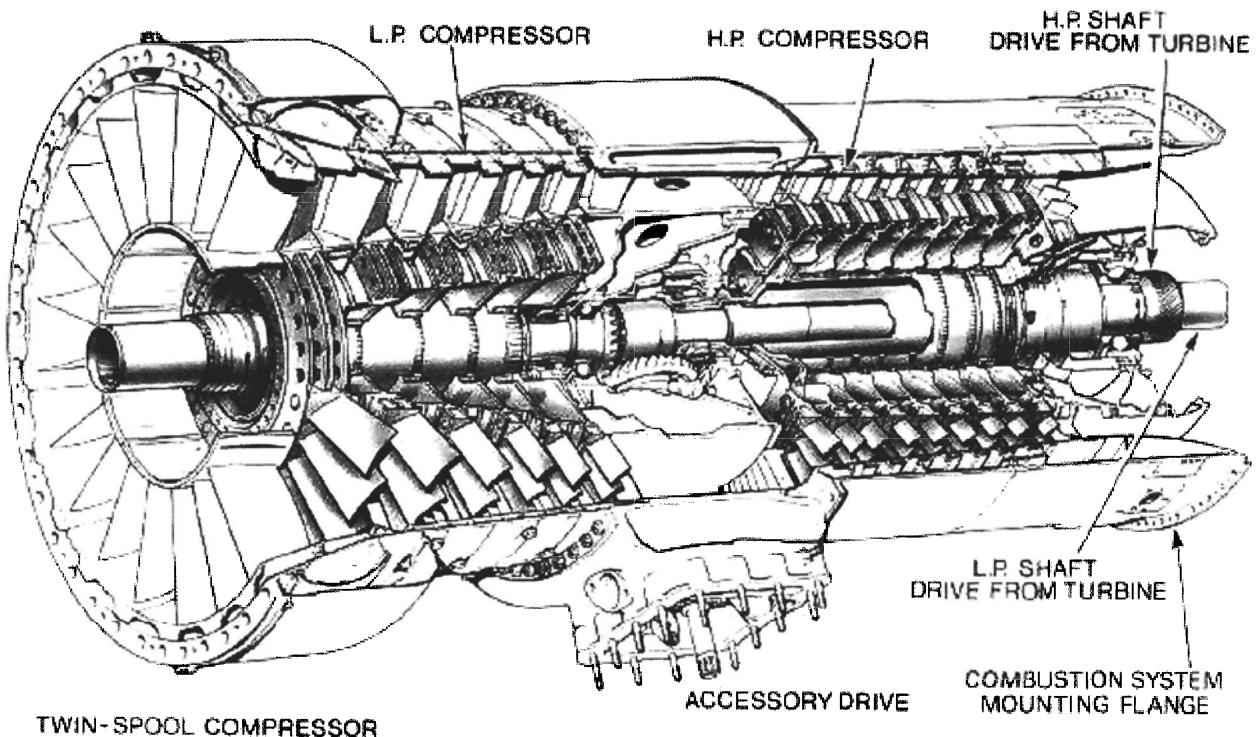


Figure 4.8: A dual-spool axial flow compressor



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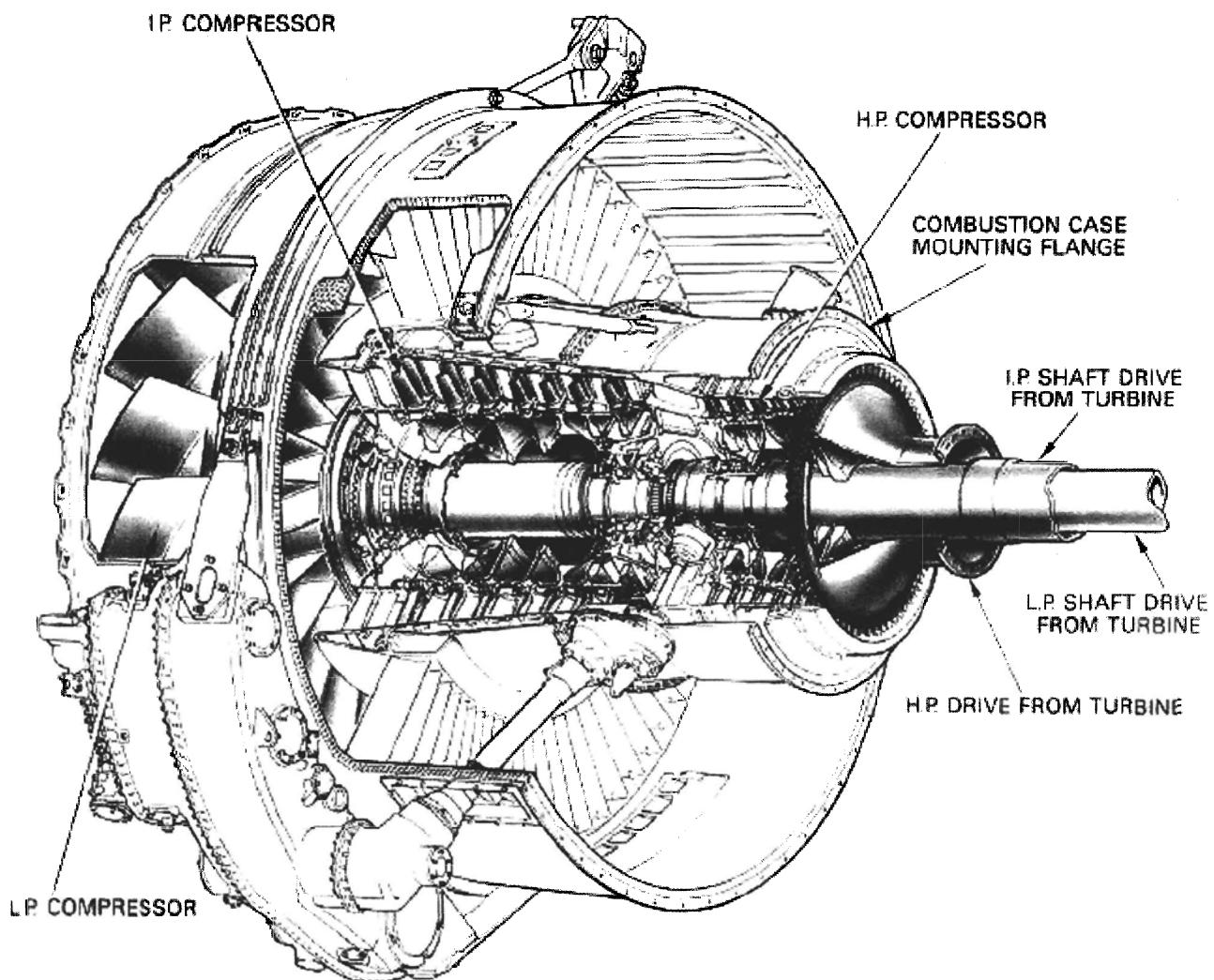


Figure 4.13: A triple-spool high-bypass fan compressor

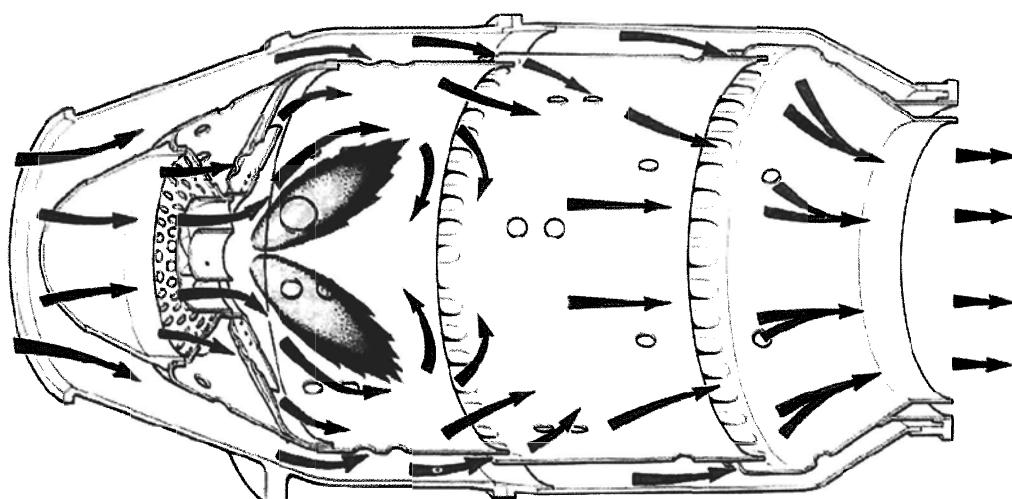


Figure 5.3: Combustion chamber gas flow



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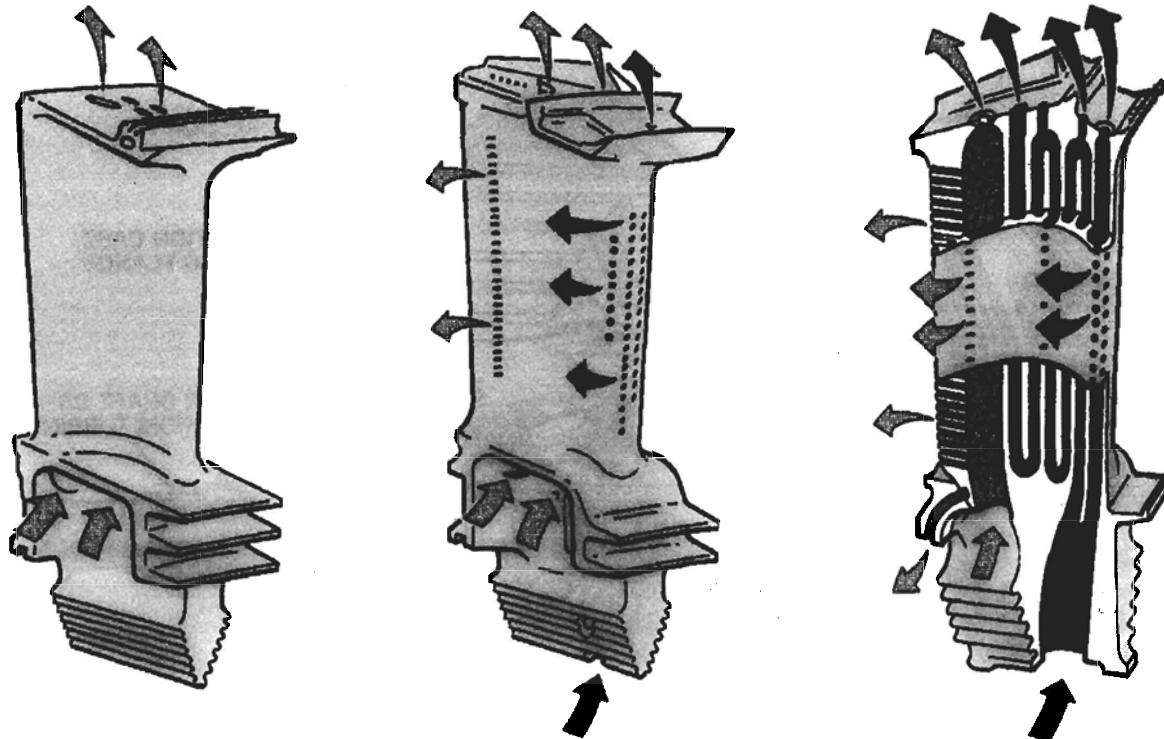


Figure 6.14: Blade cooling passages

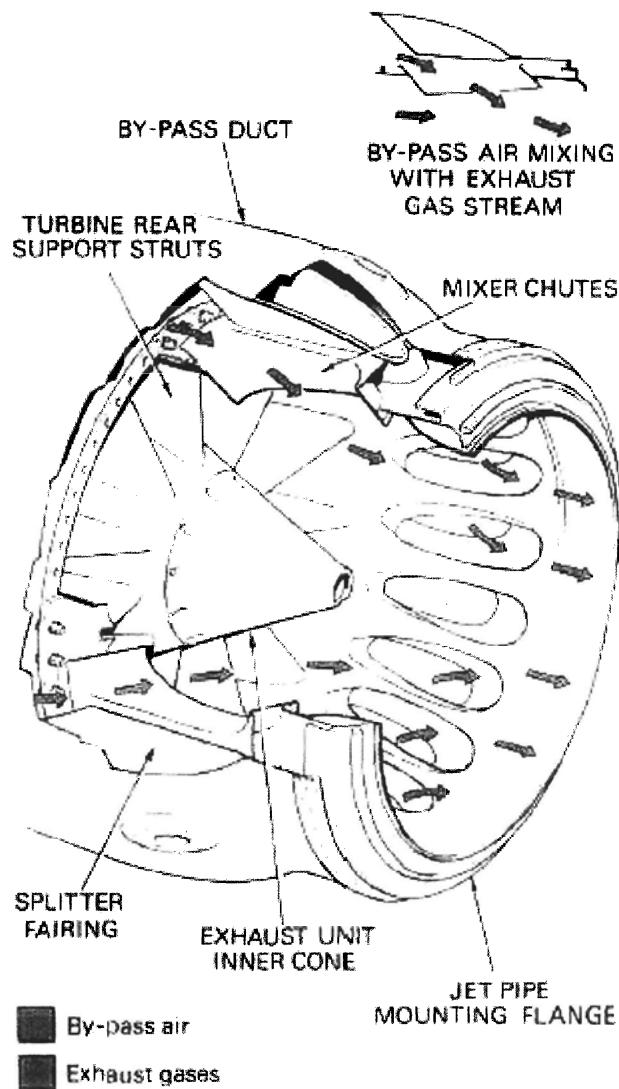
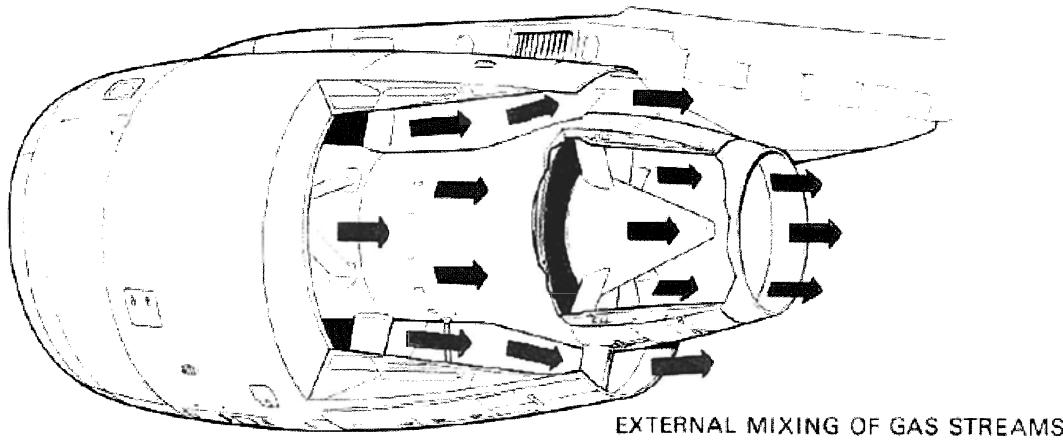


Figure 7.3: Low bypass exhaust mixer



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- Cold by-pass (fan) airflow
- Hot exhaust gases

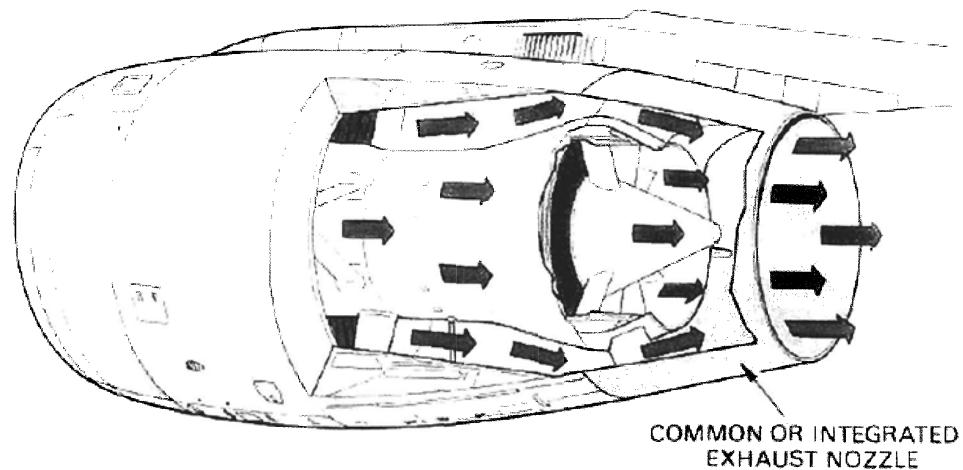
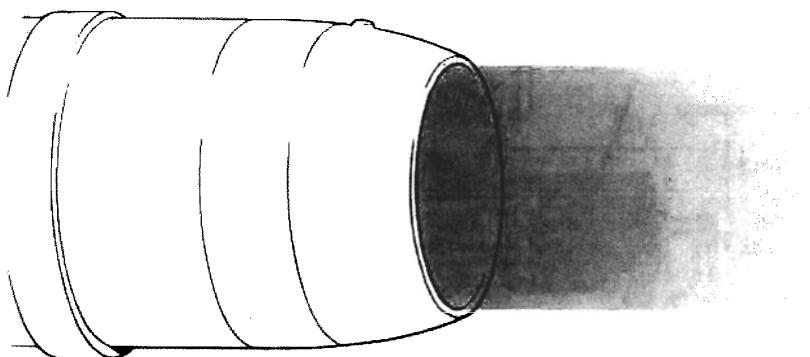
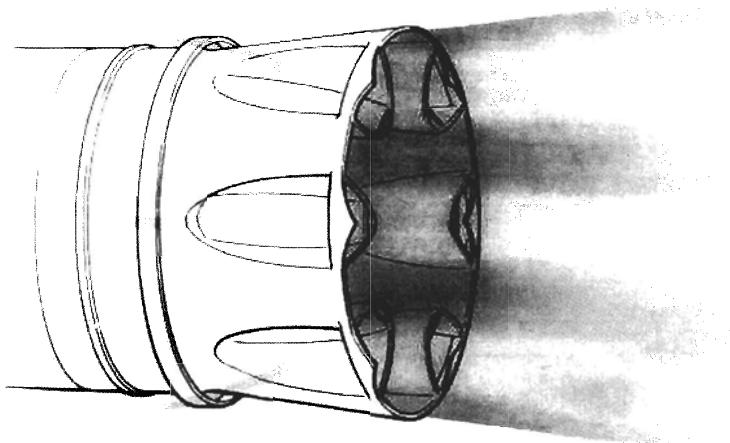


Figure 7.4: External and internal exhaust mixing of a high bypass engine

**PLAIN NOZZLE (low mixing rate) HIGH NOISE LEVEL****SUPPRESSOR NOZZLE (high mixing rate) REDUCED NOISE LEVEL****Figure 7.9: A plain nozzle and a noise suppressing nozzle**



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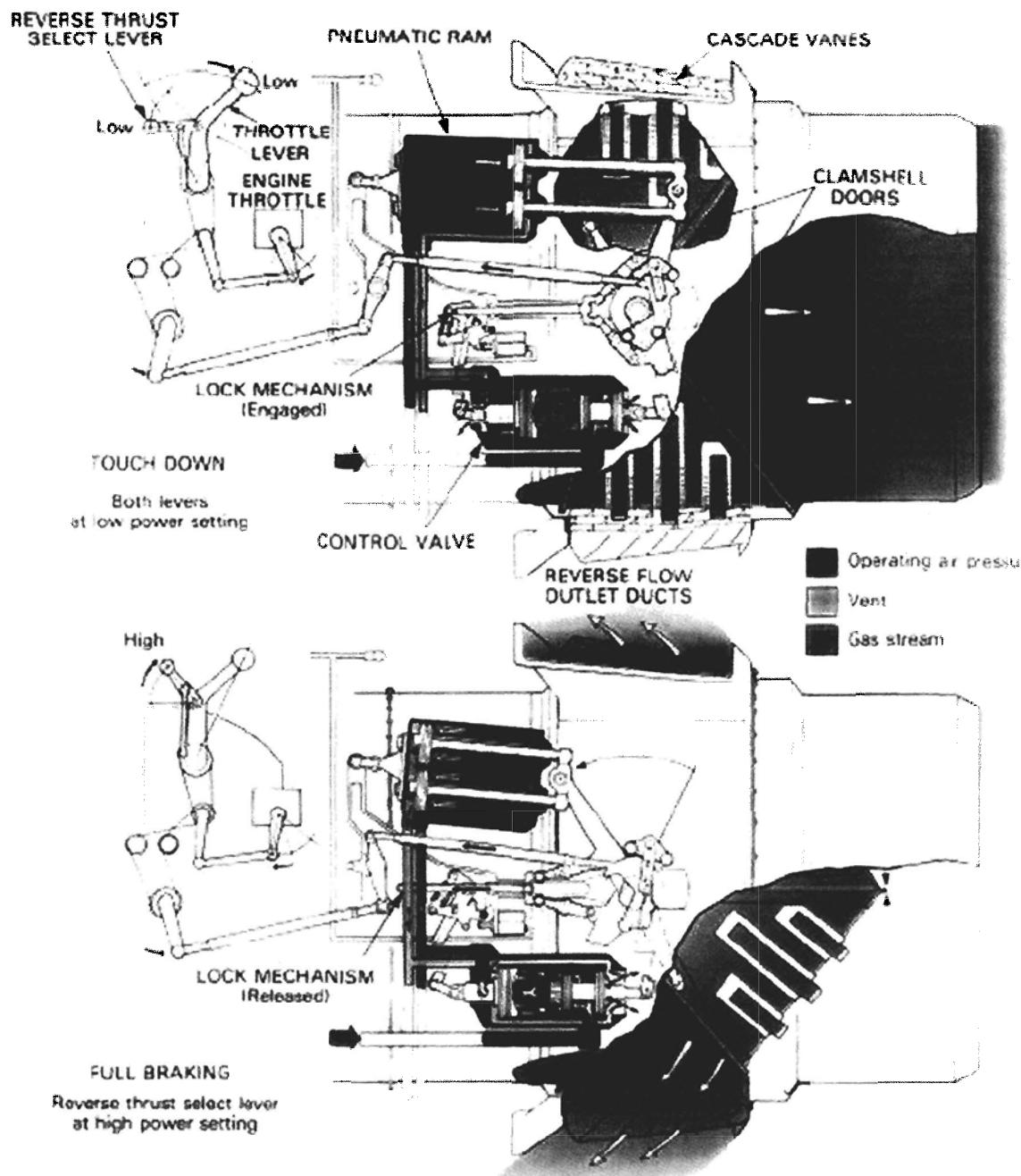


Figure 7.13: Clamshell thrust reverser system



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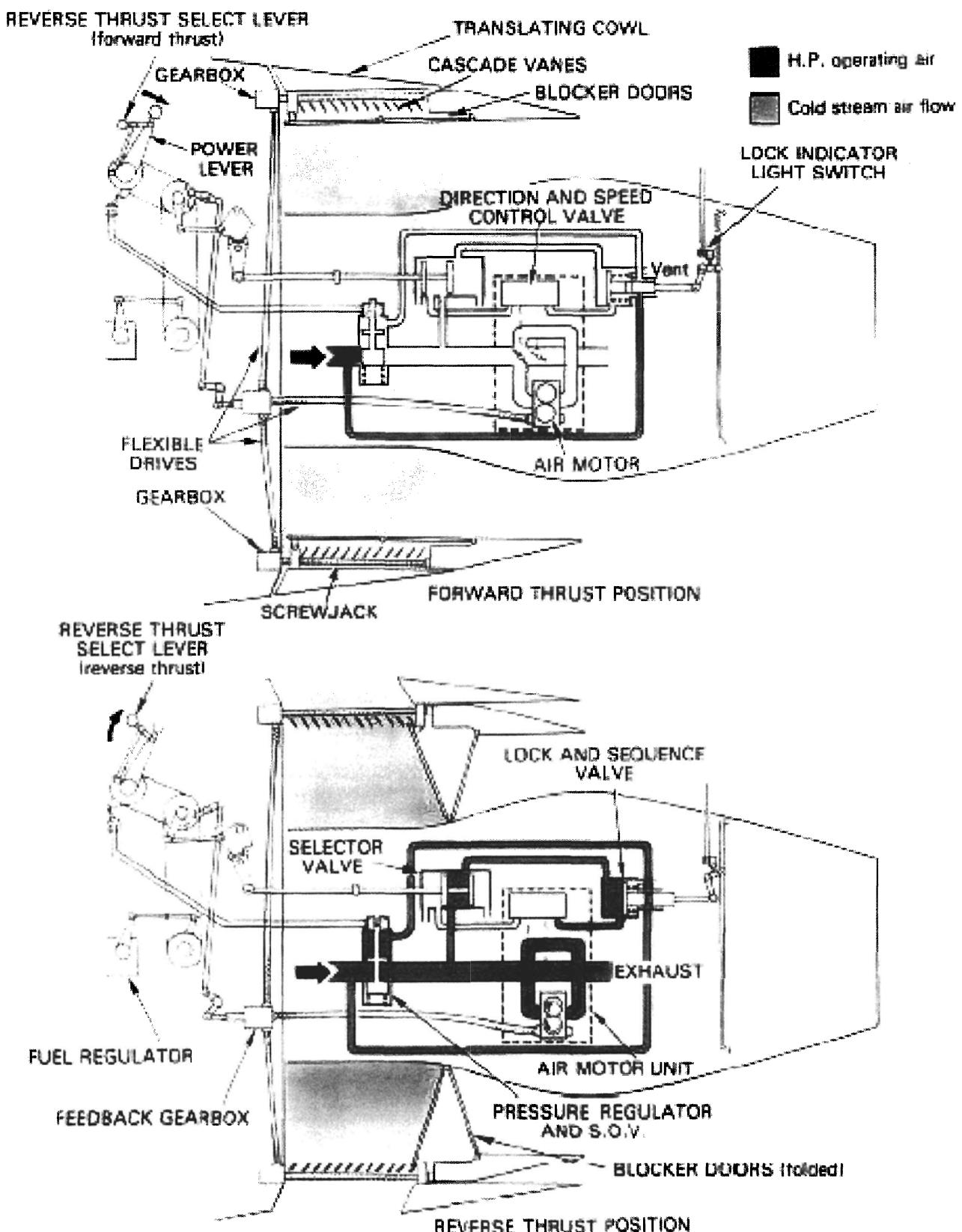


Figure 7.17: Cascade vane reverser system



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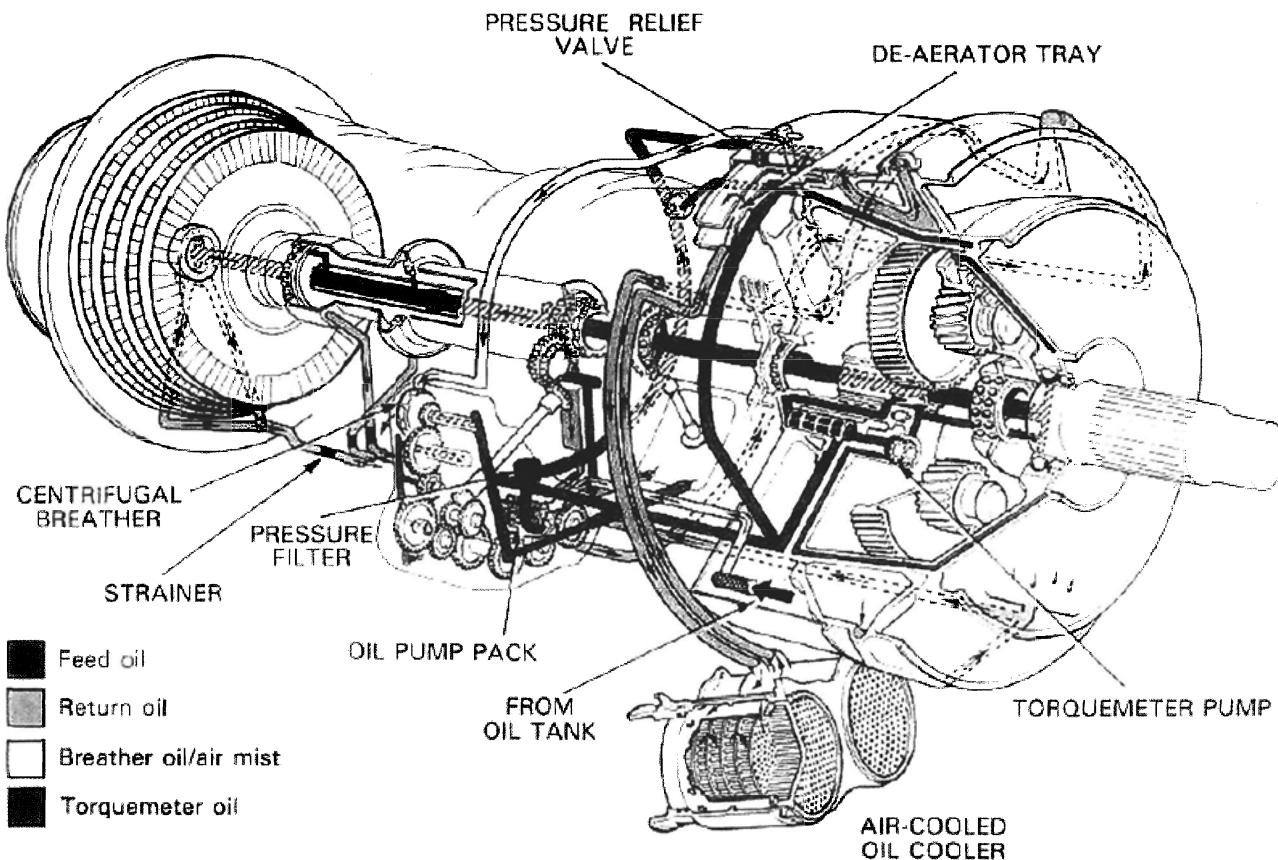


Figure 10.1: A Pressure Relief Valve Oil System

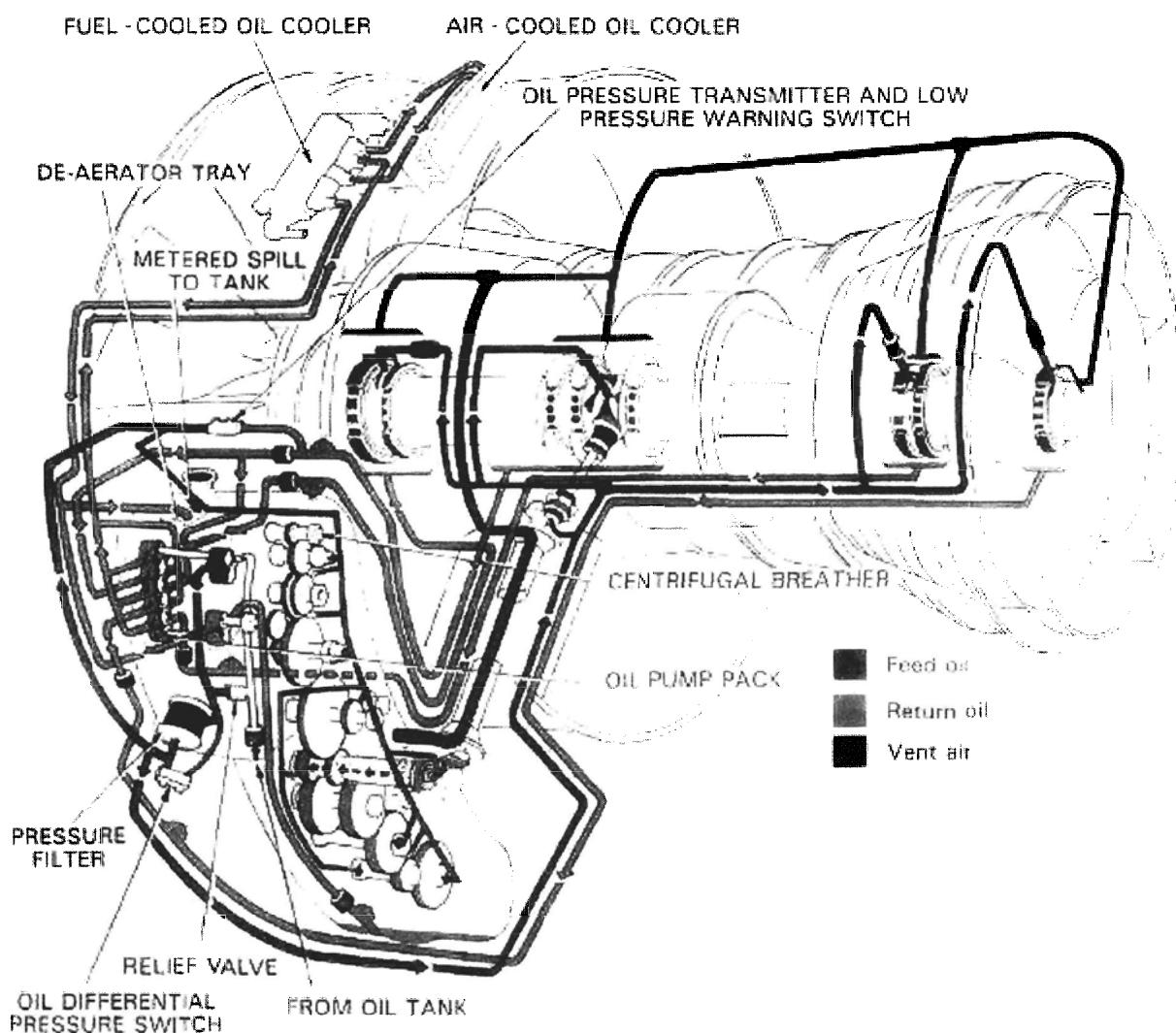


Figure 10.3: A Full Flow Oil System



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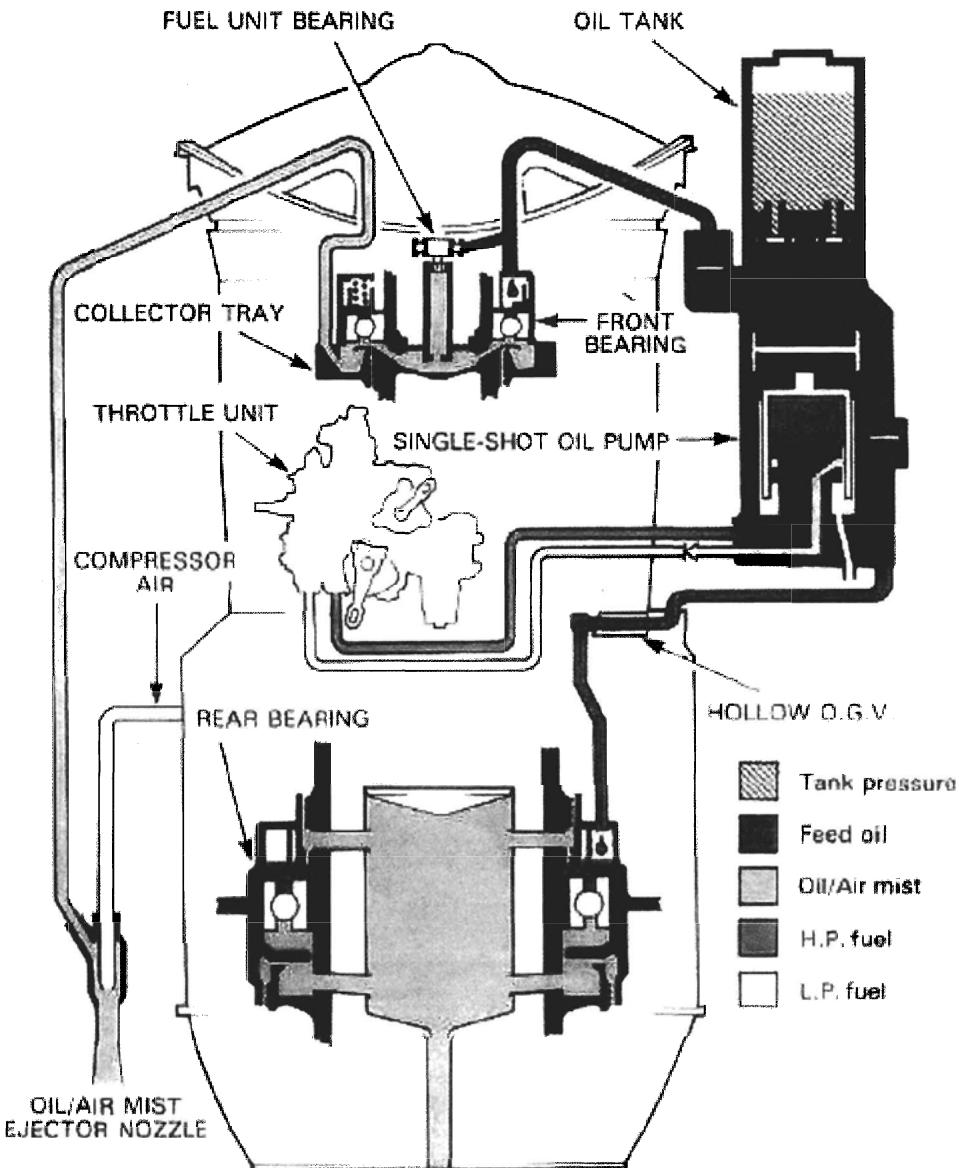


Figure 10.5: Total Loss Oil System

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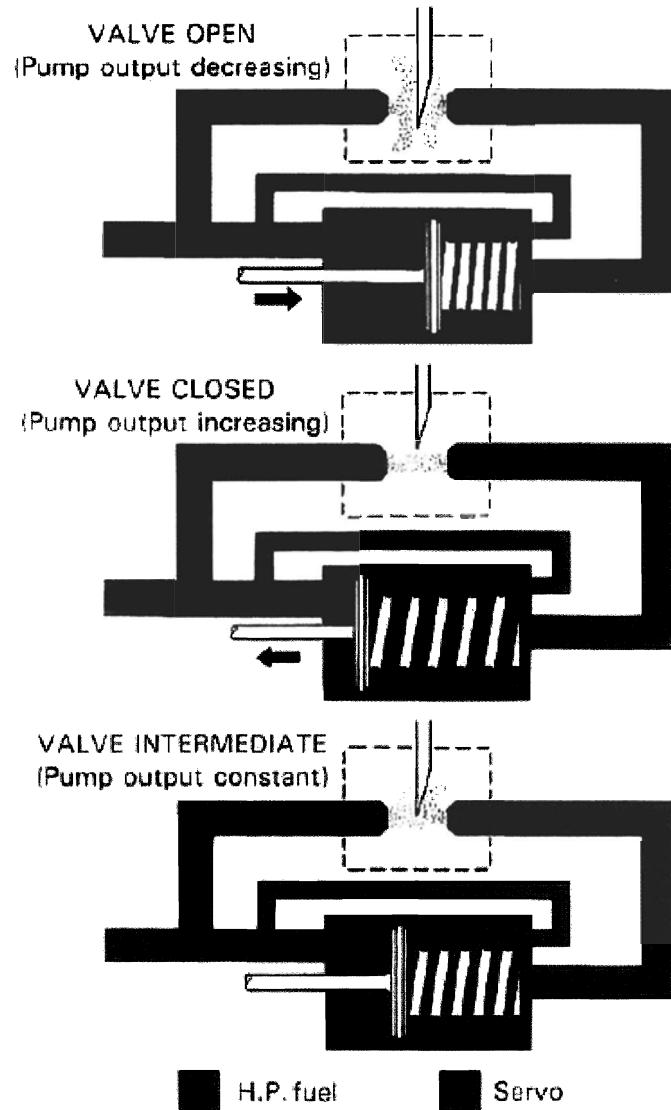


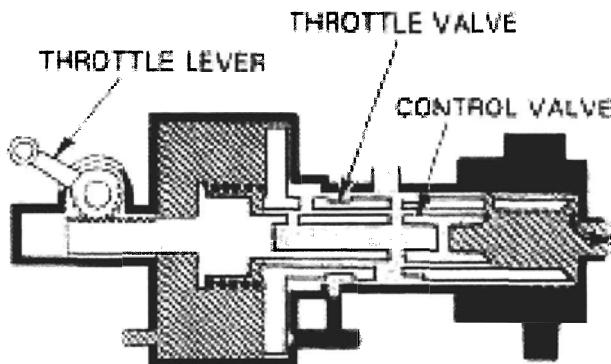
Figure 11.5: Operation of Kinetic Valves



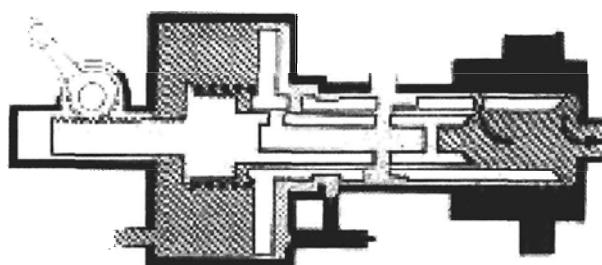
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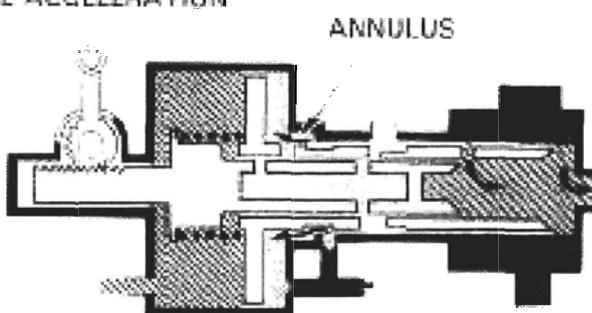
CLOSED POSITION



INITIAL ACCELERATION



FINAL ACCELERATION



FUEL PRESSURES

	Pump delivery		Low pressure
	Throttle outlet		Throttle servo
	Throttle control		

Figure 11.10: Dashpot throttle

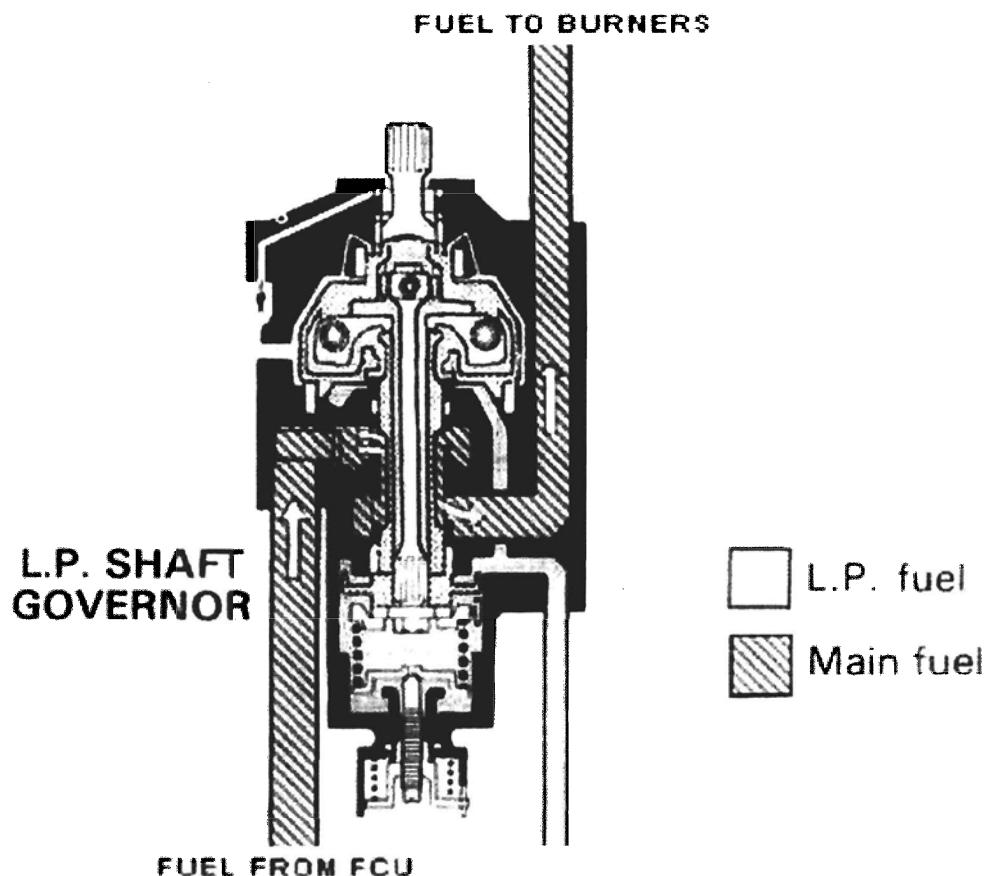


Figure 11.13: LP Shaft Governor



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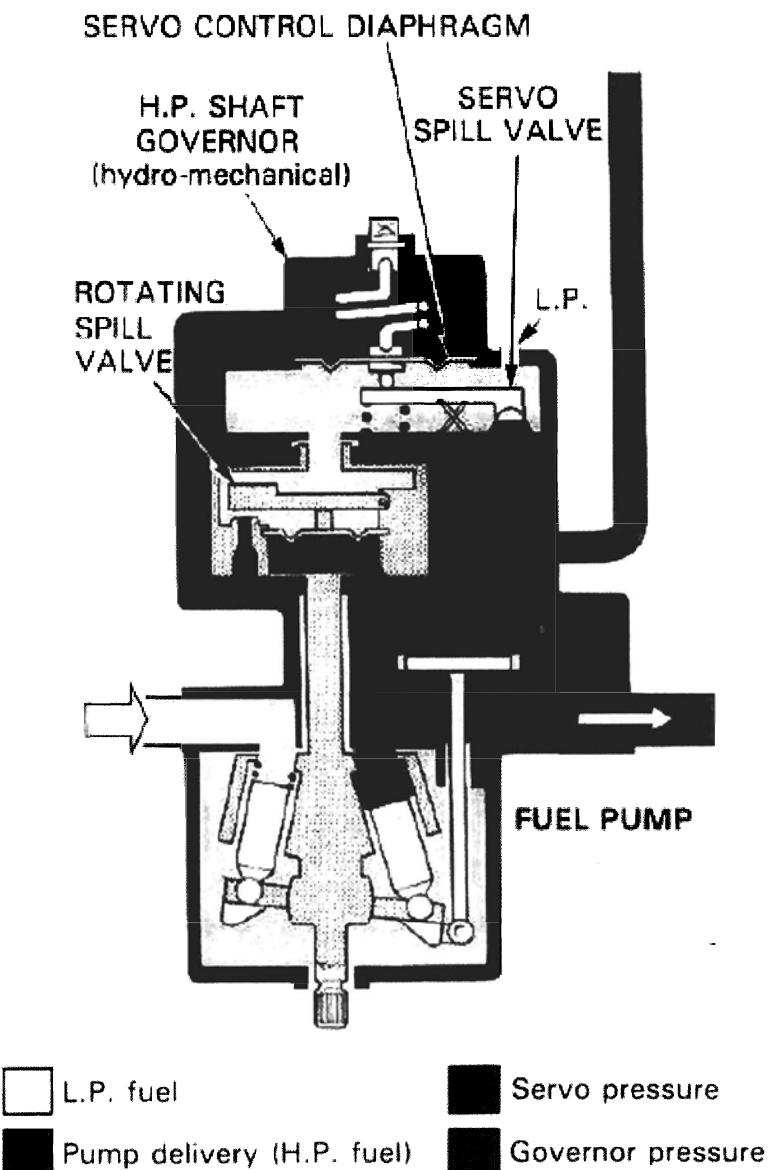


Figure 11.14: HP Hydro-Mechanical Governor



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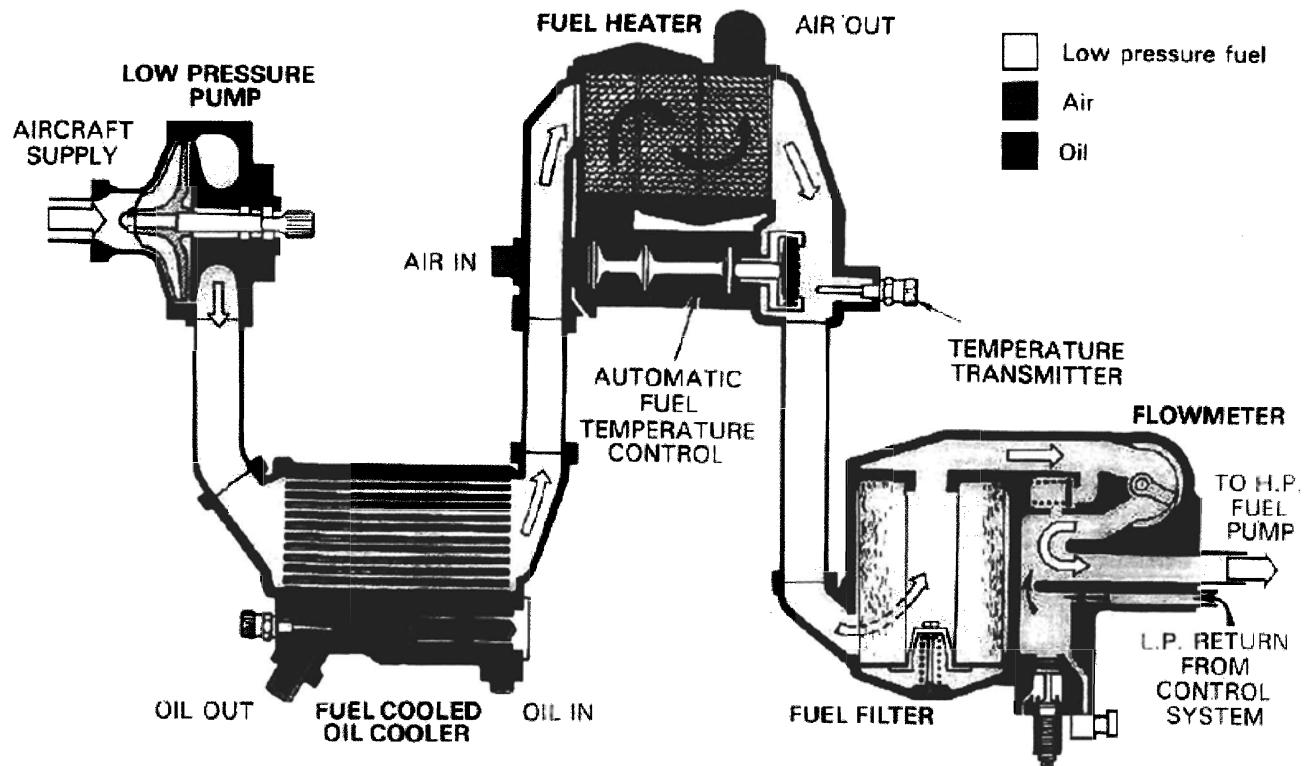


Figure 11.15: Components of the low pressure side of a fuel system

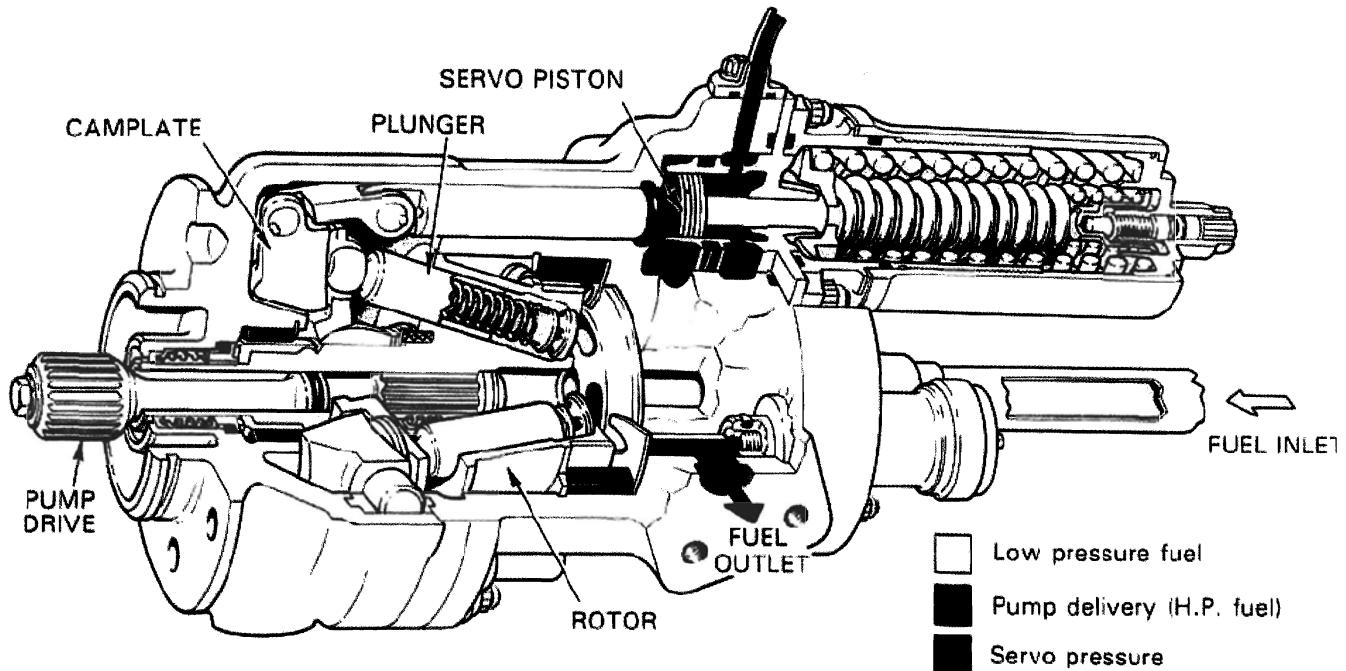


Figure 11.17: Plunger or Swash Plate Type HP Pump

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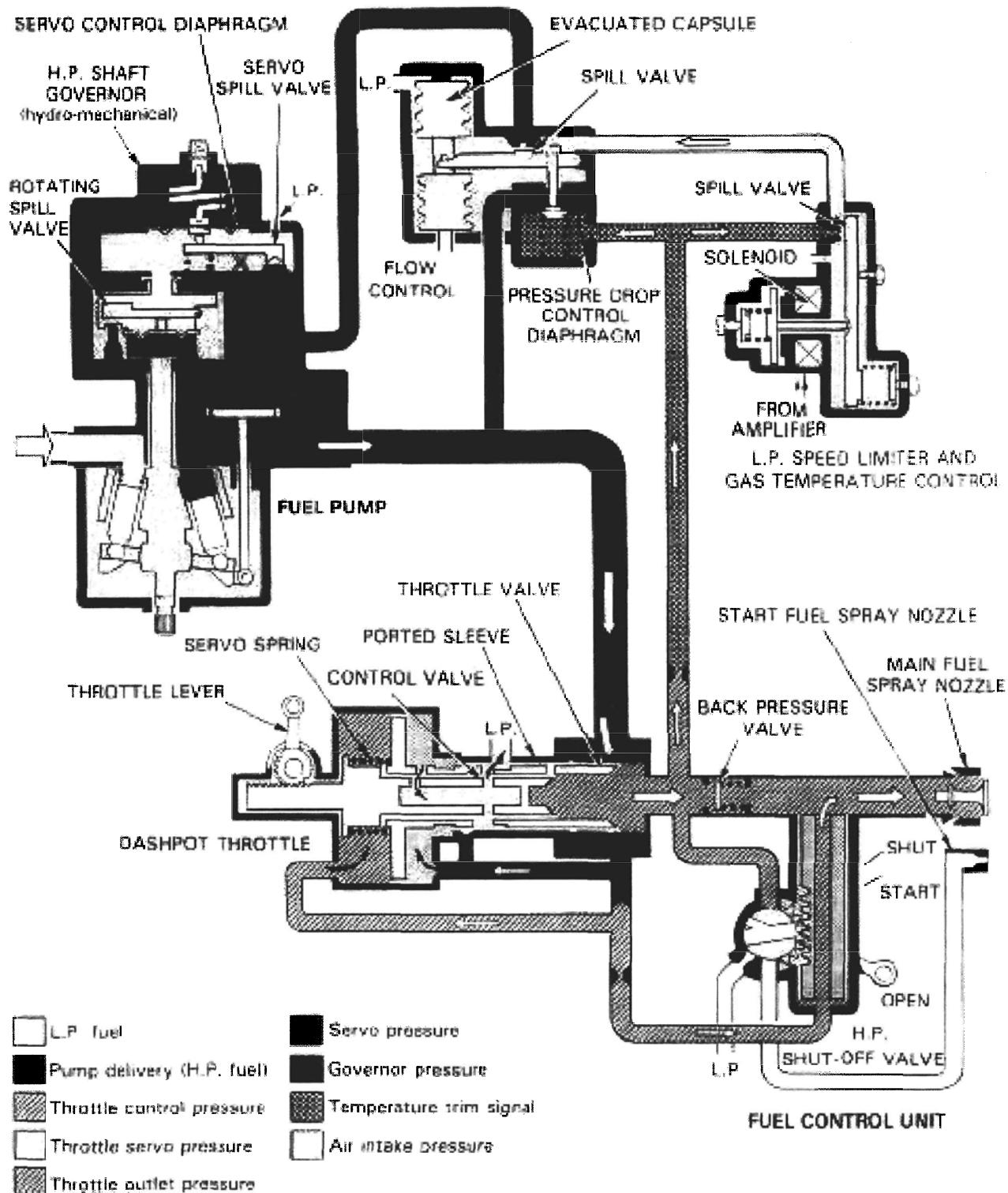


Figure 11.18: Turbo-Jet Pressure Control Fuel System



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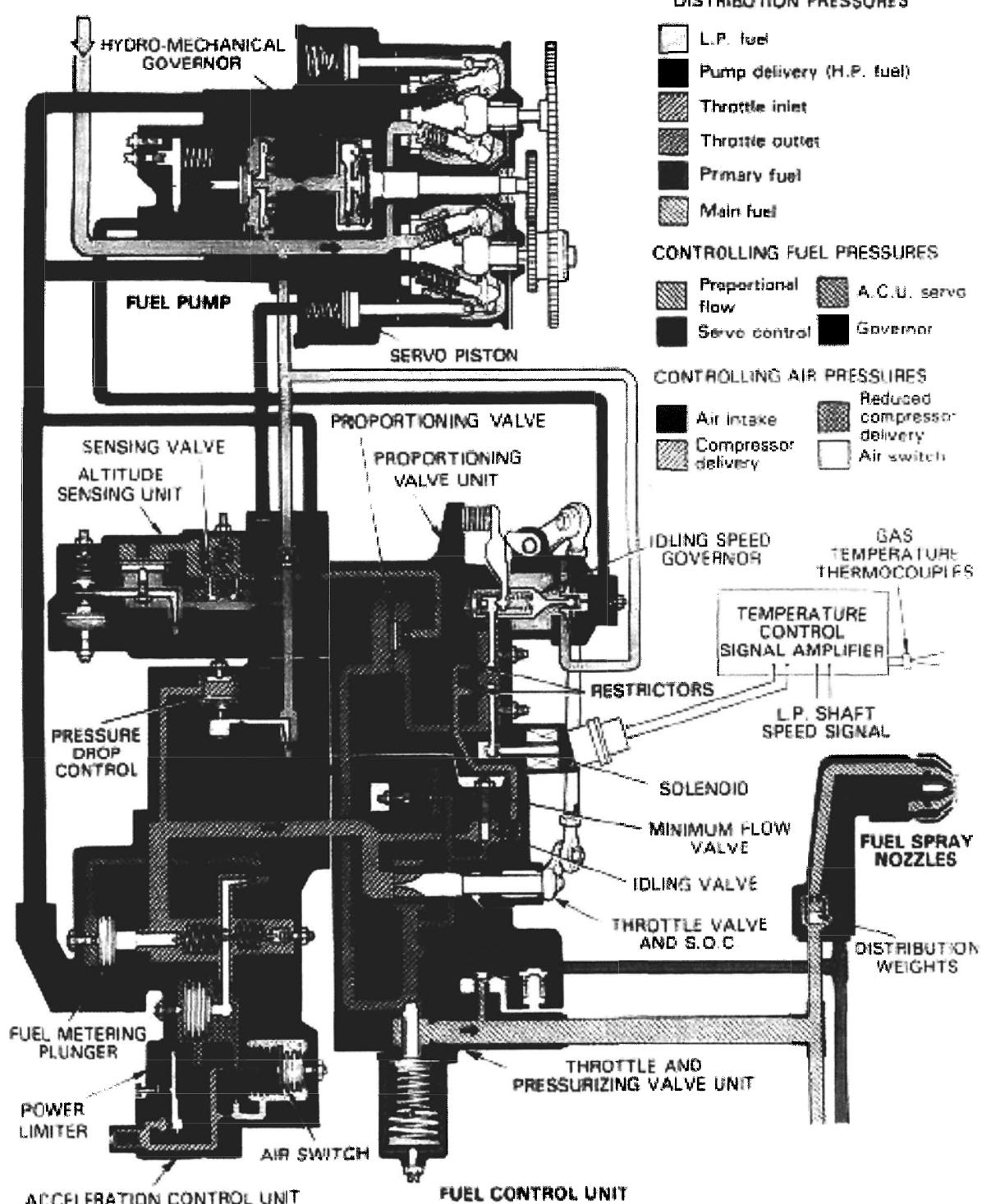


Figure 11.19: A Proportional Flow Control System

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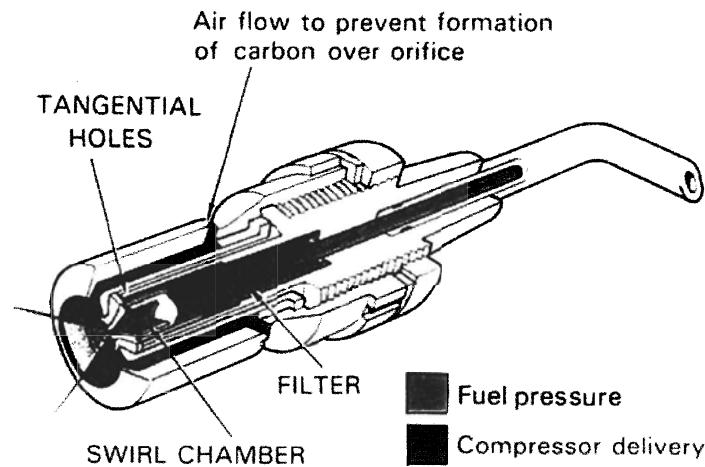


Figure 11.20: Simplex nozzle and spray patterns

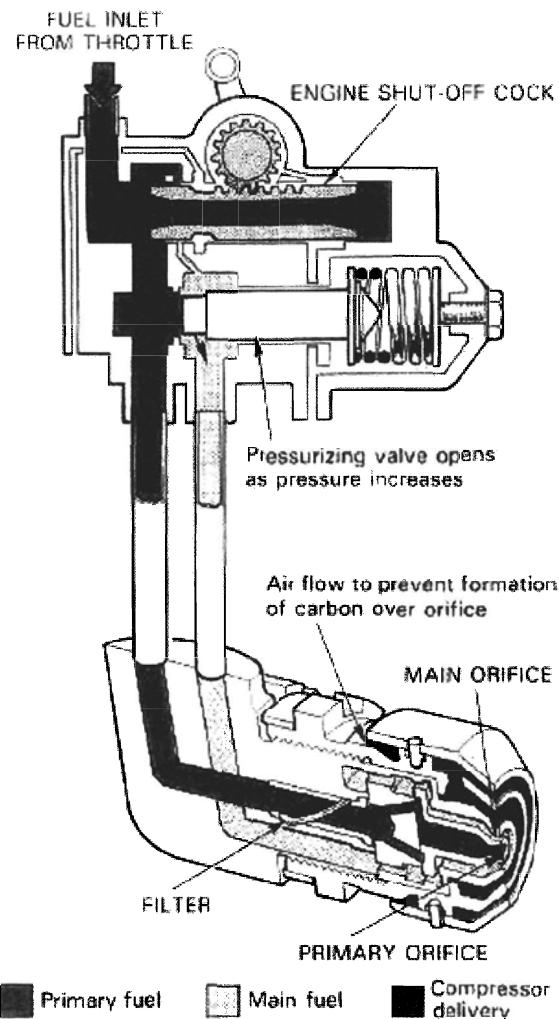


Figure 11.21: Duplex (or Duple) Burner

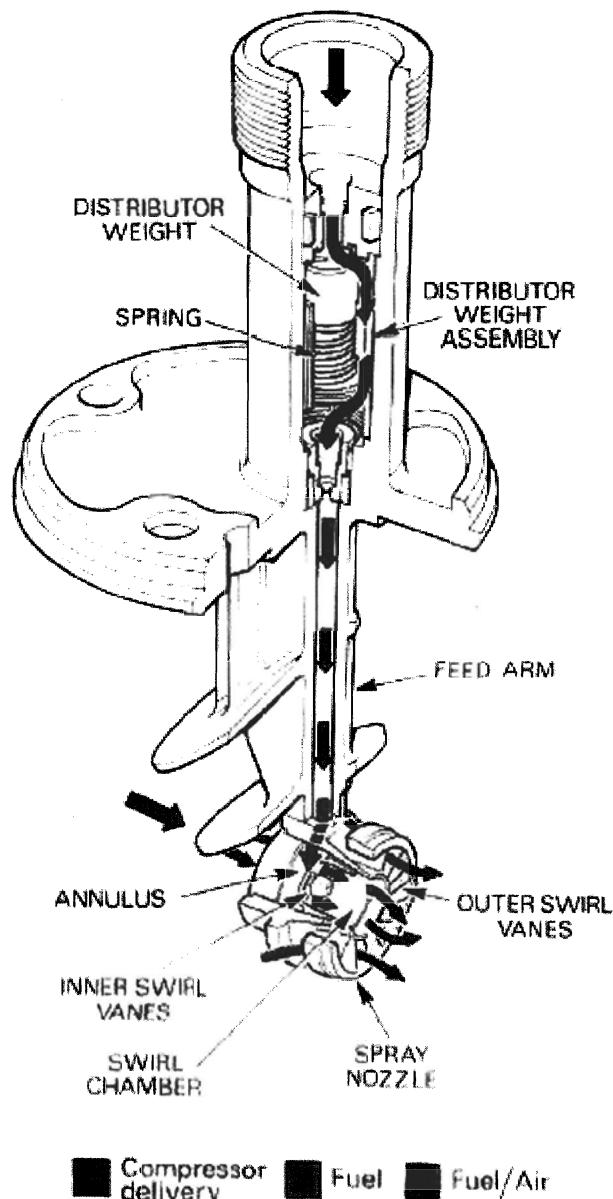


Figure 11.24: Fuel Spray Nozzle

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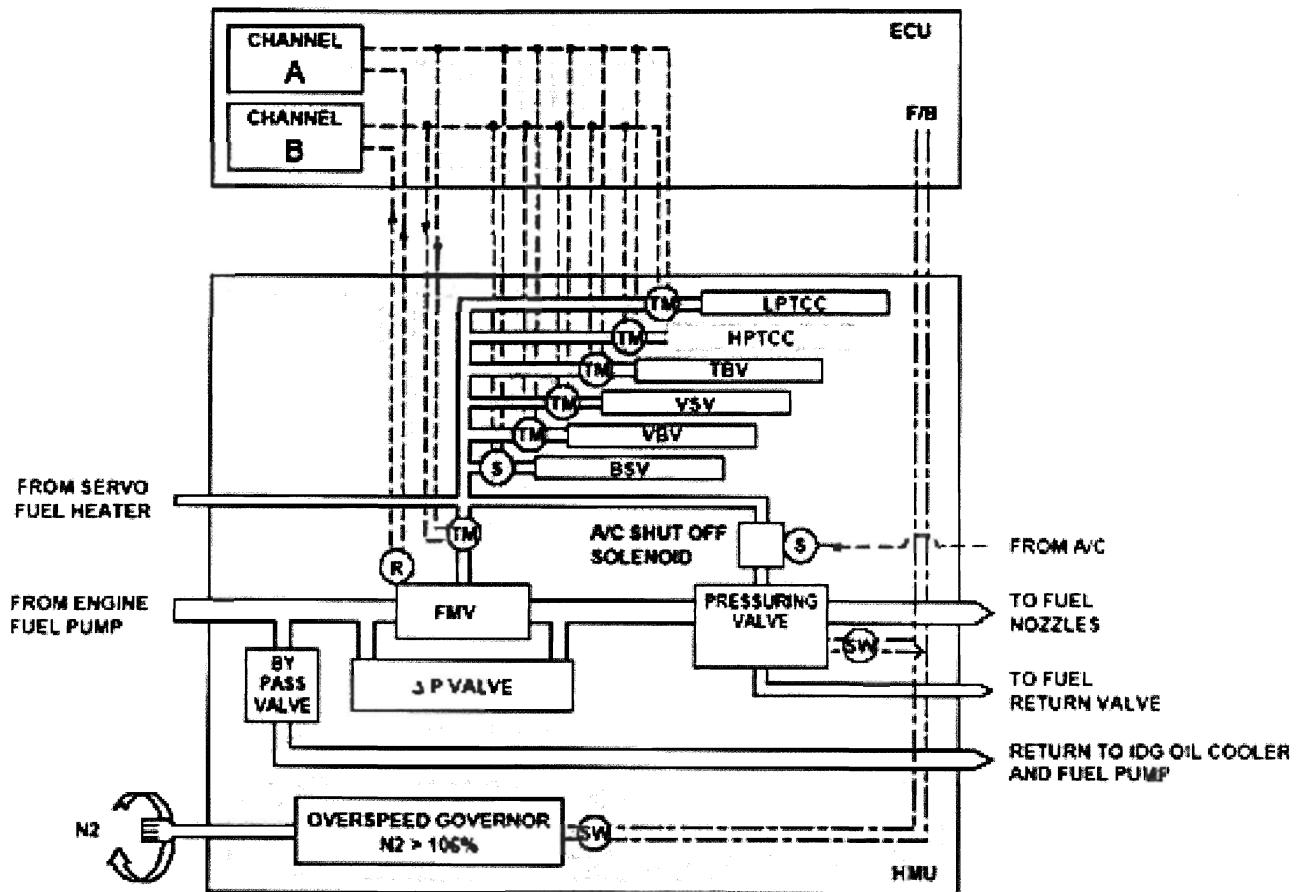
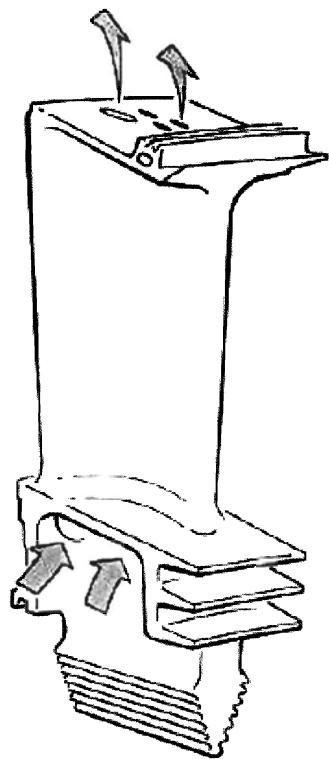


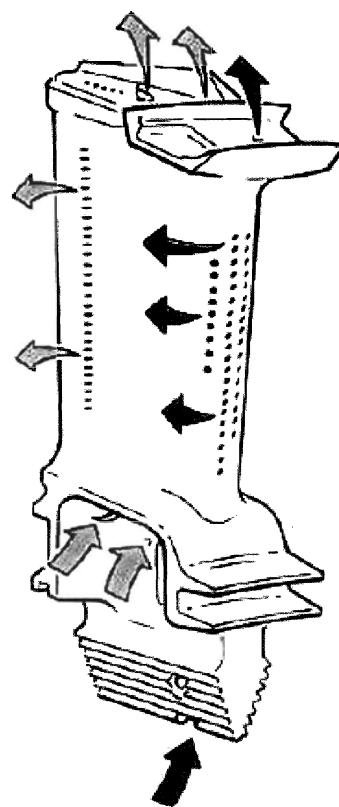
Figure 11.35: Typical HMU System



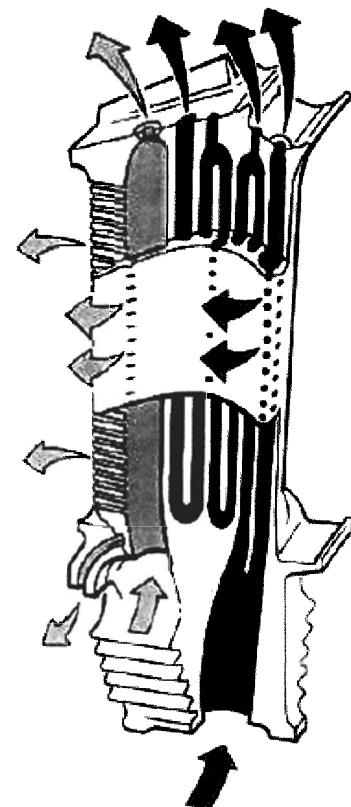
■ L.P. cooling air ■ H.P. cooling air



SINGLE PASS,
INTERNAL COOLING
(1980's)



SINGLE PASS,
MULTI-FEED
INTERNAL COOLING
WITH FILM COOLING
(1970's)



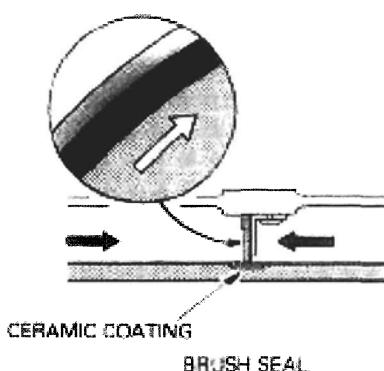
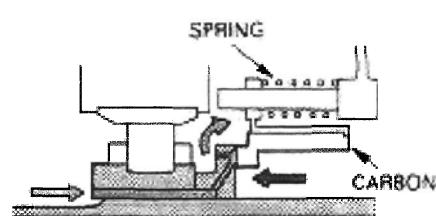
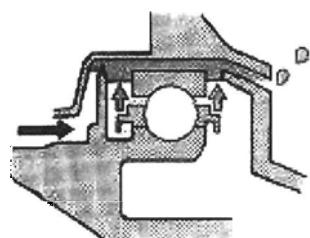
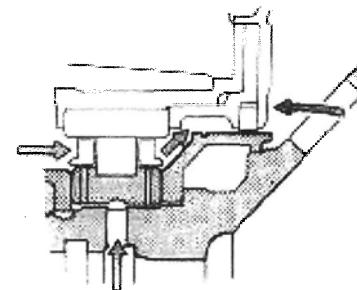
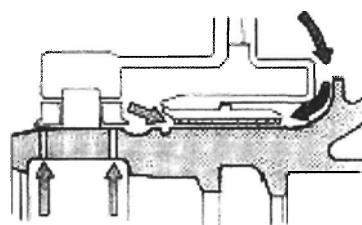
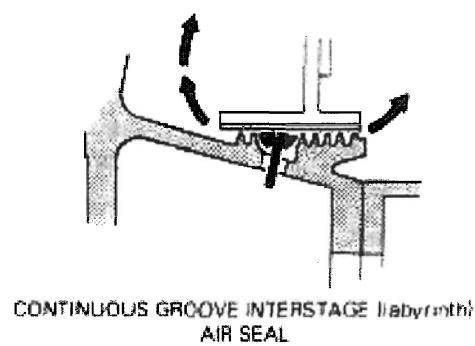
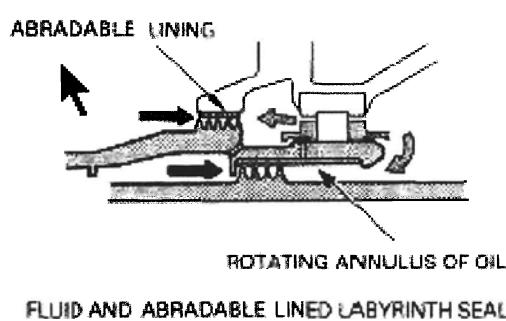
QUINTUPLE PASS,
MULTI-FEED
INTERNAL COOLING
WITH EXTENSIVE
FILM COOLING

Figure 12.4: Typical turbine blade cooling



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- Sealing air
- Oil
- Rotating assemblies

Figure 12.9: Internal Seals

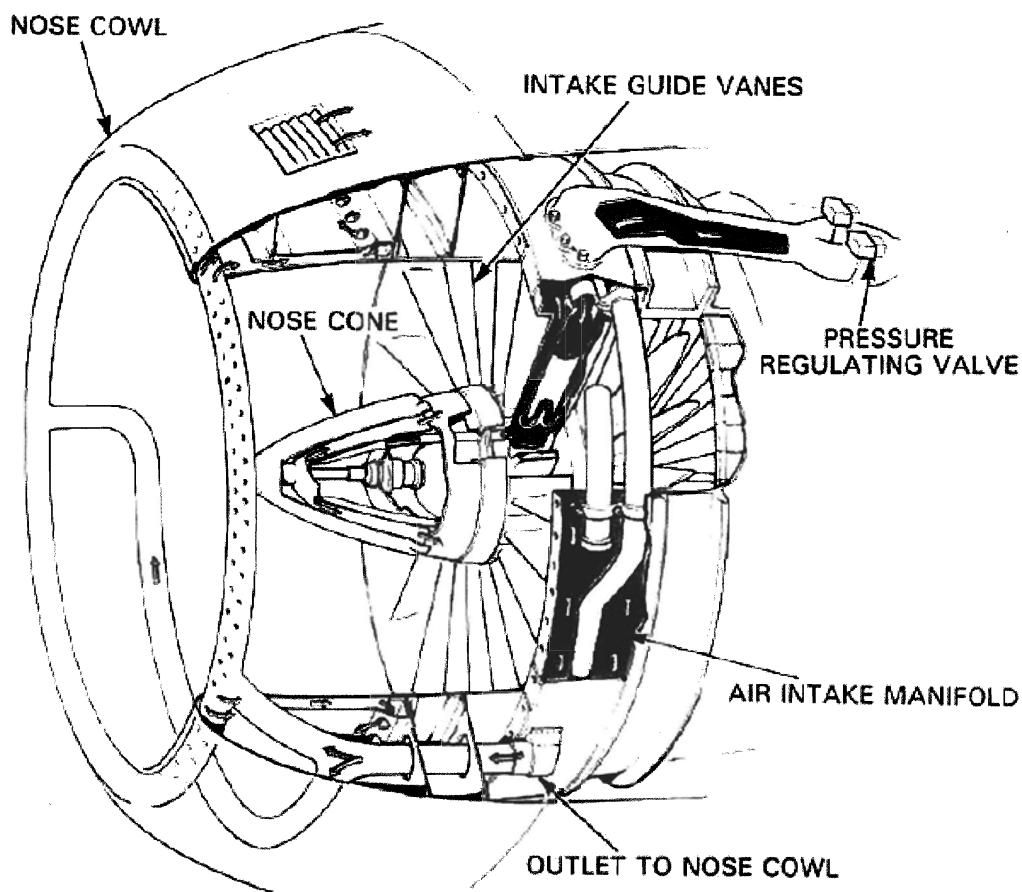


Figure 12.12: Anti-ice of the nose cowl, spinner and inlet guide vanes

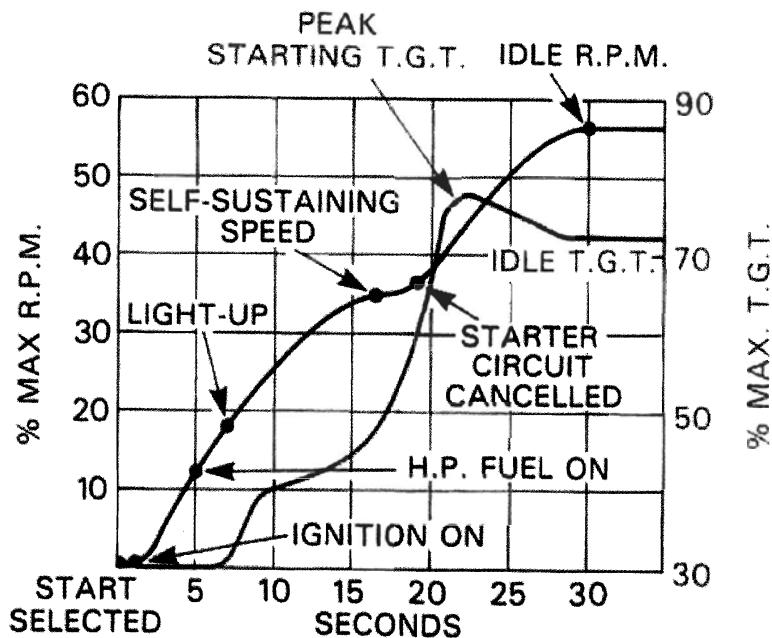


Figure 13.1: Typical engine start sequence



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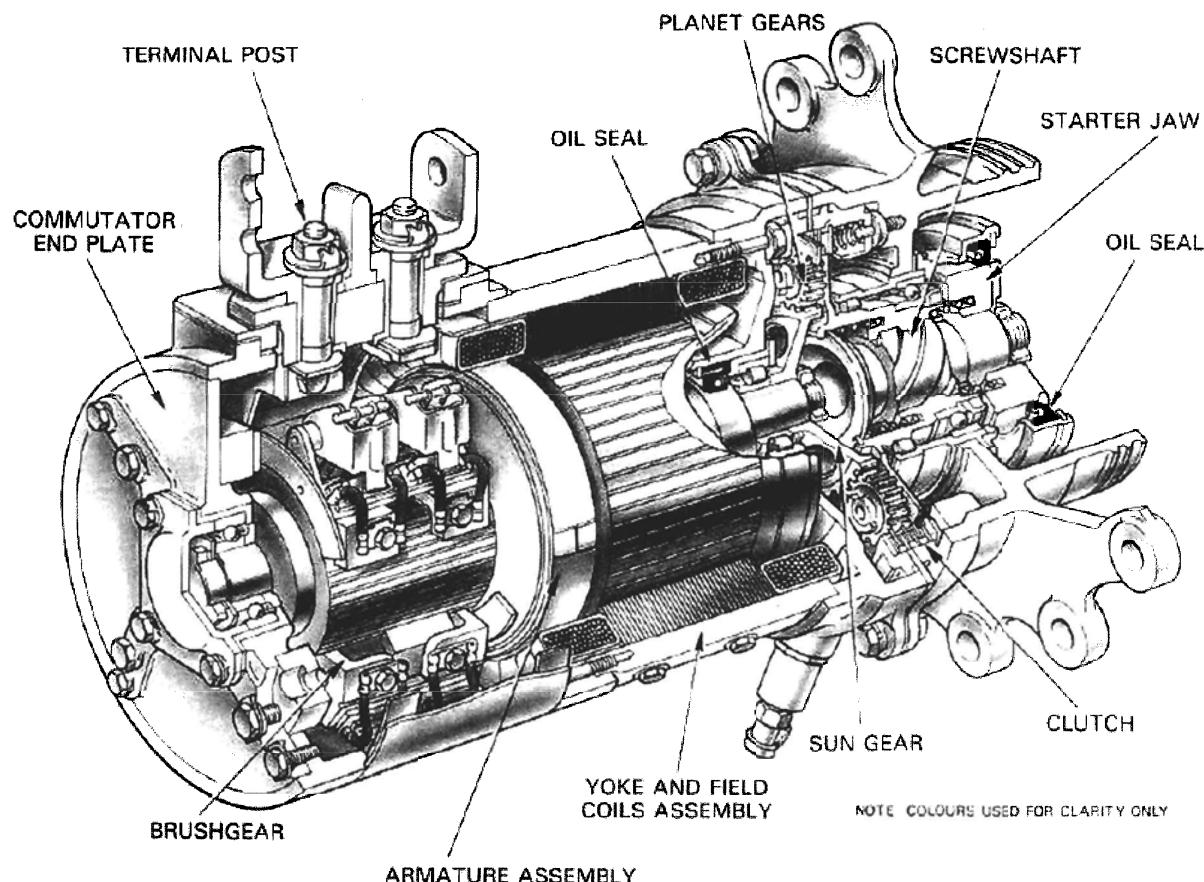


Figure 13.3: Electrical Starter Motor



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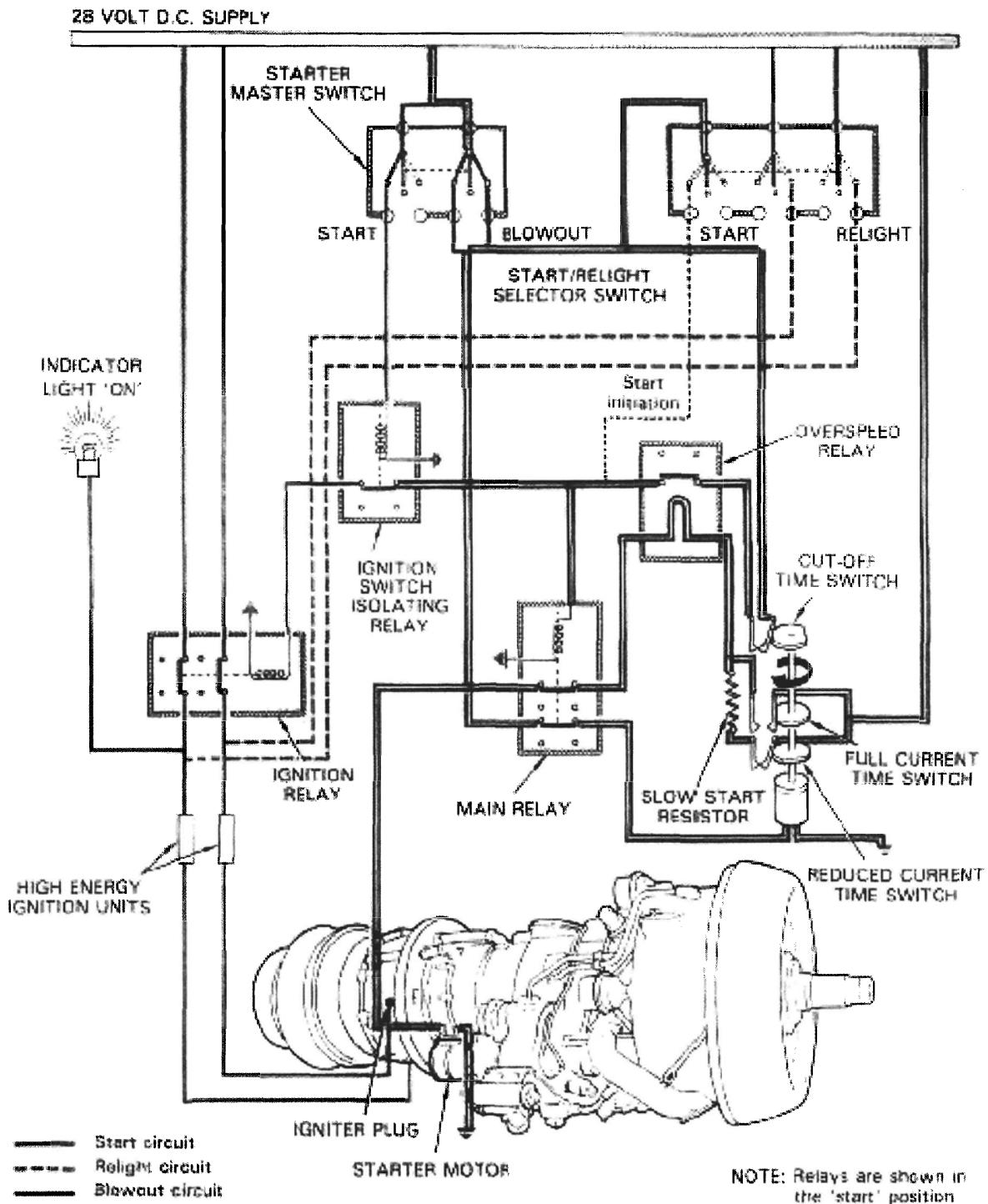


Figure 13.6: Low Voltage Starting System



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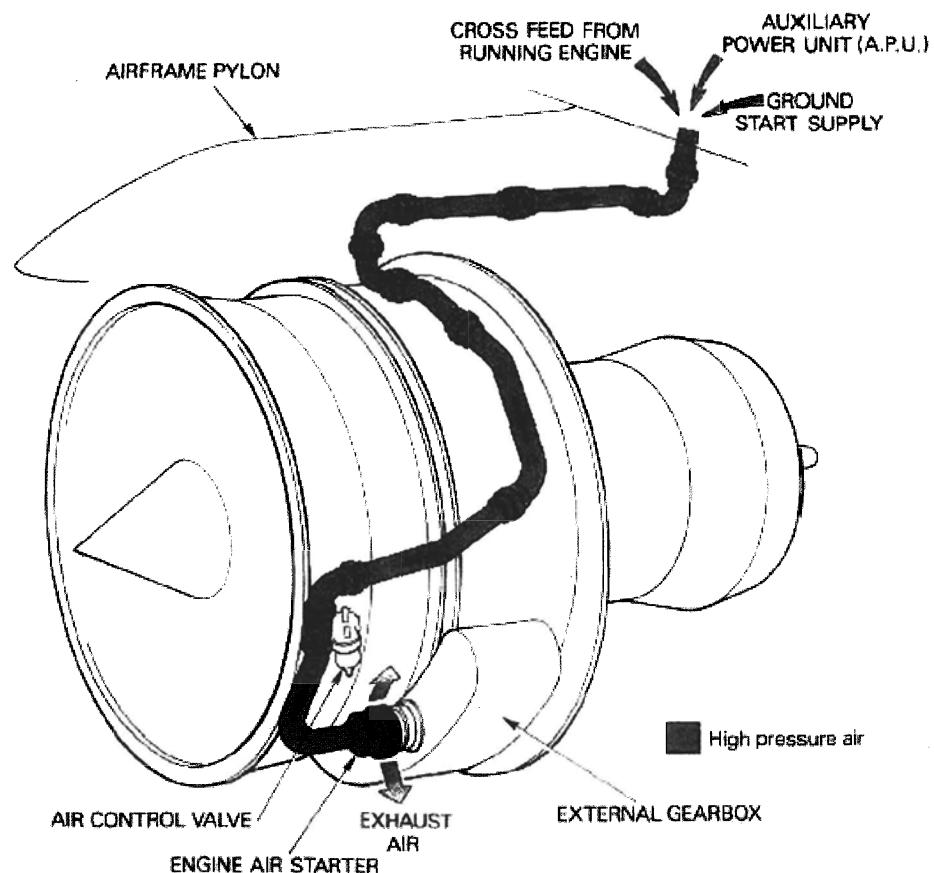


Figure 13.8: Air Starter System Layout – Boeing 757

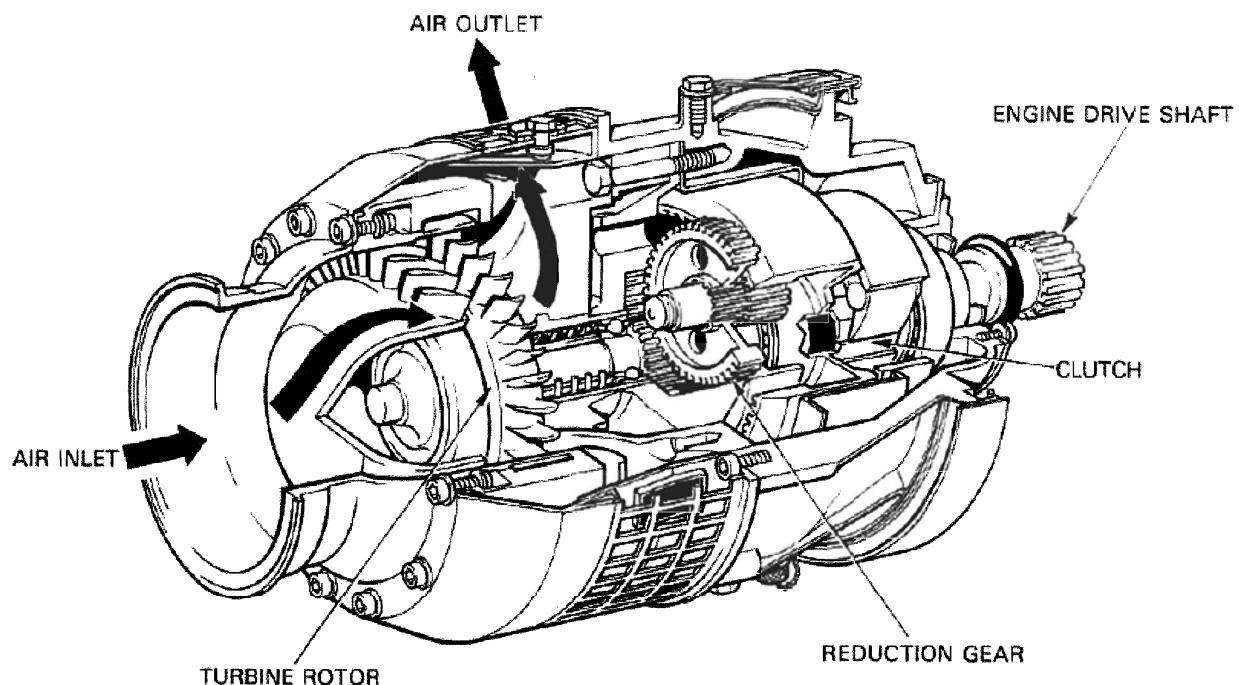


Figure 13.10: A turbine air starter



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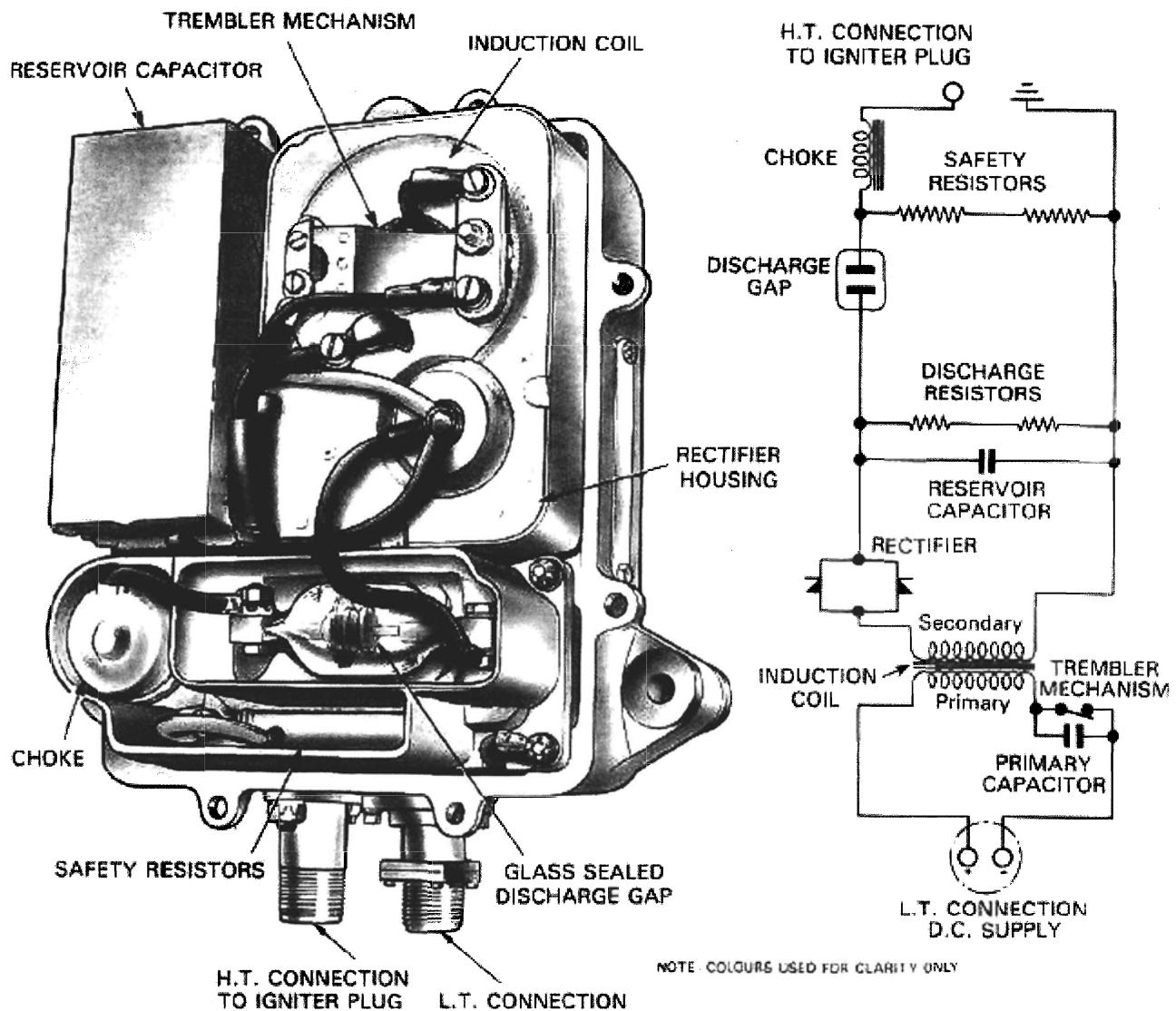


Figure 13.20: Trembler type DC Ignition Unit and Circuit

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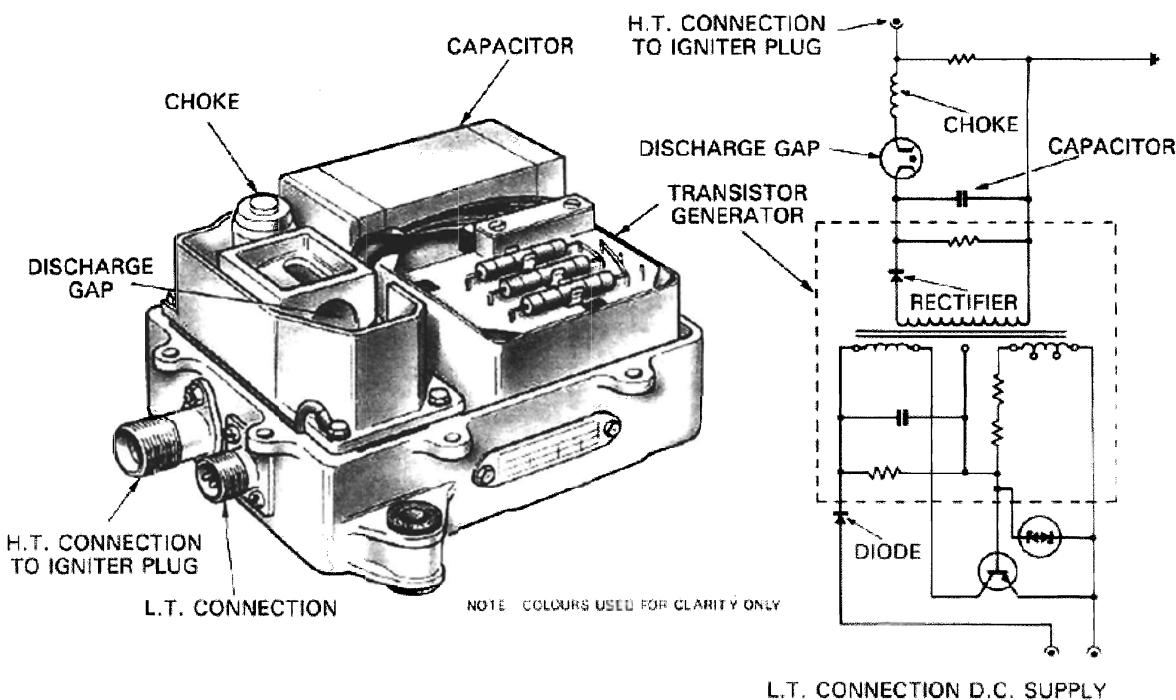


Figure 13.21: A Typical DC Transistorized Unit

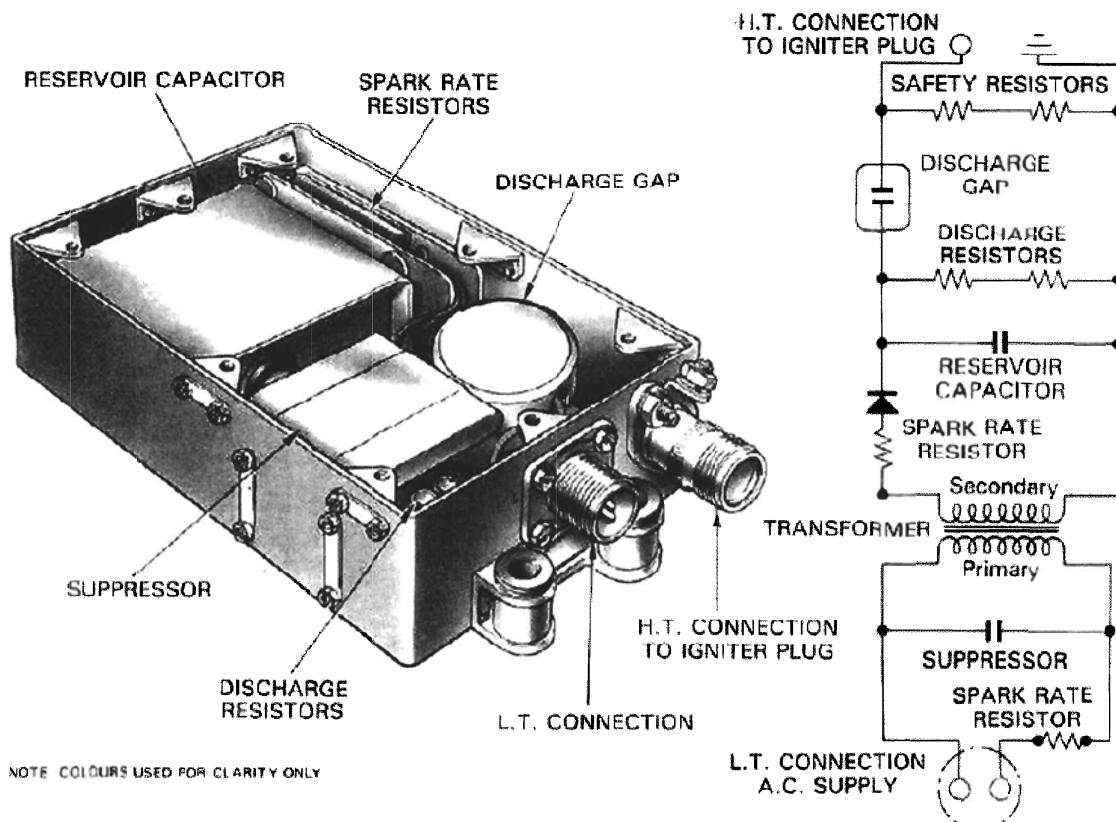


Figure 13.22: A Typical AC Ignition Unit

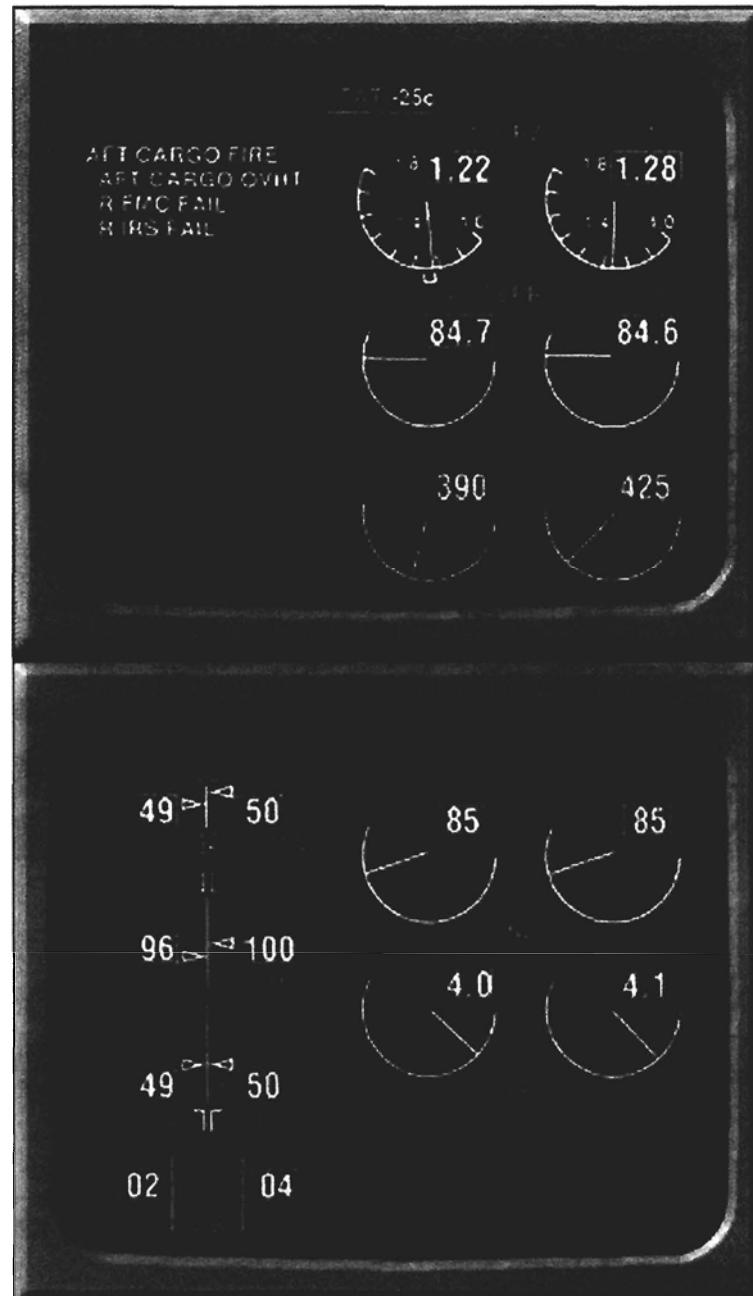


Figure 14.4: Typical EICAS screens



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The torquemeter measures hydraulically the axial load produced by the helical gears when transmitting a driving torque to the propeller

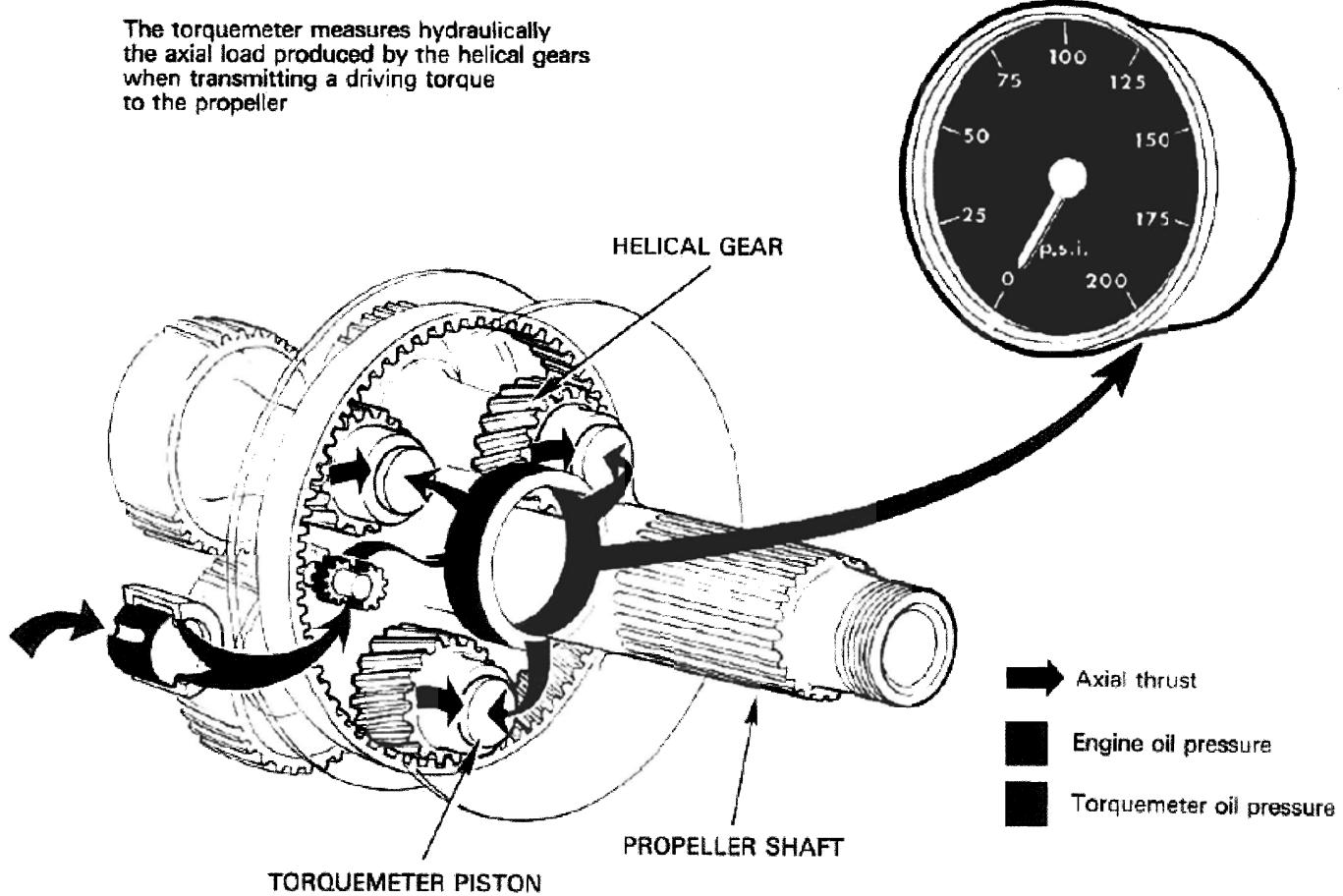


Figure 14.45: Helical Gear Torque Meter

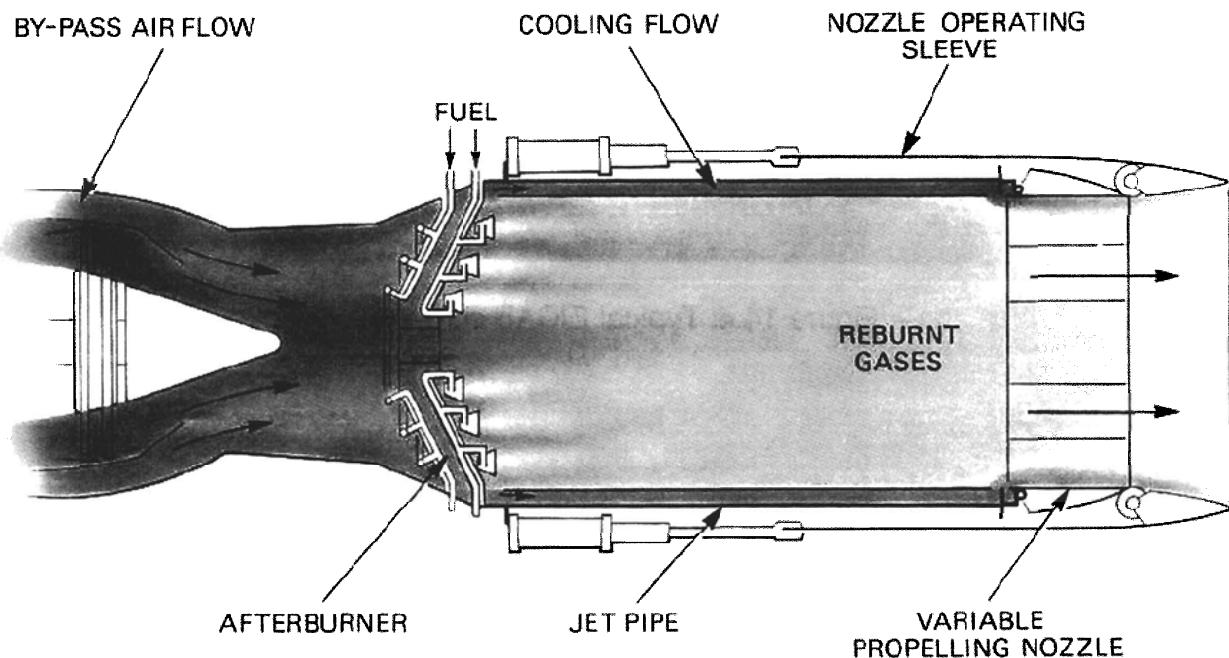


Figure 15.4: Principle of Reheat

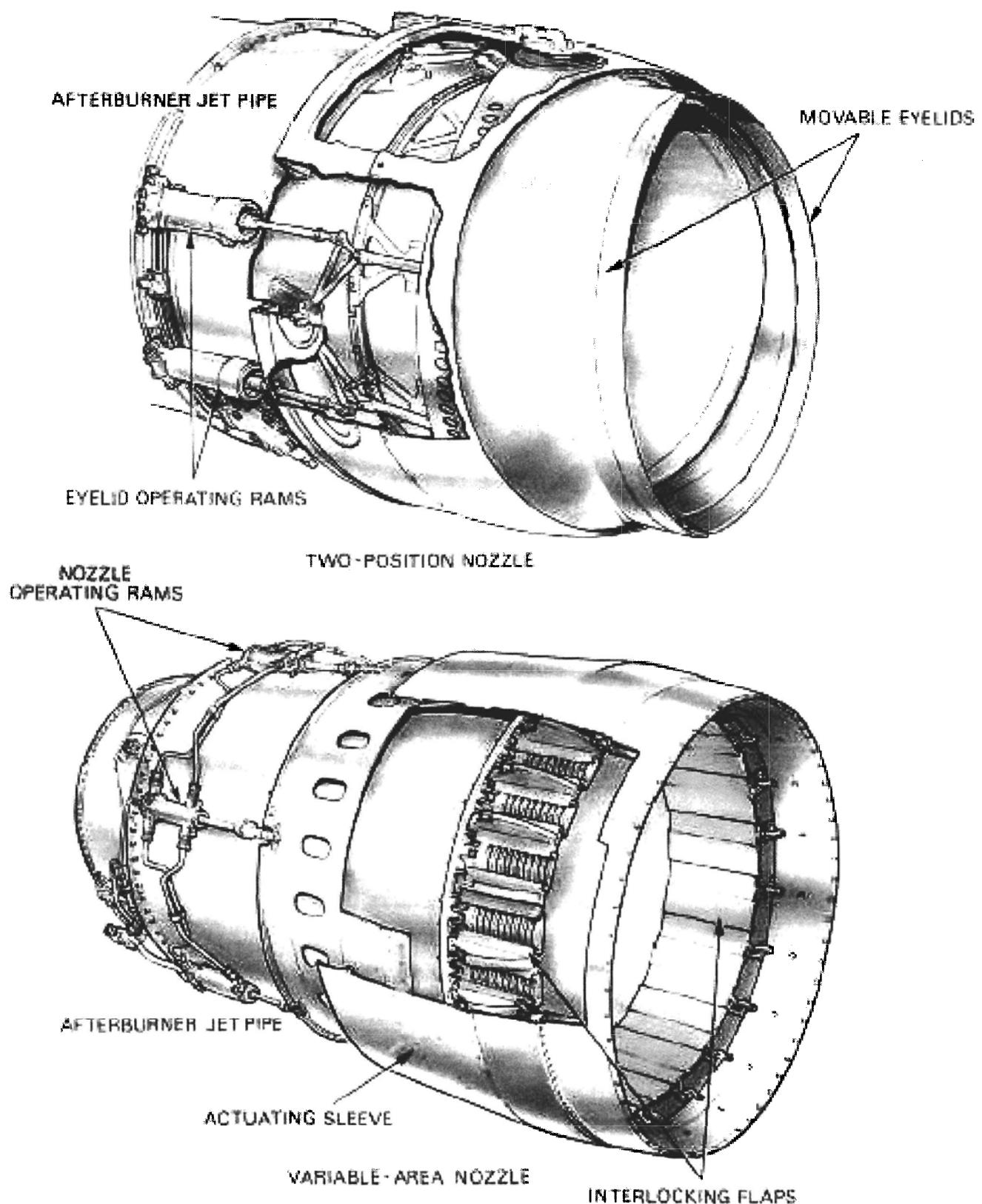


Figure 15.5: Variable Area Nozzle, and Typical Reheat Jet Pipe with Catalytic Ignitor



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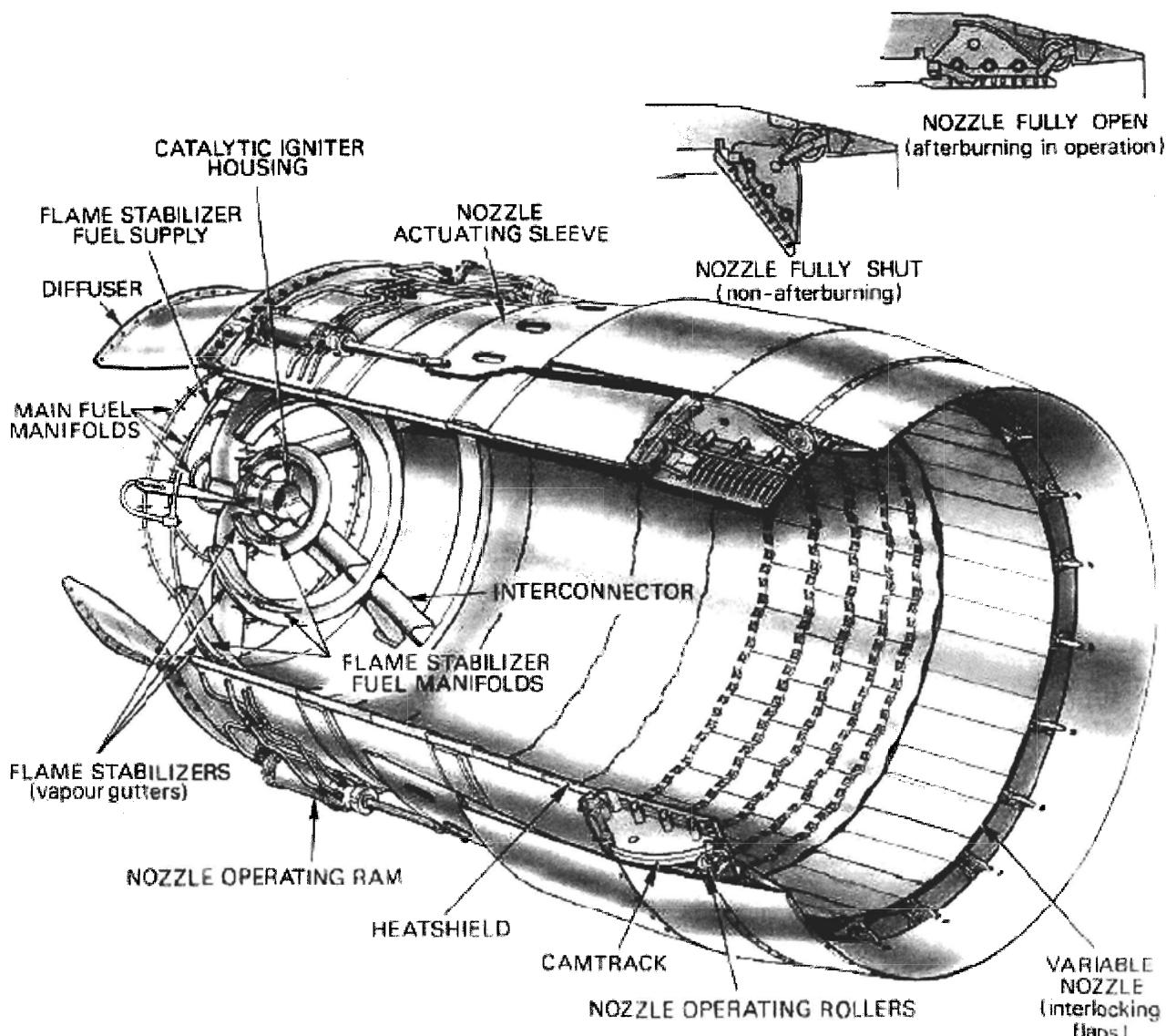


Figure 15.6: Complete reheat assembly

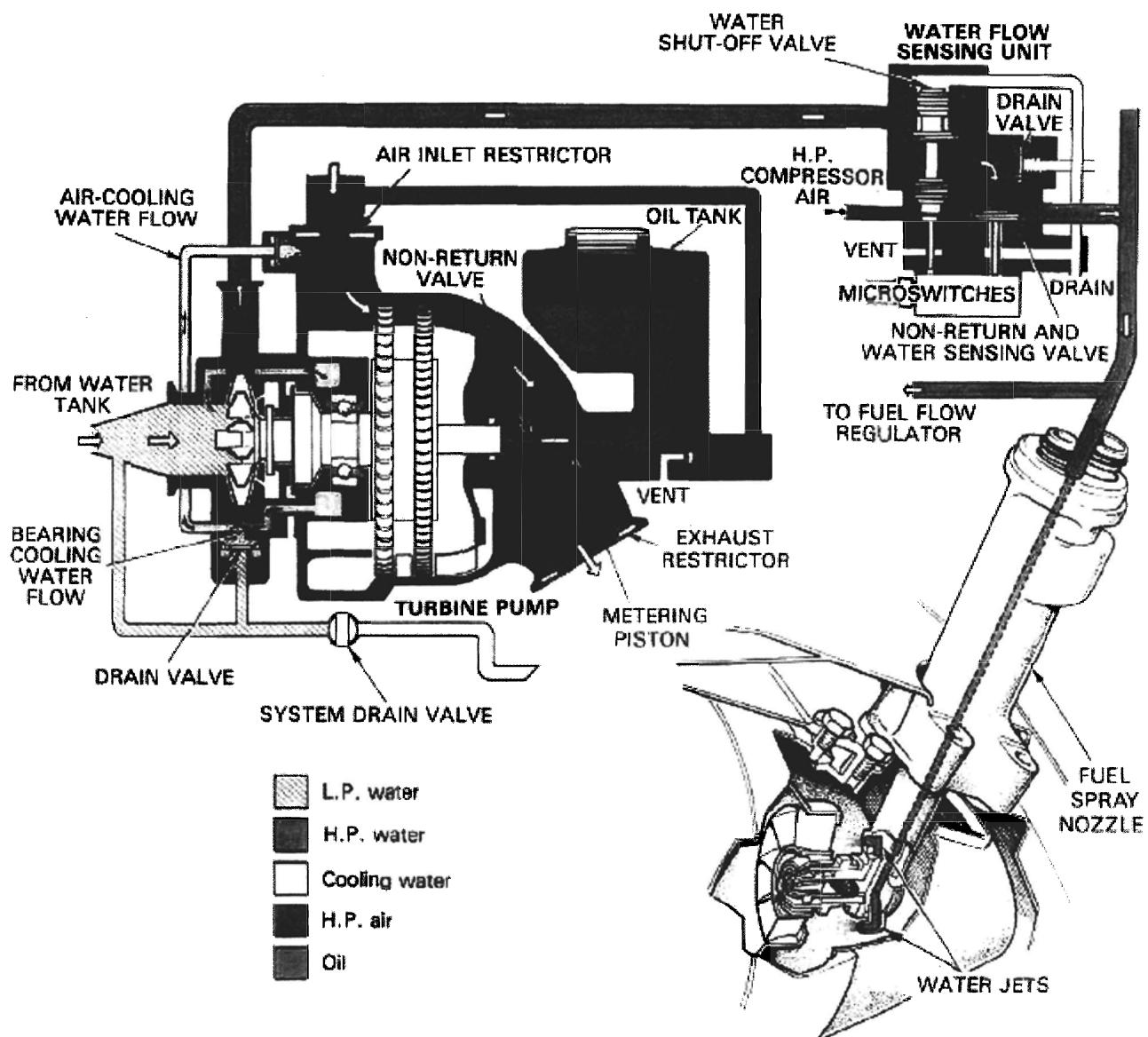


Figure 15.8: Water injection schematic



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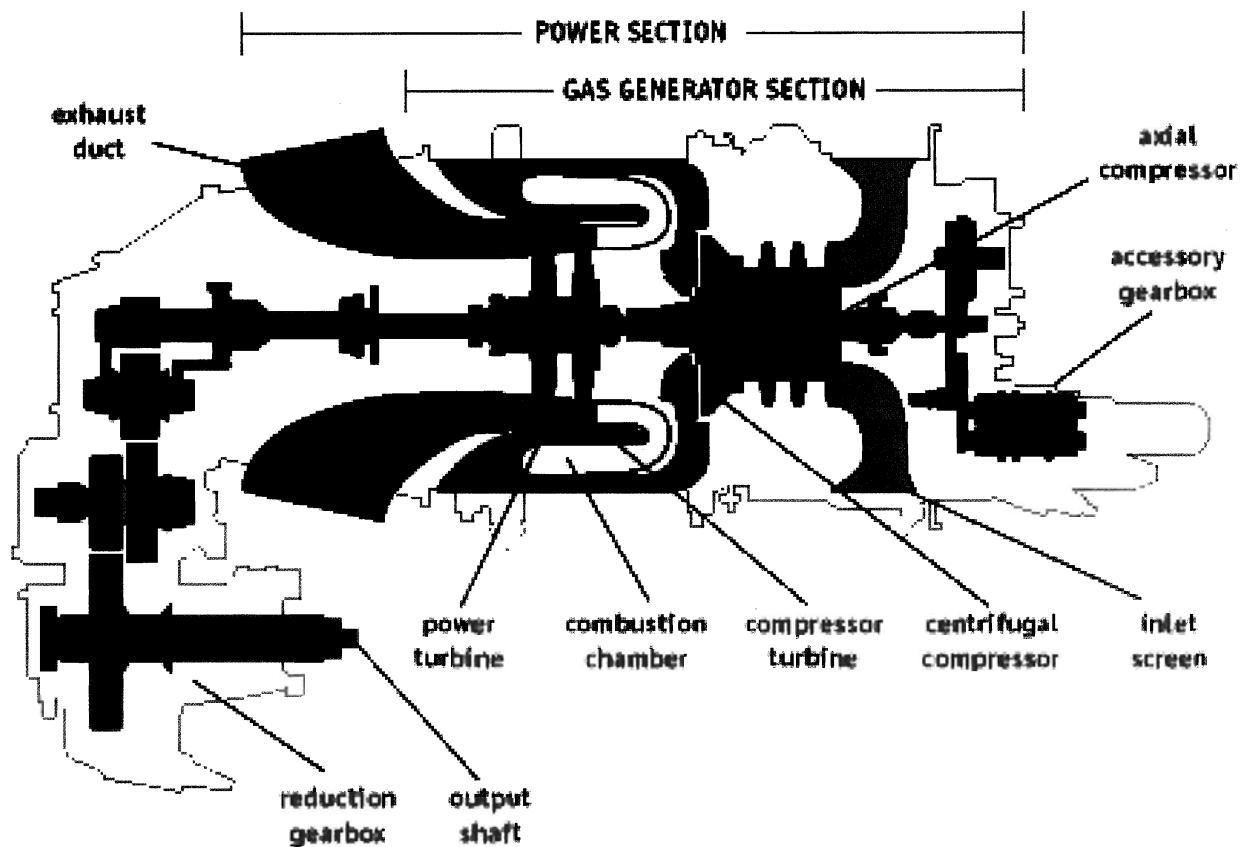


Figure 16.2: PT6 Free (Power) Turbine Engine

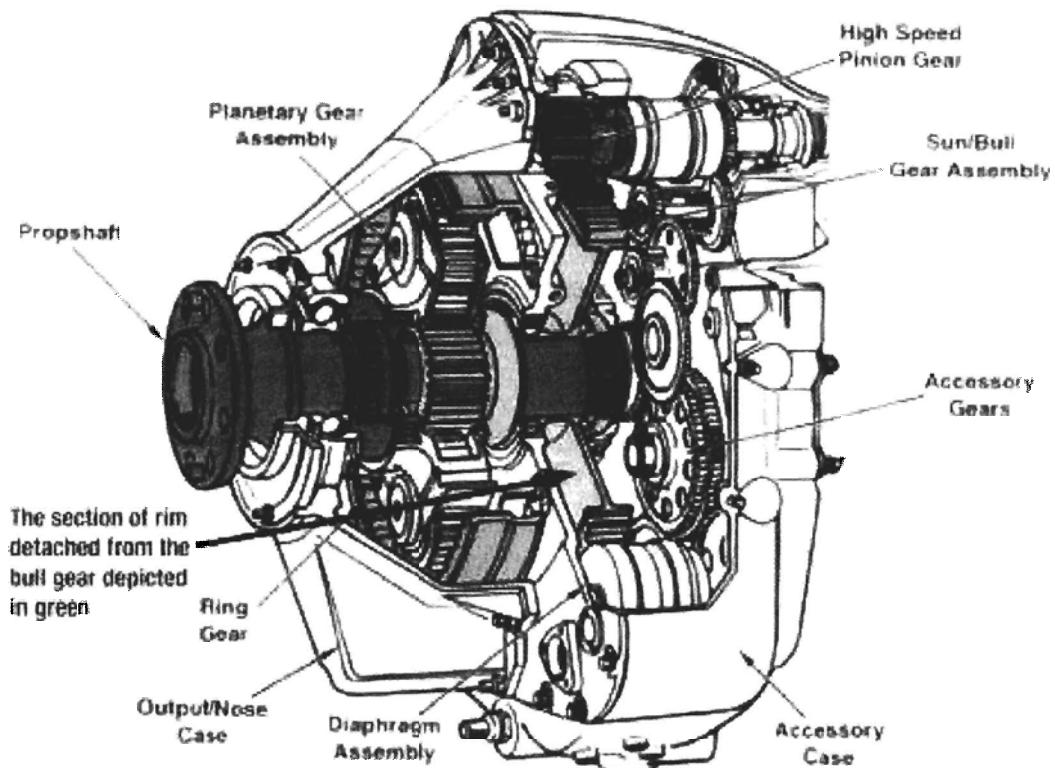


Figure 16.10: A typical epicyclic gear box



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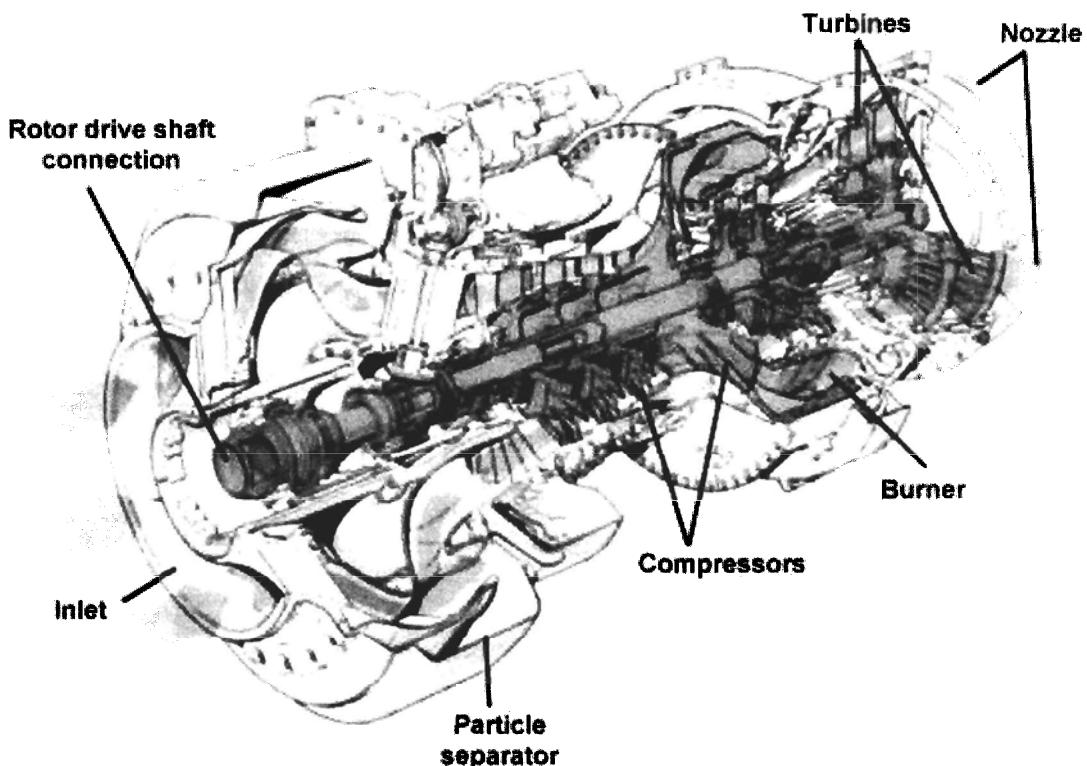
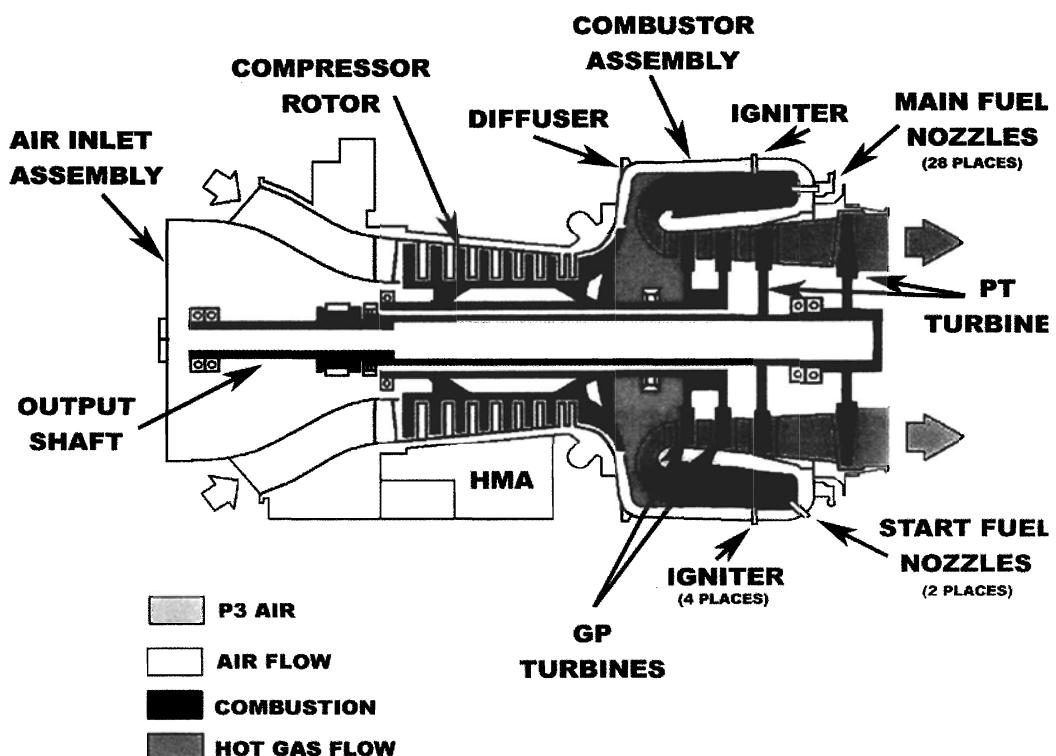


Figure 17.4: T55-714 diagram and cutaway



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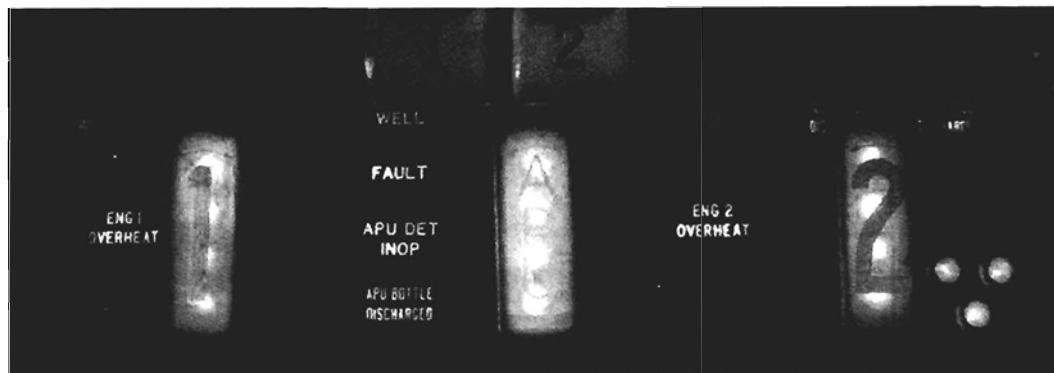


Figure 20.13: Typical fire extinguisher panel (B737)



Figure 20.13: Fire extinguisher bottle indicators (B737)

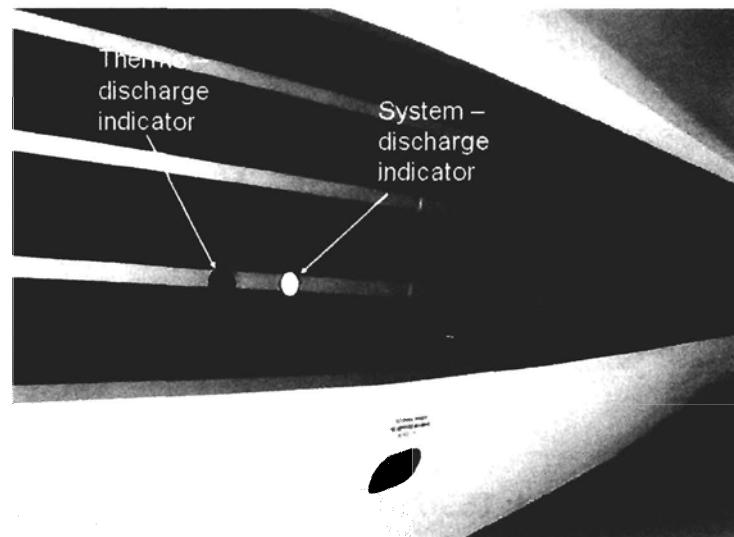


Figure 20.14: Fire extinguisher bottle indicators



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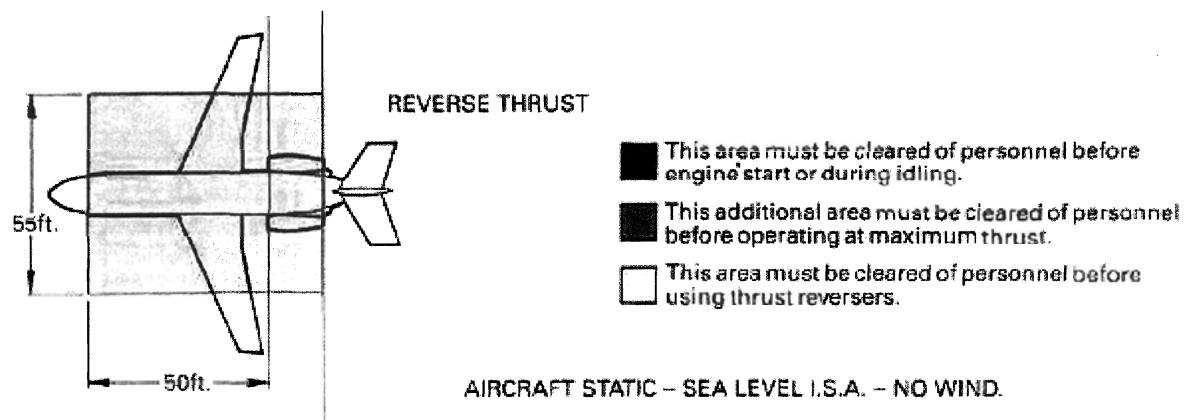
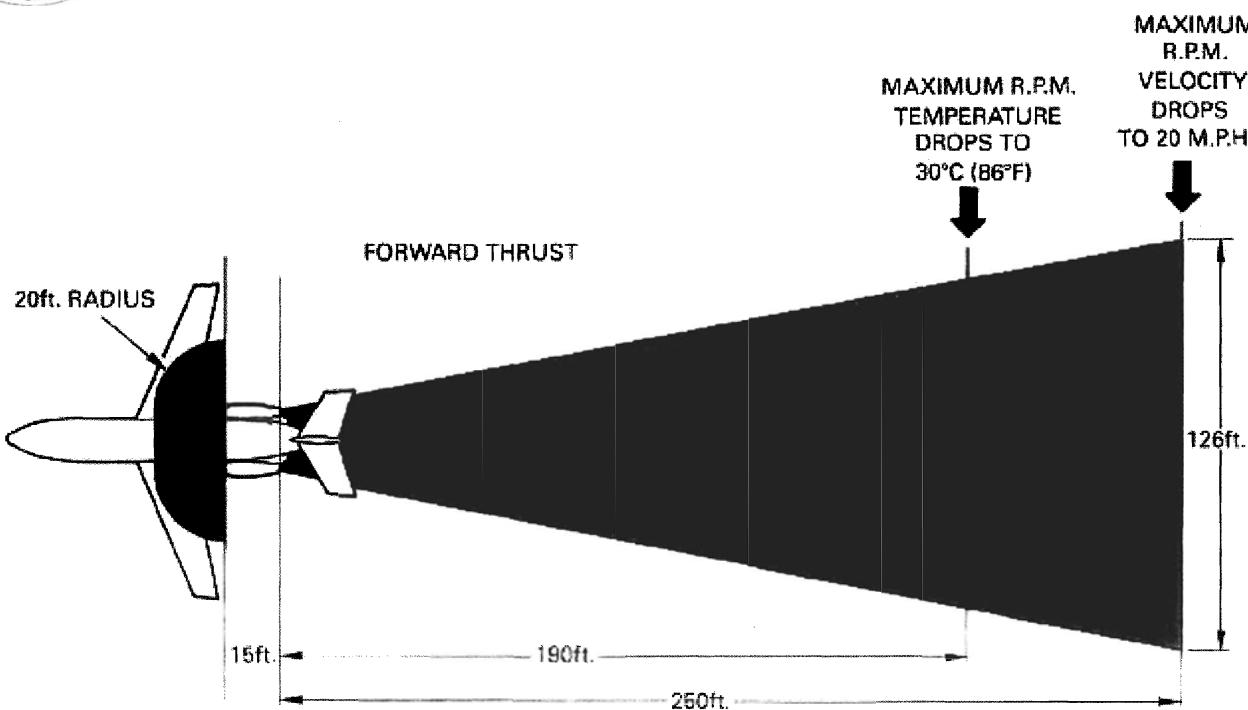


Figure 21.3: Fokker 100 Aircraft showing the engine running danger areas at idle and full power and during reverse thrust

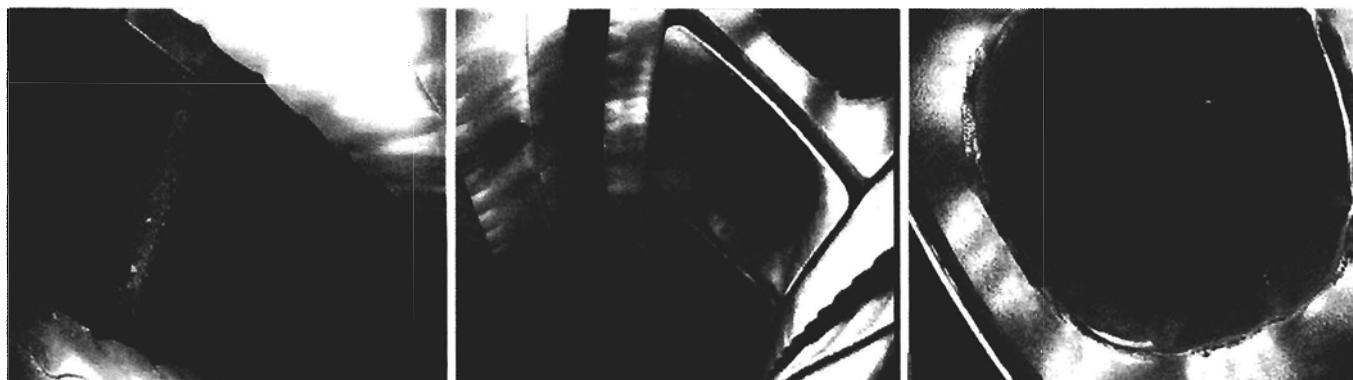


Figure 21.10: Typical images from a boroscope inspection



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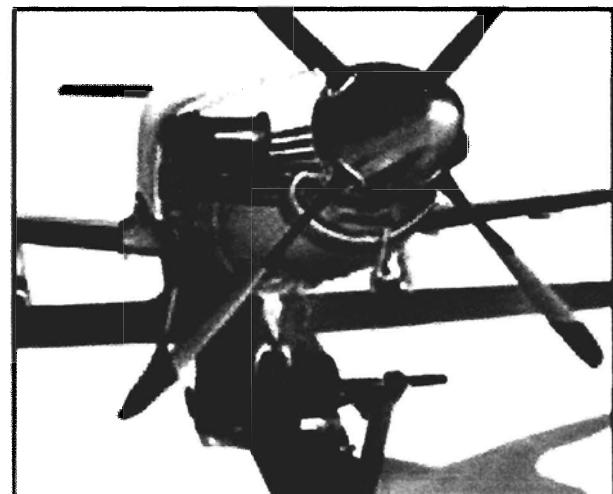
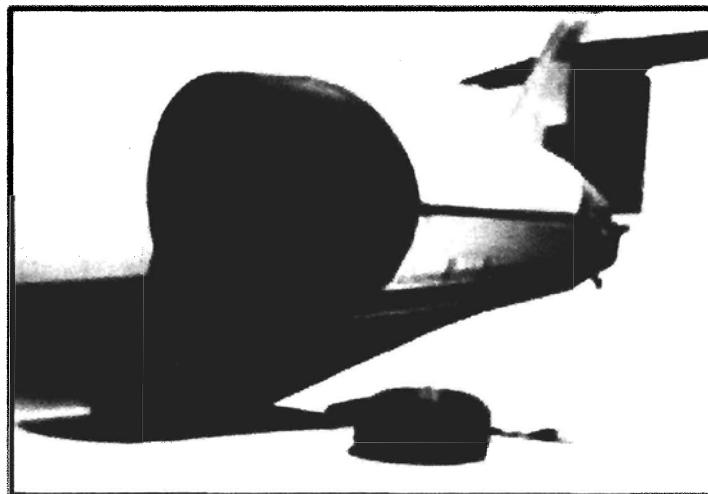


Figure 22.1: Covers and blanks fitted to a jet engine and a turboprop engine

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