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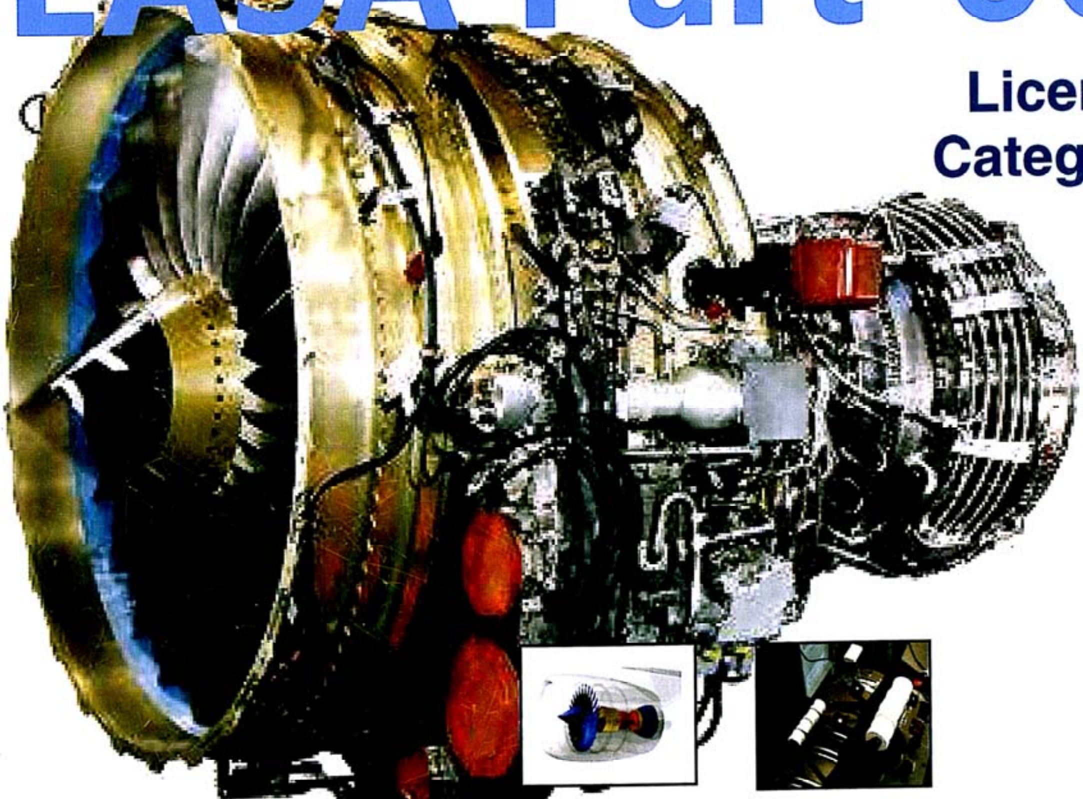
Module 15

Gas Turbine Engine
for
EASA Part-66



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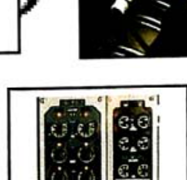

Volume 1

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Preface

Thank you for purchasing the **Total Training Support Integrated Training System**. We are sure you will need no other reference material to pass your EASA Part-66 exam in this Module.

These notes have been written by instructors of EASA Part-66 courses, specifically for practitioners of varying experience within the aircraft maintenance industry, and especially those who are self-studying to pass the EASA Part-66 exams. They are specifically designed to meet the EASA Part-66 syllabus and to answer the questions being asked by the UK CAA in their examinations.

The EASA Part-66 syllabus for each sub-section is printed at the beginning of each of the chapters in these course notes and is used as the "Learning Objectives".

We suggest that you take each chapter in-turn, read the text of the chapter a couple of times, if only to familiarise yourself with the location of the information contained within. Then, using your **club66pro.com** membership, attempt the questions within the respective sub-section, and continually refer back to these notes to read-up on the underpinning knowledge required to answer the respective question, and any similar question that you may encounter on your real Part-66 examination. Studying this way, with the help of the question practice and their explanations, you will be able to master the subject piece-by-piece, and become proficient in the subject matter, as well as proficient in answering the CAA style EASA part-66 multiple choice questions.

We regularly have a review of our training notes, and in order to improve the quality of the notes, and of the service we provide with our Integrated Training System, we would appreciate your feedback, whether positive or negative.

So, if you discover within these course notes, any errors or typos, or any subject which is not particularly well, or adequately explained, please tell us, using the 'contact-us' feedback page of the **club66pro.com** website. We will be sure to review your feedback and incorporate any changes necessary. We look forward to hearing from you.

Finally, we appreciate that self-study students are usually also self-financing. We work very hard to cut the cost of our Integrated Training System to the bare minimum that we can provide, and in making your training resources as cost efficient as we can, using, for example, mono printing, but providing the diagrams which would be better provided in colour, on the **club66pro.com** website. In order to do this, we request that you respect our copyright policy, and refrain from copying, scanning or reprinting these course notes in any way, even for sharing with friends and colleagues. Our survival as a service provider depends on it, and copyright abuse only devalues the service and products available to yourself and your colleagues in the future, and makes them more expensive too.

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Module 15 Chapters

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Module 15
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Gas Turbine Engine

15.1 Fundamentals

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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.

Table of Contents

Module 15.1 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 Reference**	**Level**
		B1
Fundamentals	15.1	2
Potential energy, kinetic energy, Newton's laws of motion, Brayton cycle;		
The relationship between force, work, power, energy, velocity, acceleration;		
Constructional arrangement and operation of turbojet, turbofan, turboshaft, turboprop.		

Module 15.1 - Fundamentals

Introduction

To understand the working principle of the gas turbine engine, the following facts about physics must be studied.

These are;

1 Newton's Laws of Motion
2 Behaviour of a gas as it flows through ducts of non-constant cross section.

Newton's Laws of Motion

First Law — **A body at rest tends to stay at rest and a body in motion tends to stay in motion in a straight line unless caused to change its state by an external force.**

Second Law — **The acceleration of a body is directly proportional to the force causing it and inversely proportional to the mass of the body.**

Third Law — **For every action there is an equal and opposite reaction.**

The first law is of little importance to the function of the gas turbine engine.

The second law is the law which is used to determine exactly the *amount* of thrust achieved by the gas turbine engine. The second law can be written as a formula:

Force = Thrust = Mass x Acceleration

The third law is of most importance to us in understanding the gas turbine engine. What it is saying is that if a mass of air is propelled backwards, the object which propelled it will be propelled forwards at an equal rate. It follows then that the more air that the gas turbine engine can propel backwards, the greater will be the forward thrust of the engine. The second law also tells us that the greater the mass propelled backwards (m), the greater is the forward force (F).

Convergent and Divergent Ducts

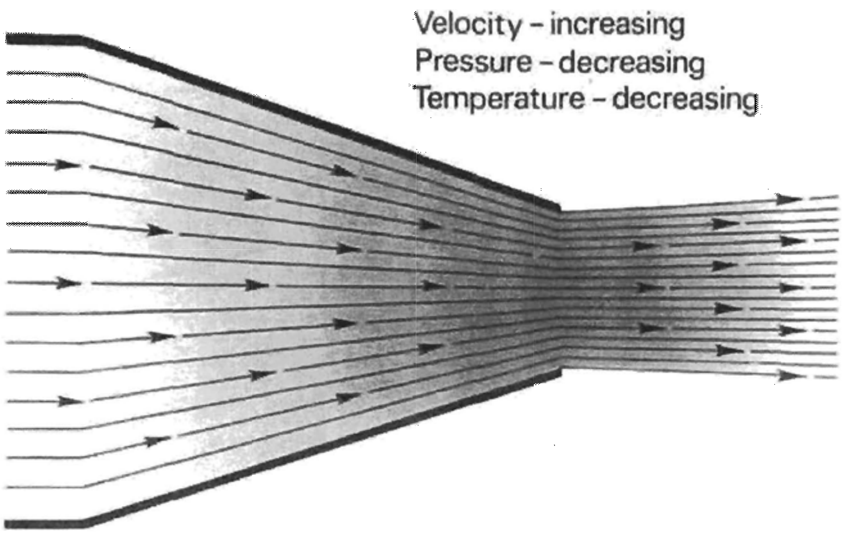

Figure 1.1: Gas Flowing Through a CONVERGENT DUCT - Subsonic Airflow

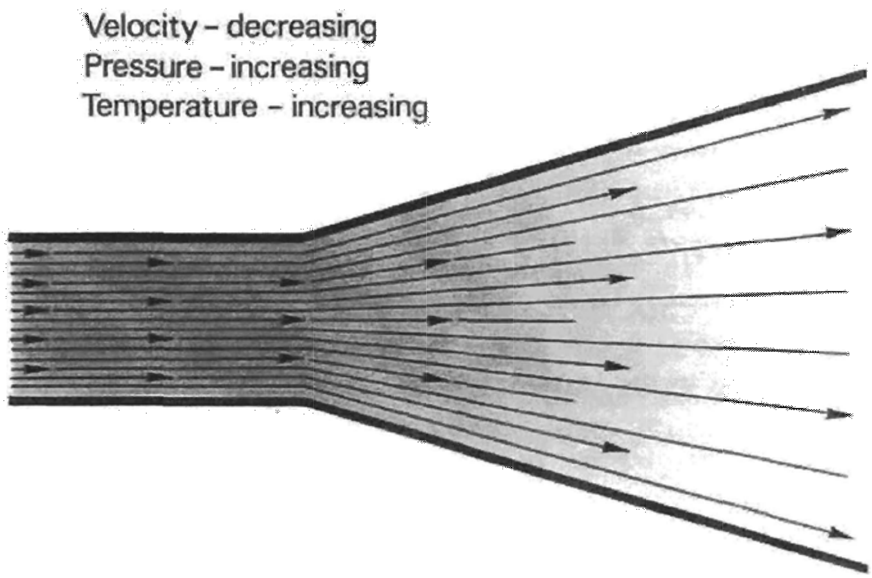

Figure 1.2: Gas flowing through a DIVERGENT DUCT - Subsonic airflow

The "Choked" Nozzle

An exception to the above rules

There is one, and only one, exception to the above rule, and that is when the gas is *at the speed of sound(Sonic Velocity)* just before it enters the **DIVERGENT** part of the duct.

It is extremely difficult to accelerate a gas to supersonic speed - the only way to do it is to have a very high pressure to begin with and increase its speed in a **CONVERGENT** duct. Once it has reached sonic speed, it is impossible to increase its speed any further - **the duct (or nozzle) is then said to be CHOKED**

If this procedure is carried out in a **CONVERGENT-DIVERGENT** duct, an additional form of thrust (additional to Newton's Third Law) can be achieved.

This can be visualised more easily if you think of a beach-ball being forced and compressed through a convergent-divergent duct. As it expands through the divergent duct, it will cause a forward reaction on the wall of the duct.

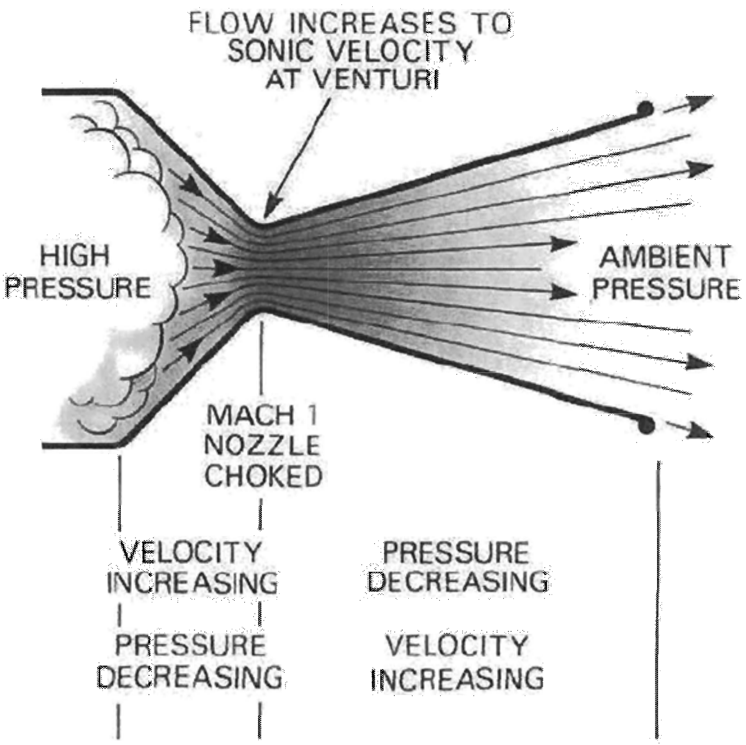

Figure 1.3: The choked nozzle

The application of the **CHOKED CONVERGENT-DIVERGENT** nozzle can be seen in supersonic military aircraft and rockets.

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The Rocket and the Ram Jet

The Rocket Engine

Although the rocket engine is a jet engine, it has one major difference in that it does not use atmospheric air as the propulsive fluid stream. Instead, it produces its own propelling fluid by the combustion of liquid or chemically decomposed fuel with oxygen, which it carries, thus enabling it to operate outside the earth's atmosphere. It is therefore, only suitable for operating over short periods.

The fuel or propellant is carried in one tank and an oxidizer in another tank. These are typically pumped to and mixed in the combustion chamber where the fuel is burned. As the gases rush out of the nozzle at the back of the engine, thrust is produced. This nozzle has a definite shape and is known as a converging-diverging nozzle. This type of nozzle is required in rockets because of the desire for extremely high velocity (highly accelerated) exhaust gases.

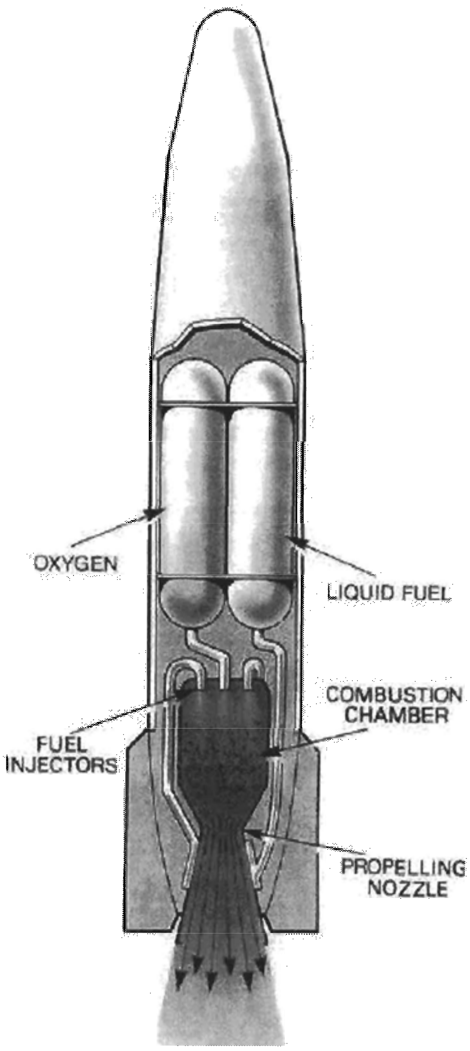


Figure 1.4: The rocket engine

The Ram Jet

The Ram Jet requires initial forward motion to get it started. It's operation is then as follows

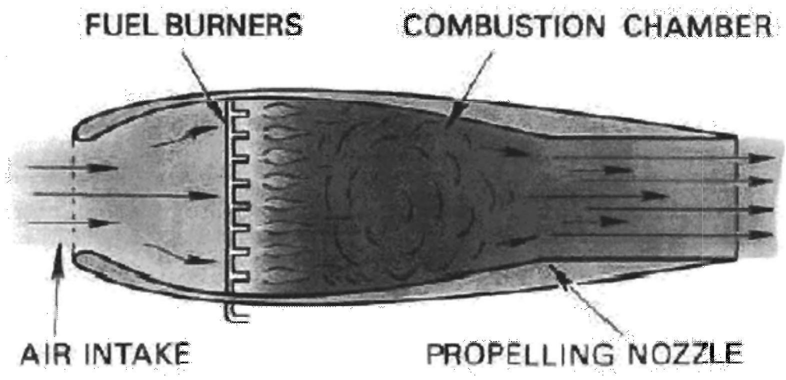


Figure 1.5: The ram jet

Intake The intake is **convergent / divergent** in shape and therefore the air flowing through it will **decrease/increase** in pressure.

Combustion At a certain pressure, the air is mixed with fuel and ignited. Its temperature will increase and it will expand. This expansion takes the form of an increase in velocity.

If the gas increases in velocity inside the jet, it will obey Newton's 2nd Law, which is that:

Force = Mass x Change in Velocity through the duct

Exhaust Before entering the exhaust nozzle, the gas may be of high enough pressure to be accelerated to supersonic speed. The exhaust nozzle would then be choked. The force produced as a result of the acceleration is known as momentum or kinetic thrust. A second type of thrust is produced in the divergent part of the exhaust nozzle and is called **pressure thrust**.

The total force produced will, according to Newton's 3rd Law, produce an equal and opposite reaction on the inner workings of the engine. This is known as Thrust

The Turbojet Engine

Introduction

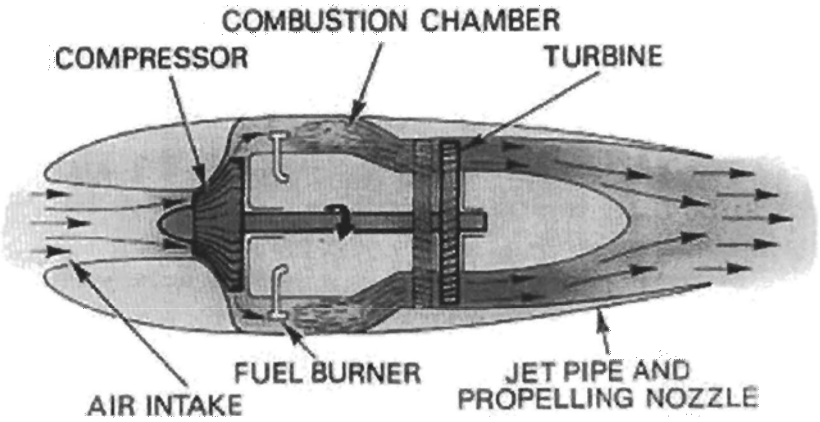


Figure 1.6: The pure turbo-jet

In 1931 Sir Frank Whittle patented the self sustaining Gas Turbine Engine. It consists of a single rotating spool comprising of a compressor and turbine. The advantage of this engine over the ram jet is that it is self sustaining without the need for forward speed. In other words it can be started whilst stationary on the ground

The engine is started by spinning the compressor. This establishes a rearward flow of air into the combustion zone where fuel is added and ignited. The gasses increase in temperature and therefore expand rearwards. Before the gasses reach the exhaust nozzle, some of its energy is extracted by rotating the turbine, which in turn drives the compressor.

To increase the thrust of the gas turbine engine, more fuel is added which raises the energy level of the gas stream. The turbine will therefore be turned at a greater speed which will turn the compressor at a greater speed. The compressor will therefore deliver a greater mass of air, and the thrust force of the gas turbine engine is therefore increased according to Newton's 2nd Law.

The thrust produced by the turbojet is proportional to the change in momentum of the gas stream. To increase the thrust, more fuel is introduced which raises the energy level of the gas stream and the turbine and compressor rotates at a higher speed. The compressor delivers a larger mass of air to the combustion zone and there is a corresponding increase in the thrust produced by the engine.

The gas turbine can also be compared with the piston engine where fuel and air are burned inside a cylinder to cause a piston to move and turn a crankshaft. The working cycle of the gas turbine engine is indeed similar to that of the 4-stroke piston engine as in each gas turbine engine there is induction, compression, combustion and exhaust. In the piston engine cycle the combustion cycle is intermittent where as in the gas turbine engine it is continuous. The gas turbine engine has a separate compressor, combustion chamber, turbine wheel, and exhaust system with each part concerned only with its function. Thus the combustion in a gas turbine engine takes place as a continuous process at a constant pressure. This, combined with the absence of reciprocating parts, provides a much smoother running engine that can be of a lighter structure, enabling more energy to be released for useful propulsive work.

The modern gas turbine engine is basically cylindrical in shape because it is essentially a duct in which a mass airflow is the same from the intake to the exhaust nozzle. Into this duct the necessary parts are fitted. The parts from front to rear are an air compressor, a combustion chamber, a turbine wheel, and an exhaust duct. A shaft connects the turbine wheel to the compressor, so that turning the turbine will also turn the compressor. In side the combustion chambers are fuel burners and the means of igniting the fuel.

Because the jet engine is basically an open ended duct it is not satisfactory to ignite the fuel in static air, because this would allow the gas to expand equally forwards and backwards without doing any useful work; when the air was used up the flame would die out. Before lighting the fuel it is, therefore, essential that the air is moving, and the moving columns of air must be moving through the engine from the front towards the rear. This movement is brought about by using a starter motor to spin the compressor and the turbine wheel in excess of 1500rpm; this drives a large volume of air through the combustion chamber. When the airflow is sufficient, fuel is injected into the chambers through spray nozzles, and is ignited by means of ignitor plugs. (Note that the gas turbine engine is not an alternate firing engine. The spark ignitors are only used for the initial firing, and the fuel in all the combustion chambers burns continuously like a blowtorch). This burning will cause the airflow towards the rear to increase in velocity and drive the turbine wheel as it flows over the turbine blades in its headlong rush through the exhaust system out to atmosphere. The spinning turbine wheel turns the compressor through the drive shaft, and the compressor feeds more air into the combustion chamber to complete a cycle of operations that continues as long as fuel is fed to the burners. The turbine wheel also originates a drive to a gearbox that provides external drives for items such as:

Fuel pumps
Hydraulic pumps
Electrical generators
Other engine accessories

The Constant Pressure Cycle

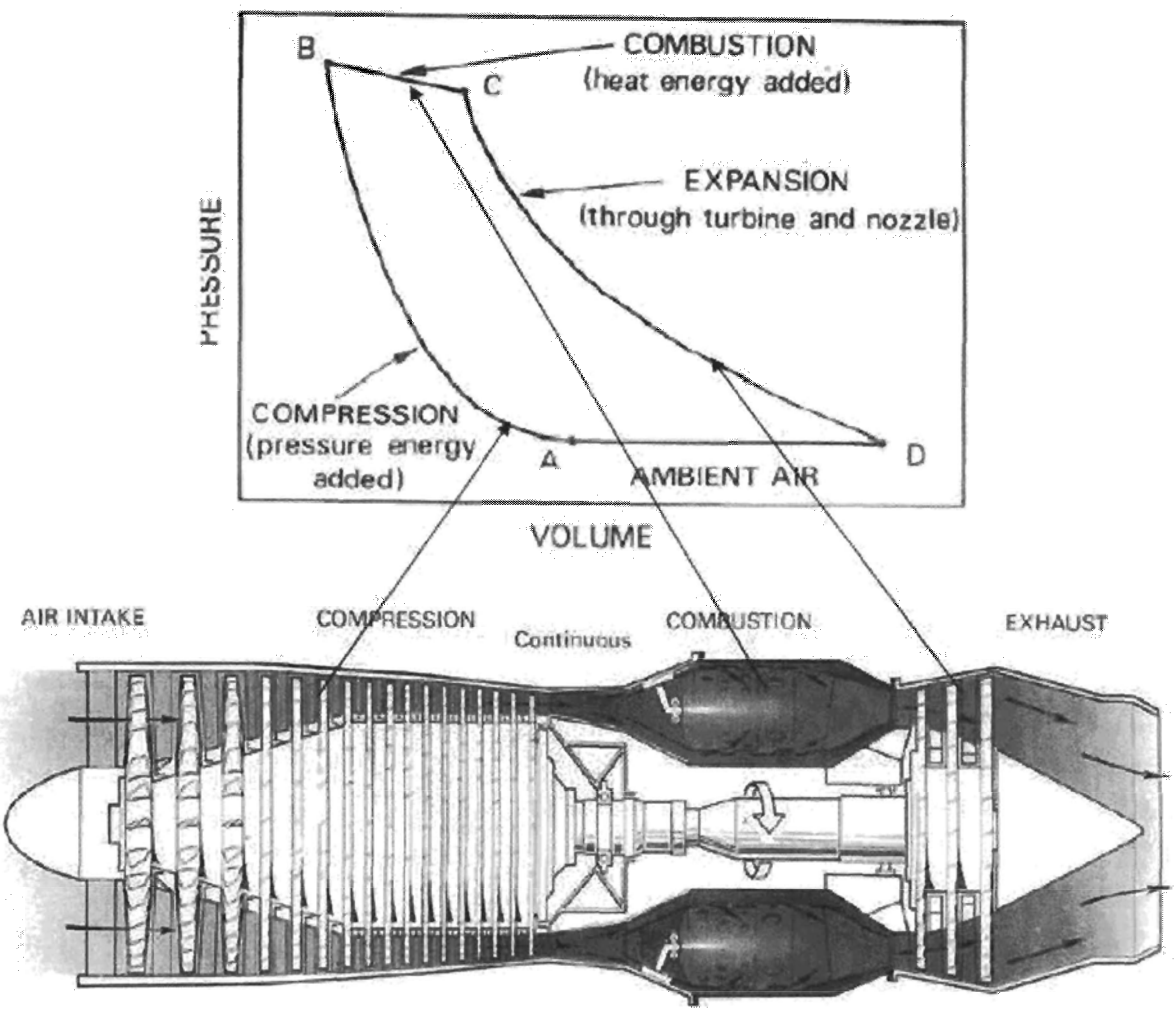


Figure 1.7: The constant pressure cycle

The Constant Pressure Cycle or Brayton Cycle is so called because the heat is added within the combustion chamber where a theoretical constant pressure is maintained. (In fact there is always a very slight – less than 3% - pressure drop due to friction between the gases and the combustion liner.

Constructional Arrangements

The basic design of Whittles gas turbine engine exists in all gas turbine engines. However various applications have been derived over the past 60 years to suit the airframe and industrial requirements.

Single Spool Axial Flow Engine

A modern **single spool axial flow turbojet engine** produces its thrust from the acceleration of the flow of the hot gases. Air enters the engine inlet and flows into the compressor where its pressure is increased. Fuel is added in the combustor where it is ignited and burns, expanding the gases as they leave the tail pipe produces the reaction we know as thrust.

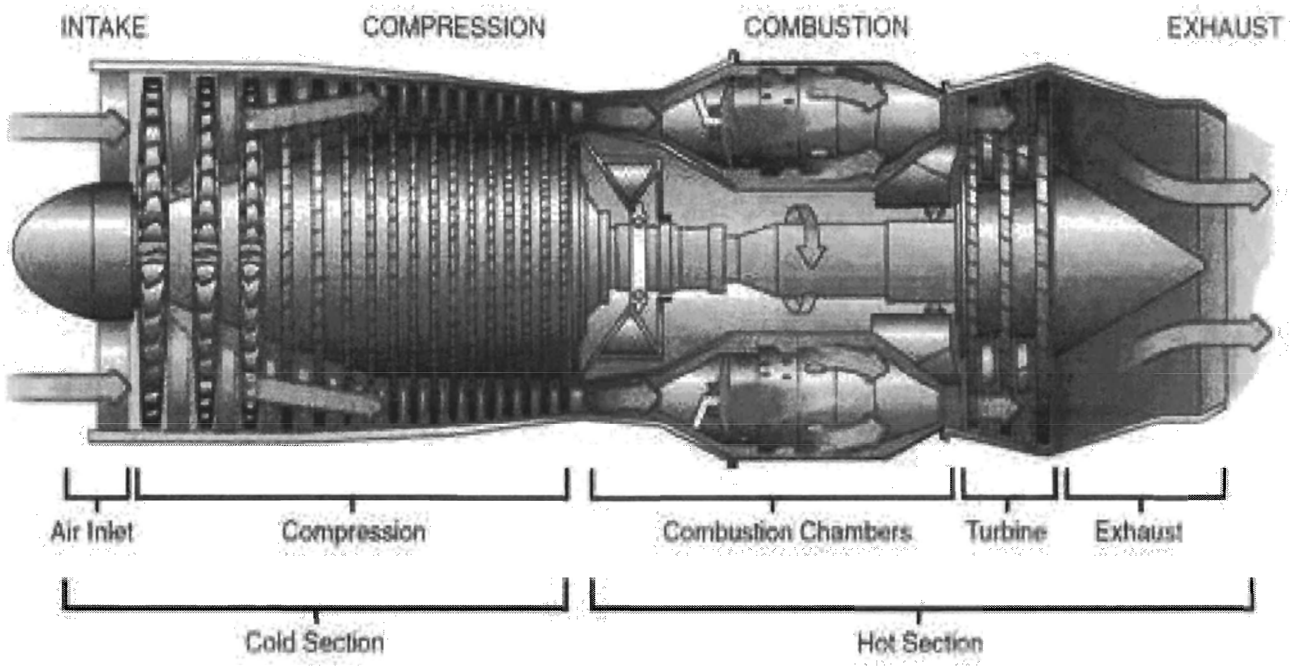


Figure 1.8: A single spool axial flow engine

The use of a multi stage axial flow compressor enabled higher compression ratios to be obtained and hence more thrust.

The single spool turbo jet has very low propulsive efficiency, high specific fuel consumption (SFC) and an undesirable noise level.

Multi-Spool Design

Dual and triple spool axial compressors were developed for the operational flexibility they provide to the engine in the form of high compression ratios, quick acceleration, and better control of stall characteristics. This operational flexibility is not possible with single spool axial flow engines.

For any given power lever setting, the high pressure (HP) compressor speed is held fairly constant by a fuel control governor. Assuming that a fairly constant energy level is available at the turbine, the low pressure (LP) compressor will speed up and slow down with changes in aircraft inlet conditions resulting in changes in atmospheric changes or manoeuvres in flight. The varying LP compressor output therefore, provides the HP compressor with the best inlet condition within the limits of the design. That is, the LP compressor tries to supply the HP compressor with a fairly constant air pressure for a particular air pressure for a particular power setting.

To better understand when the low pressure compressor speed up and slow down, consider that when ambient temperature increases, the air's molecular motion increases. In order to collect air molecules at the same rate as temperature increases, the compressor would have to change either its blade angles, which it cannot do, or its speed, which it in fact does.

Twin Spool Axial Flow Turbo Fan

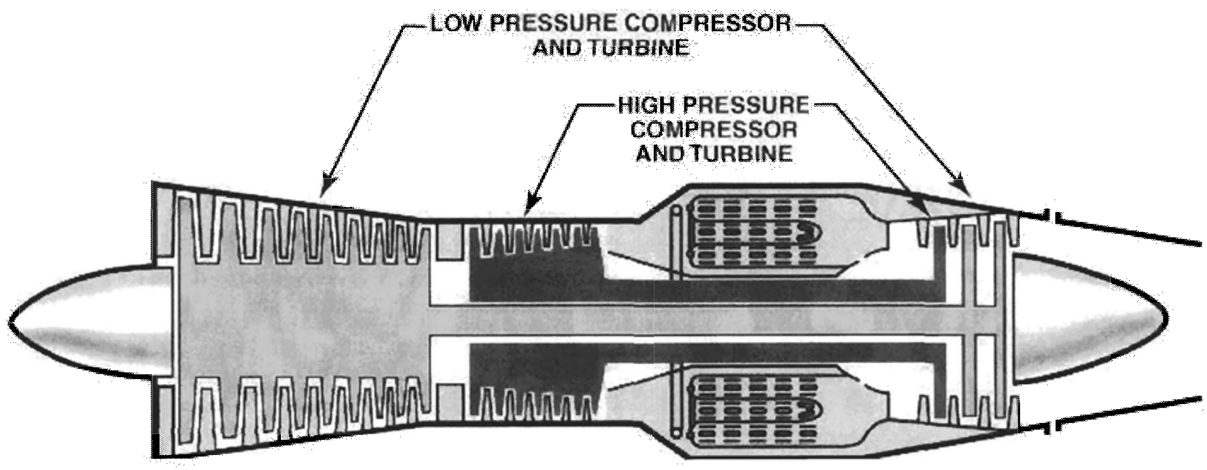


Figure 1.9: A twin spool axial flow engine

By-Pass Engines

Twin Spool Low By-Pass Turbo Fan

This type of engine has a twin spool layout with the addition that the L.P. compressor is of larger diameter than before and thus handles a greater mass of air than is required by the H.P. compressor. The airflow which is not required by the H.P. compressor is fed into the by-pass duct and it rejoins the normal gas flow behind the turbines. The airflow is split approximately 50 % each way. The mixing of the "hot" and "cold" gas streams promotes very rapid expansion of the gasses, which gives good power output with a low fuel consumption. Low bypass engines are defined as having a bypass ratio of 3:1 or less

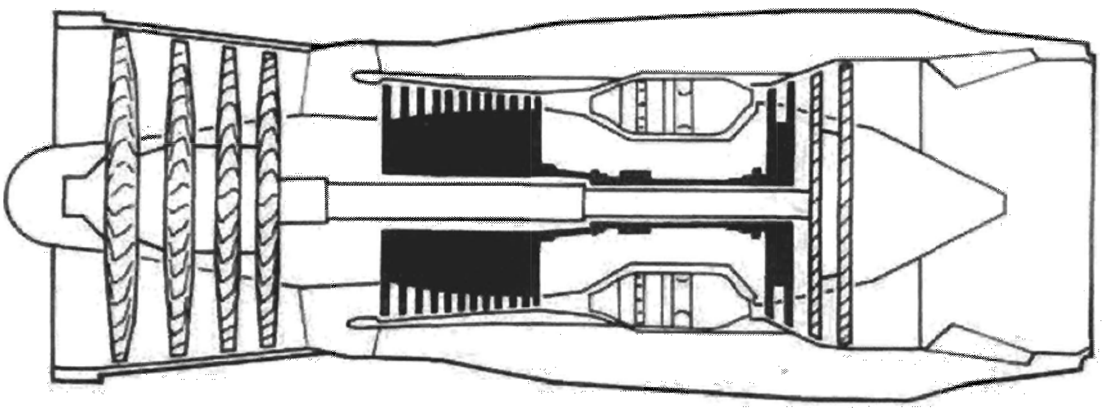


Figure 1.10: A twin-spool by-pass turbo-jet

High By-Pass Turbo Fan

The difference in operation between a propeller and a pure jet engine can be summarised as follows;

A propeller accelerates a large quantity of air rearwards at a low rate.
A pure jet engine accelerates a small quantity of air rearwards at a high rate.

The net result is the same, but the efficiency of each depends on the required speed of the aircraft. For medium speed aircraft, a combination of the two has been developed. On the following pages are two examples of high bypass multi-spool engines. High Bypass is defined as a bypass ratio of 4:1 up to 8: 1 Ultra high bypass engines are being researched with a bypass ratio of 10: 1 and above.

A high bypass engine is more efficient than a pure turbo jet because its principle of operation is more akin to that of a propeller, in that it accelerates a relatively large mass of air at a low rate.

Twin Spool High Bypass

The amount of air going through the by-pass section (or "fan") is typically 5 or 6 times that going through the combustion section. Approximately 80 % of the thrust produced is from the by-pass air ducting.

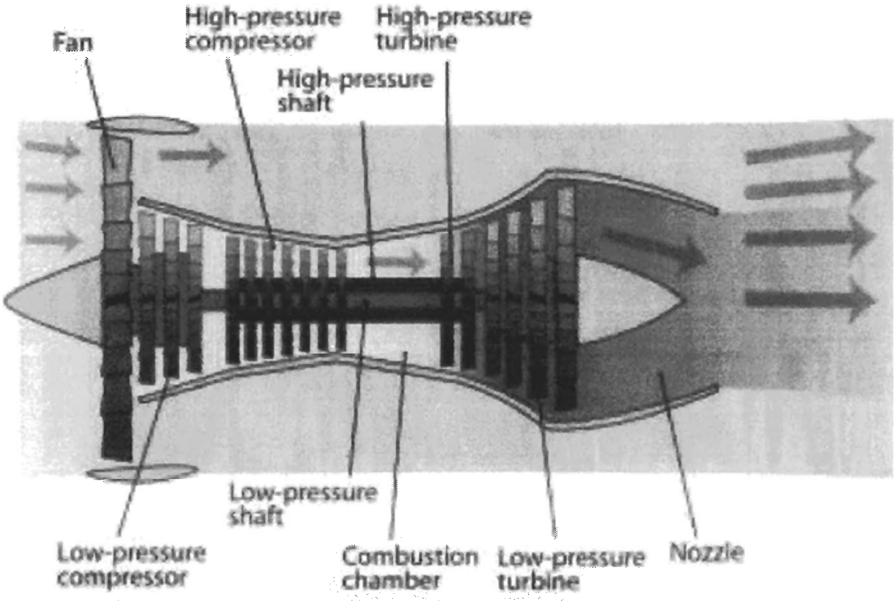


Figure 1.11: A twin-spool high-bypass engine

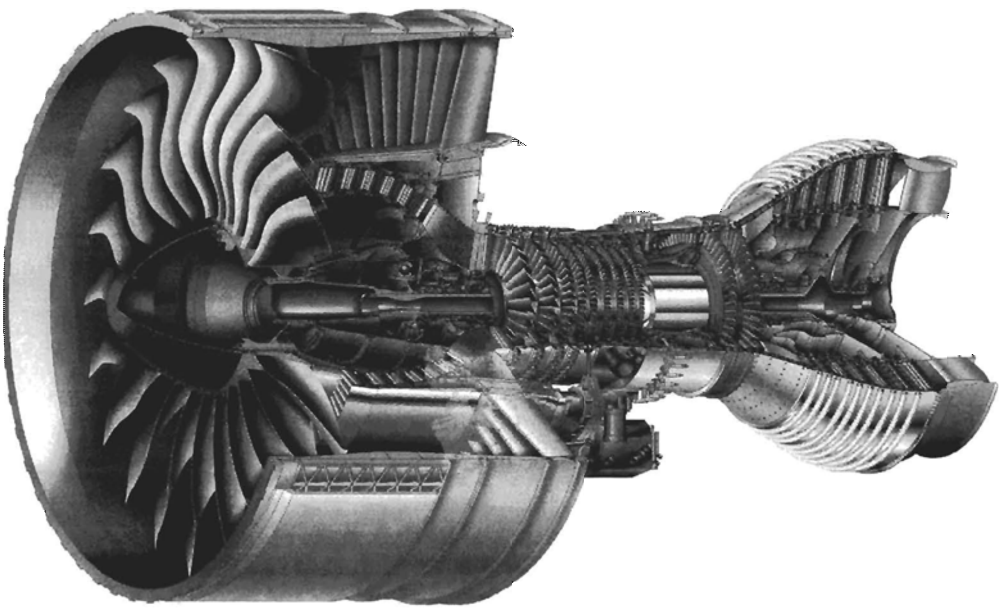
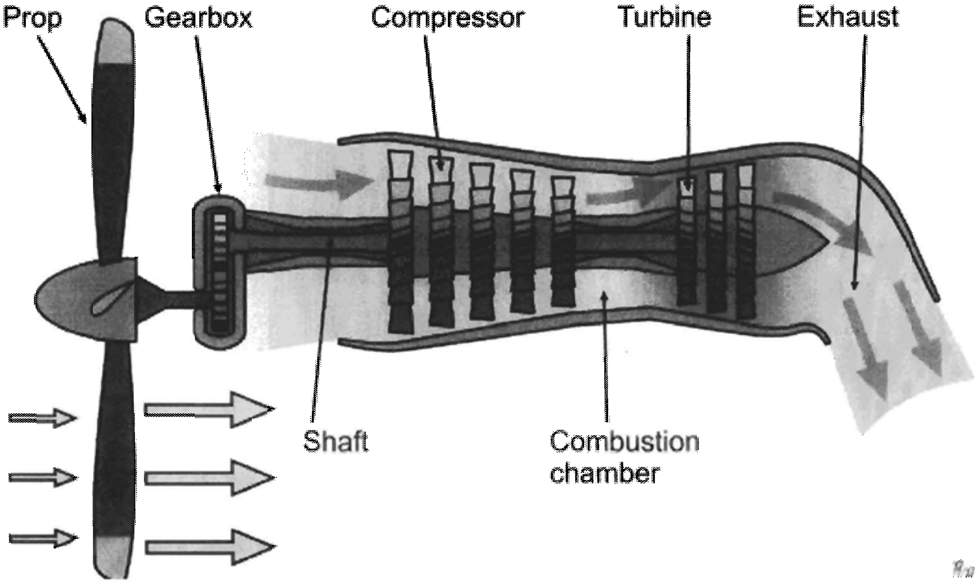


Figure 1.12: Pratt and Whitney GP7000

Turbo Prop Engines

The advent of the twin spool engine enabled easier starting (only the small HP compressor needs to be rotated by the starter) and better surge resistance as the two spools run at their own optimum speeds. This type was used as a pure thrust engine, but the example shown above drove a propeller on the end of the LP compressor shaft via a reduction gear



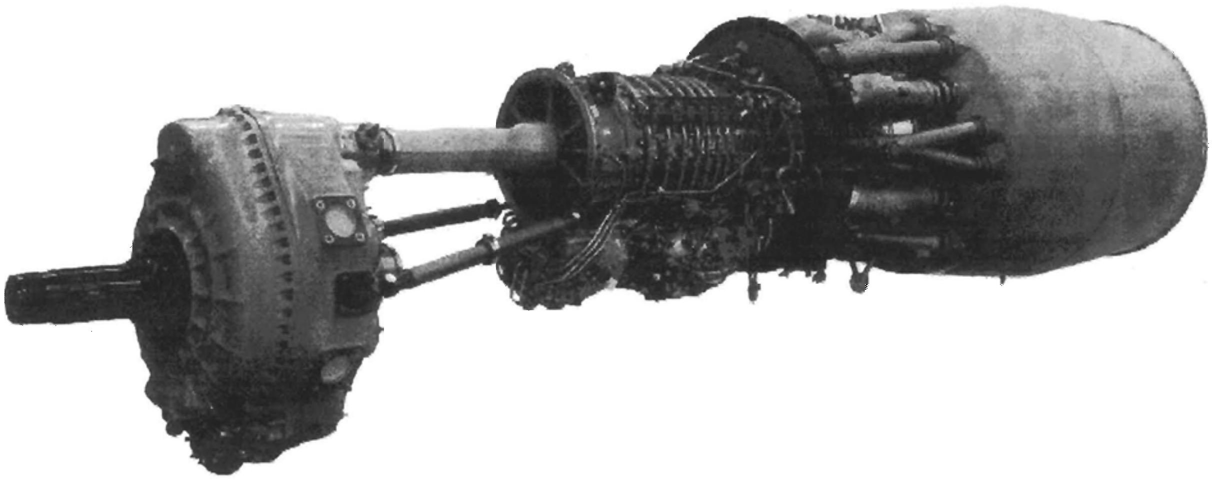


Figure 1.13: Geared turbo-prop engines

All types invariably use a multi-stage turbine and an epicyclic reduction gear. Multi-stage turbines with small diameter discs can run at higher rev/min and thus absorb more energy from the gas stream than a single large disc that must necessarily be restricted in rev/min because of high centrifugal loading. Epicyclic gearing is selected for the reduction gear because:

(a) A high degree of speed reduction can be obtained.
(b) The propeller shaft and thrust lines remain on the same centre line as the compressor and turbine shafts, thus causing little interference with the entry of air into the air intake. Streamlining of the whole unit is, therefore, an easier task.

This type of gas turbine engine is used wherever the direct thrust from the engine is not required,

All the energy in the gasses is absorbed by the turbines and transformed into a rotational force - or **TORQUE**.

There is usually little or no thrust produced in the exhaust.

The reduction gearbox is required because the gas turbine engine is most efficient at high RPM, but the device which it drives (propeller, helicopter rotor etc.) becomes inefficient at such high speed.

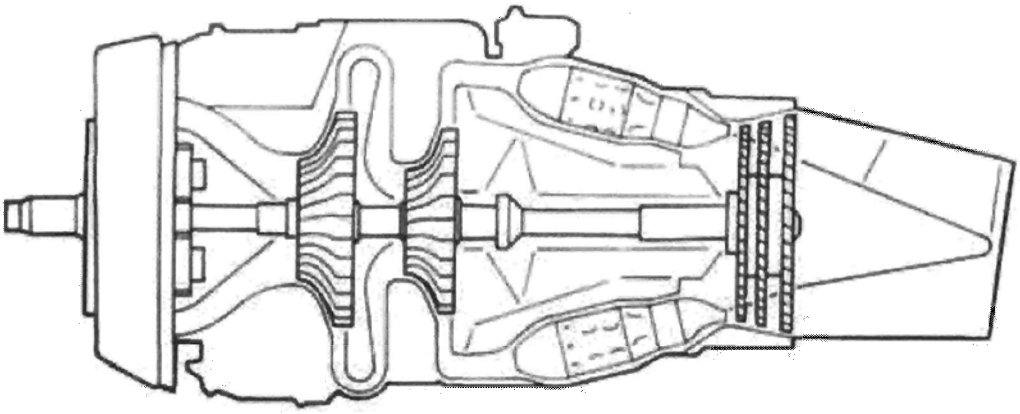


Figure 1.14: A direct-coupled single spool centrifugal flow turbo-prop engine

This example of a turboprop engine uses two centrifugal compressors in tandem. They are driven, along with the reduction gear by a three-stage turbine, all on one shaft. Compared to the axial flow twin spool turbo prop shown above this engine produces much less power and is very inefficient.

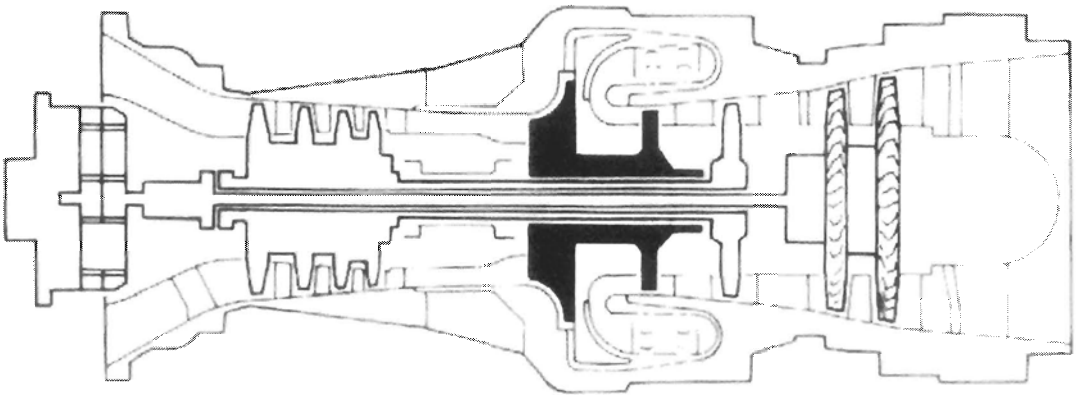


Figure 1.15: Twin Spool Turbo Shaft engine with free power turbine

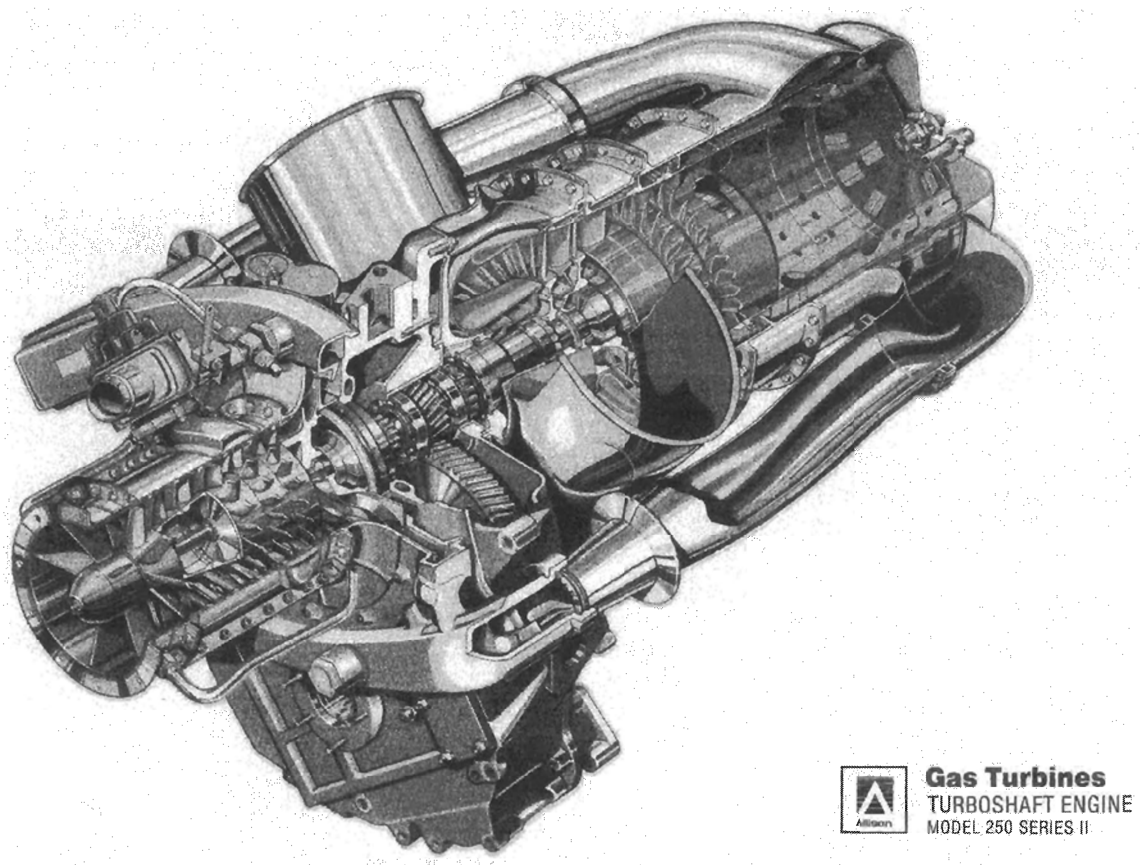


Figure 1.16: The Allison 250 series turbo-shaft engine

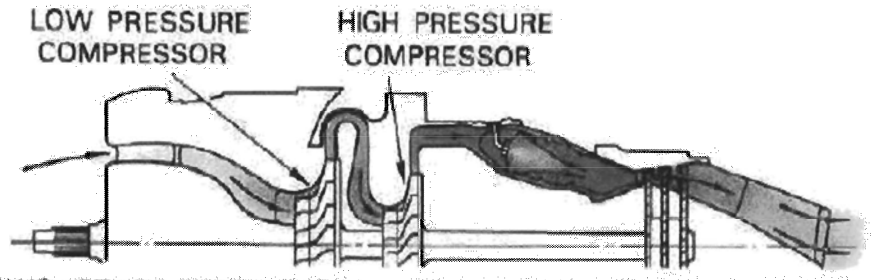
A turbo-shaft engine is used to drive any industrial application that requires high torque output.

For example:

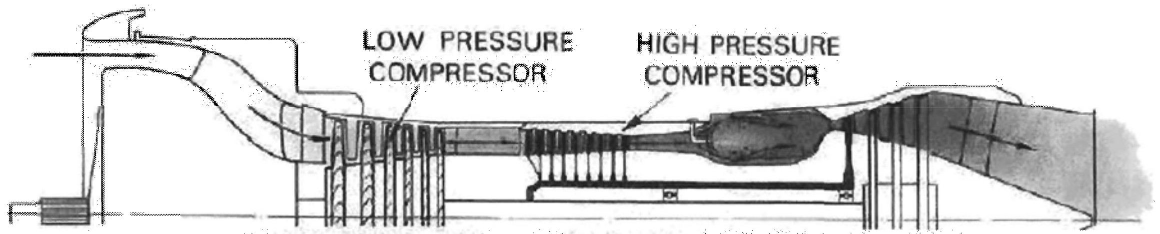
- Helicopter rotors
- Ship Drive shafts
- Hovercraft engines
- Oil pumps
- Generator sets

This example uses **a free or power turbine**. All the energy not required to drive the gas generator compressor is used to drive the free turbine which drives the output shaft. The output shaft is shown above coming out o the front of the engine but it can be geared to come out at any angle, even through the exhaust directly connected to the rear of the turbine.

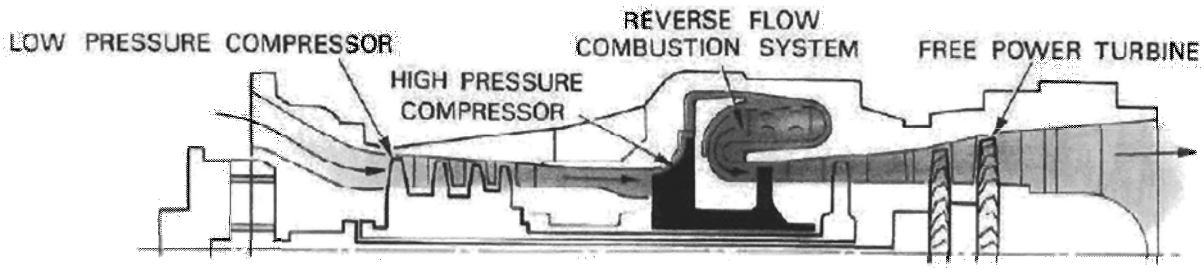
Summary of Engine Types



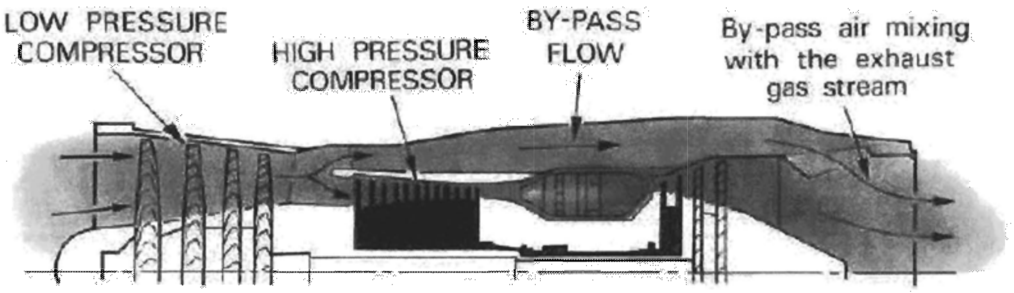
TWO-STAGE CENTRIFUGAL FLOW TURBO-PROPELLER ENGINE



TWIN-SPOOL AXIAL FLOW TURBO-PROPELLER ENGINE



TWIN-SPOOL TURBO-SHAFT ENGINE(with free power turbine)



TWIN-SPOOL AXIAL FLOW BY-PASS TURBO JET ENGINE(low by-pass ratio)

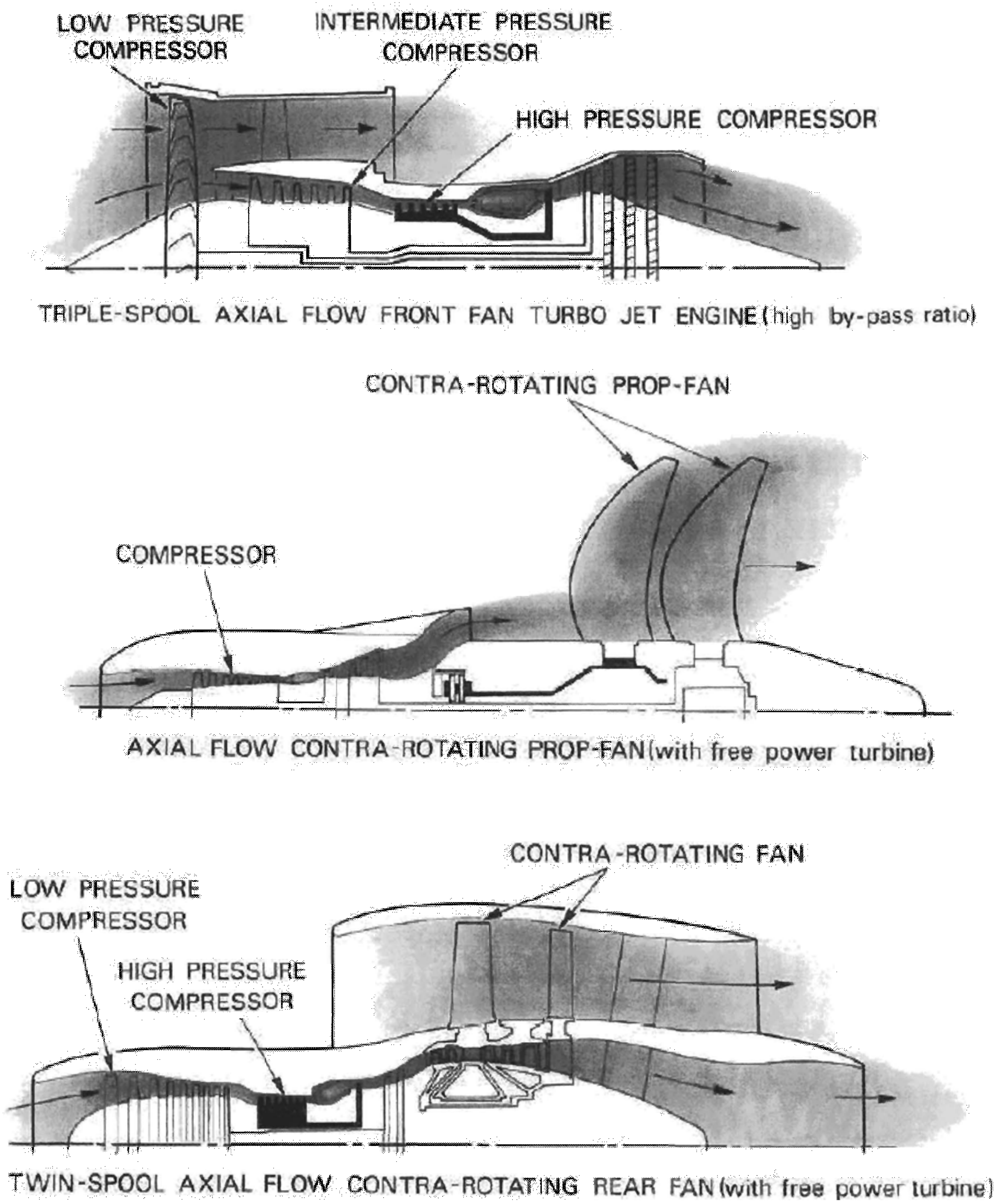


Figure 1.17: Various engine types

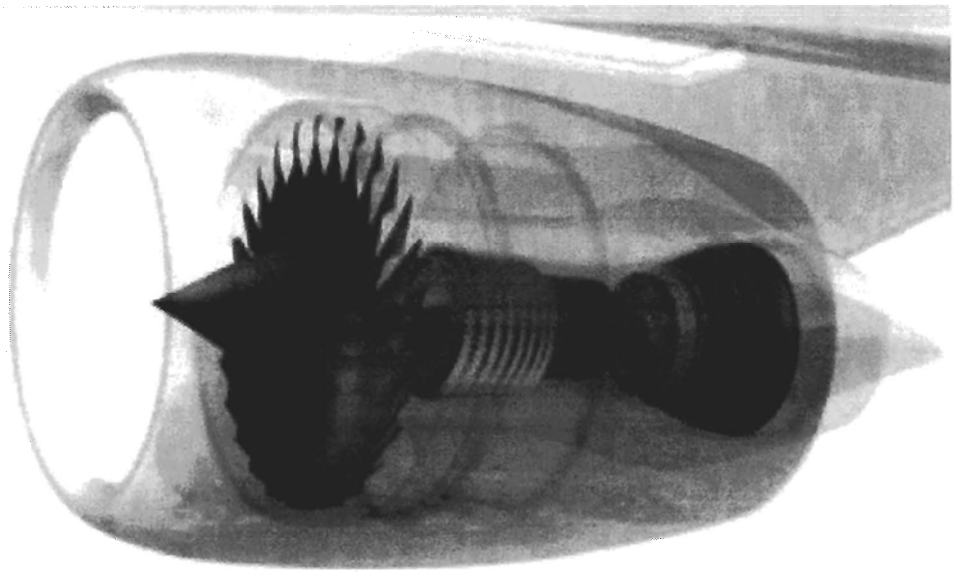


Figure 1.18: The triple spool high-bypass engine

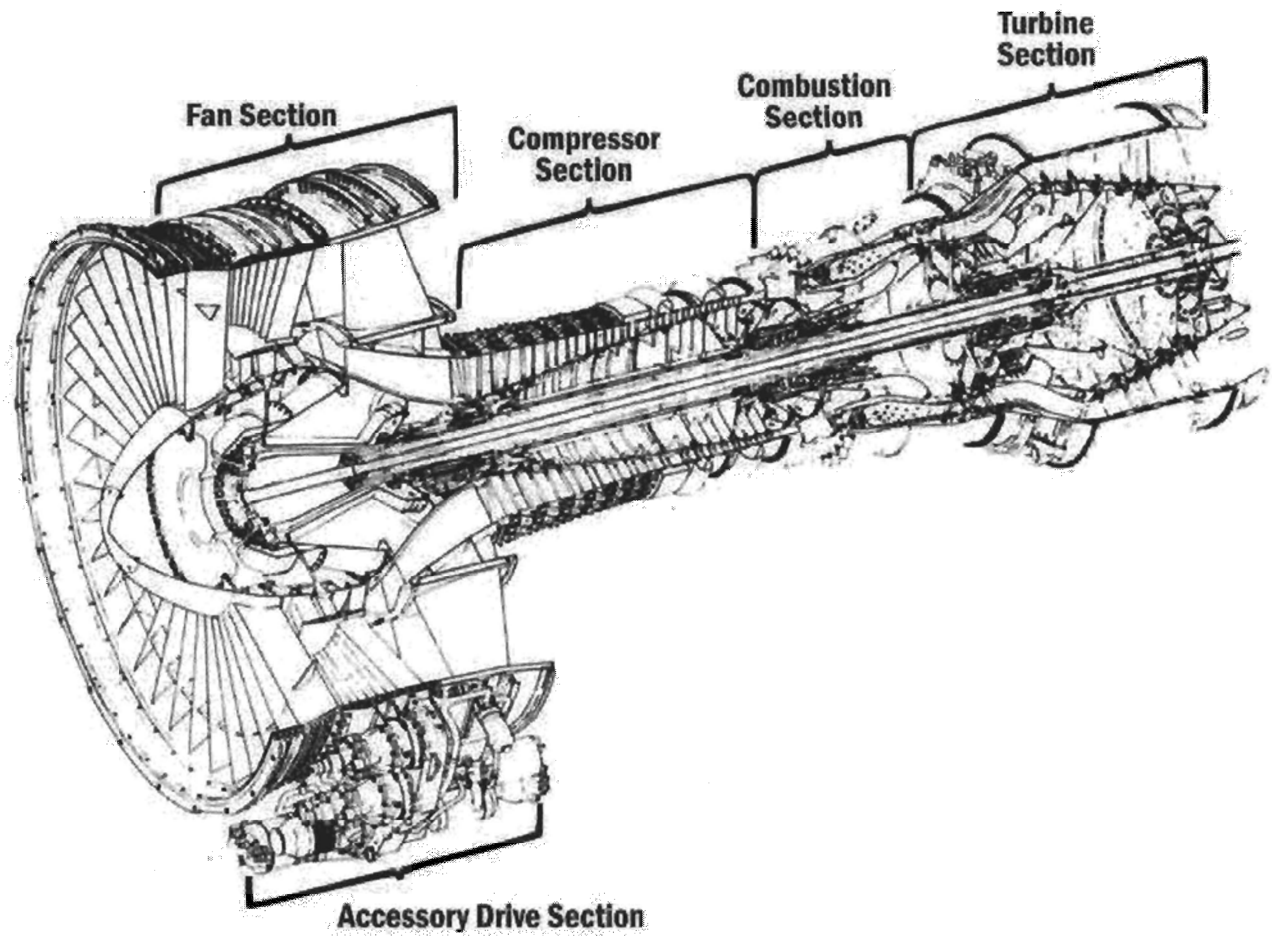


Figure 1.19: The sections of a fan engine

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Module 15
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Gas Turbine Engine

15.2 Performance

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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.
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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.

Table of Contents

Module 15.2 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 Reference**	**Level**
		B1
Engine Performance	15.2	2
Gross thrust, net thrust, choked nozzle thrust, thrust distribution, resultant thrust, thrust horsepower, equivalent shaft horsepower, specific fuel consumption;		
Engine efficiencies;		
By-pass ratio and engine pressure ratio;		
Pressure, temperature and velocity of the gas flow;		
Engine ratings, static thrust, influence of speed, altitude and hot climate, flat rating, limitations.		

Module 15.2 - Performance

Thrust

Consider a basic gas turbine moving through the atmosphere with an inlet velocity of V_a and an exit velocity of V_j. Mass flow of air through the engine is $\dot{m}$.

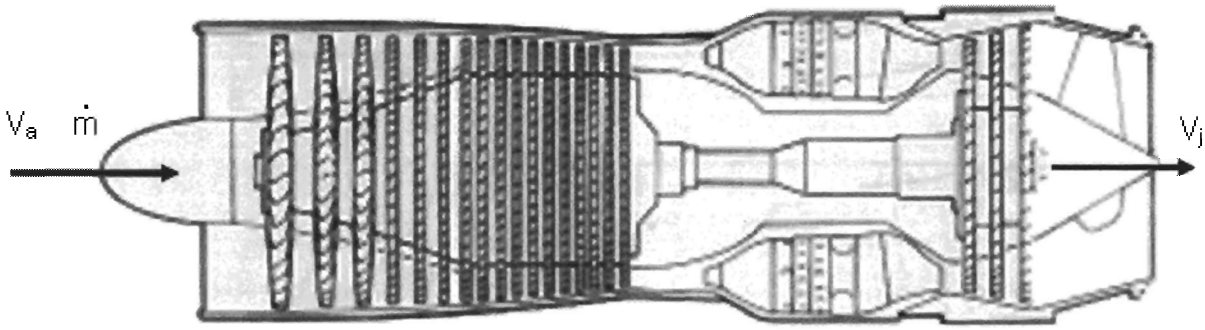

Figure 2.1: Inlet velocity (V_a), outlet velocity (V_j), and inlet mass flow rate ($\dot{m}$)

Momentum Thrust

From Newton's Second Law

Force = Mass x Acceleration

But Thrust is a Force

Therefore Thrust = Mass x Acceleration

$$= \text{mass} \frac{(V_j - V_a)}{t}$$

$$= \frac{\text{mass}}{t} (V_j - V_a)$$

$$= \text{mass flow } (\dot{m}) \times (V_j - V_a)$$

Units are Newtons or lbf

This type of thrust is known as Momentum Thrust

Momentum Thrust = $\dot{m}$ x (V_j - V_a)

Choked Nozzle Thrust or Pressure Thrust

If the air speed at the exit nozzle reaches Mach 1 the speed of sound a shock wave will form and the nozzle is said to be choked. As a result the pressure in the jet pipe (P_j) will increase and when it gets above 1.4:1 compared to ambient pressure (P_a) then significant pressure thrust begins to be produced.

Engines designed for commercial passenger aircraft have the exit nozzle designed so that the nozzle is only just at Mach 1 hence pressure thrust is negligible for these types. To fully exploit pressure thrust and the choked nozzle concept a convergent /divergent nozzle is required. For military applications and rockets with convergent/divergent exit nozzles pressure thrust becomes more significant

Pressure Thrust = A_j (P_j - P_a)

Total thrust = Momentum Thrust + Pressure Thrust.

Net Thrust

Net thrust takes into account the term V_a in the momentum thrust formula therefore net thrust varies with airspeed.

Gross Thrust

When the aircraft is stationary on the ground the value of Va is zero

Therefore Gross thrust = $\dot{m}$ Vj + pressure thrust

Gross thrust is that thrust developed when the engine is stationary on the ground or on the test bed

Gross Thrust is sometimes known as Static Thrust

Gas Turbine Working Cycle and Airflow

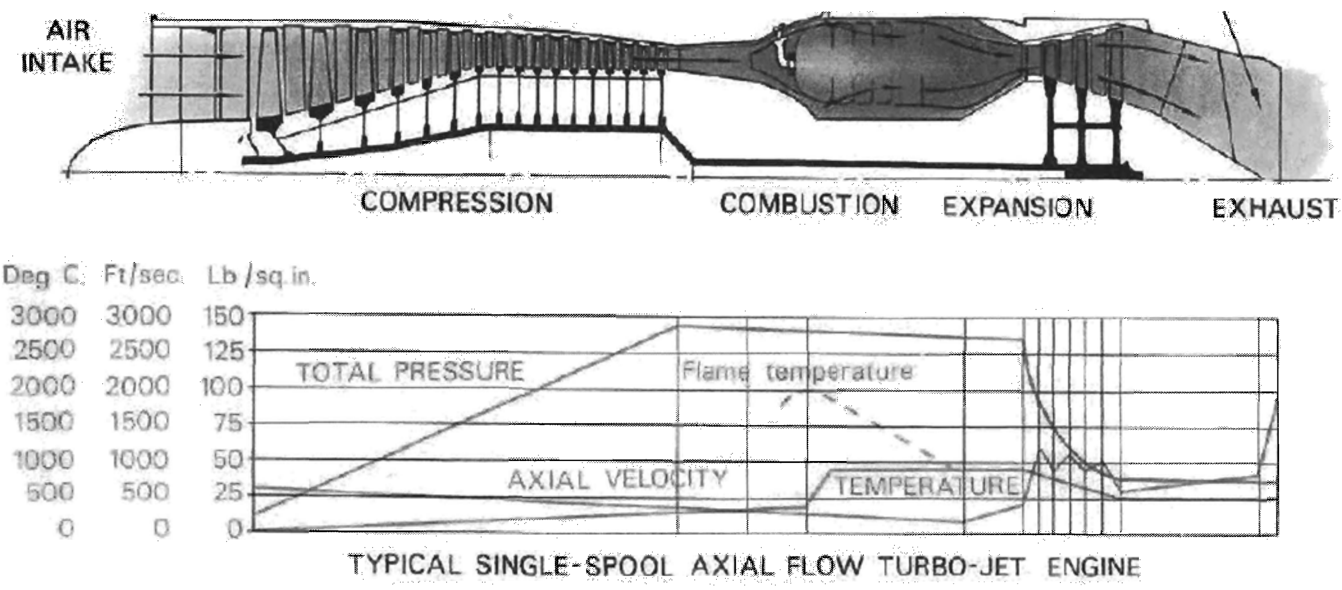

Figure 2.2: Pressure, temperature and velocity distributions through a turbo-jet engine

As the air is induced into the compressor the pressure and temperature rise. Note that velocity which you would expect to decrease remains almost constant due to the convergent annulus formed by the compressor casing and the compressor rotor.

Fuel is added to the combustion chamber and ignited. Flame temperature rapidly increases to a level far greater than the melting point of the turbines, so the remainder of the air is added to the combustor and the temperature reduces as the air reaches the turbines.

Note that the pressure through the combustor remains almost constant. (See the Constant Pressure cycle diagram in section 15.1) . Velocity of the gases increases as the gases pass through the convergent nozzles of the turbine and pressure decreases
If the pressure is above atmospheric as it leaves the jet pipe then pressure thrust will be generated in addition to the momentum thrust.

It is worth noting at this point that the Speed of Sound (and its associated shock waves) rises as temperature rises. At ISA conditions Speed of Sound = 315 m/s. Due to the high temperatures the hot section of the engine will not suffer shock effects until the exit nozzle is reached. The nozzle being sized to just choke the nozzle to enable maximum momentum thrust to be obtained with little or no pressure thrust.

Thrust Distribution

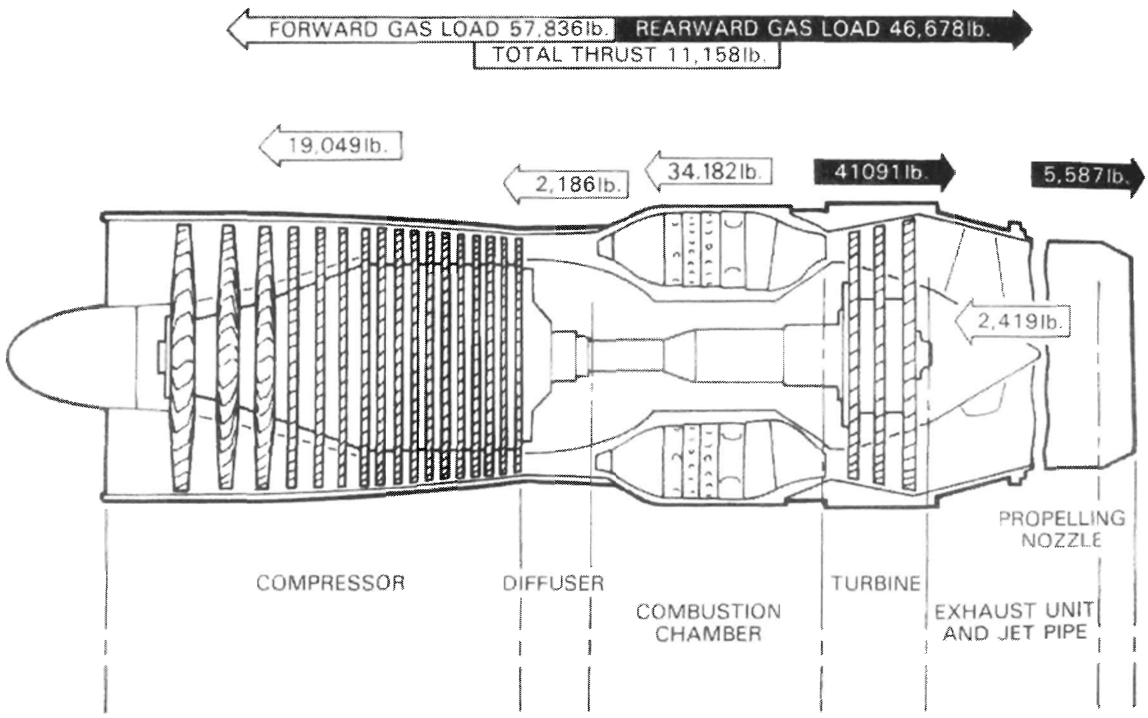

Figure 2.3: Forward loads and rearward loads on a turbo-jet engine

At the start of the cycle, air is induced into the engine and is compressed. The rearward accelerations through the compressor stages and the resultant pressure rise produces a large reactive force in a forward direction. On the next stage of its journey the air passes through the diffuser where it exerts a small reactive force, also in a forward direction.

From the diffuser the air passes into the combustion chamber where it is heated, and in the consequent expansion and acceleration of the gas large forward forces are exerted on the chamber walls.

When the expanding gases leave the combustion chambers and flow through the nozzle guide vanes they are accelerated and deflected on to the blades of the turbine. Due to the acceleration and deflection, together with the subsequent straightening of the gas flow as it enters the jet pipe, considerable 'drag' results; thus the vanes and blades are subjected to large rearward forces, the magnitude of which may be seen on the diagram. As the gas flow passes through the exhaust system, small forward forces may act on the inner cone or bullet, but generally only rearward forces are produced and these are due to the 'drag' of the gas flow at the propelling nozzle.

It will be seen that during the passage of the air through the engine, changes in its velocity and pressure occur.
Where the conversion is to velocity energy, 'drag' loads or rearward forces are produced; where the conversion is to pressure energy, forward forces are produced.

Power Measurement in Turboprop Aircraft

Shaft Horsepower

As in reciprocating engines the gas generator of a turbo-prop engine is used to drive a propeller. It is the propeller that develops the thrust that drives the airframe.

To measure the power that is developed one needs to devise a system that can monitor the turning force on the propeller shaft.

If an engine produces torque (T) at N revs/min

$$\text{Power} = 2\ NT$$

The Imperial Unit of Power is Horsepower.

$$\text{Horsepower} = \frac{2\ NT}{33000}$$

Horsepower developed by an engine output shaft is known as shaft horsepower.

Brake Horsepower

To measure shaft horsepower it is usual to use a brake dynamometer. Hence, Shaft Horsepower is sometimes known as Brake Horsepower. Numerically it is the same.

Equivalent Shaft Horsepower

The turboprop engine uses the majority of gas power to drive the turbines, with the free or power turbine driving the propeller shaft. There is always a residue of gas power exiting the exhaust however. As long as the exhaust is directed parallel to the thrust line of the engine then this exhaust will add to the thrust the propeller is producing. The total thrust production of the engine is therefore the Shaft Horsepower plus exhaust or jet thrust. It is called equivalent shaft horsepower.

$$\text{ESHP} = \text{SHP} + \text{Jet Thrust}$$

If the aircraft is in flight then the efficiency of the propeller must be taken into account.

$$\text{ESHP} = \text{SHP} \times \text{prop-eff.} + \text{Jet Thrust}$$

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Efficiency

Propulsive Efficiency

Propulsive efficiency is concerned with the efficiency of the engine to drive the aircraft in flight.

If P_{eff} = propulsive efficiency
V_a = Aircraft speed
V_j = Exhaust Velocity

Then $$P_{eff} = \frac{2V_a}{V_j + V_a}$$

Consideration of the formula reveals that:

If $V_a = V_j$ then the efficiency will be 100%. But if $V_a = V_j$ there is no difference in velocity through the engine and hence there can be no thrust. Therefore 100% efficiency is impossible. Also note there would be no energy used to drive the compressors if 100% of energy was used for propelling the aircraft.

If the aircraft is stationary on the ground then $V_a = 0$. In this case efficiency would be 0. This shows that propulsive efficiency is concerned with propelling the aircraft through the sky, not just producing thrust.

Propulsive Efficiency Graphs

The graph reveals how propeller-driven aircraft gain their efficiency first at low airspeeds because the controllable pitch propeller is capable of moving large mass airflows. The curves all peak out as soon as more fuel energy is introduced to create an exhaust velocity increase. Work then comes out in the form of increase aircraft speed.

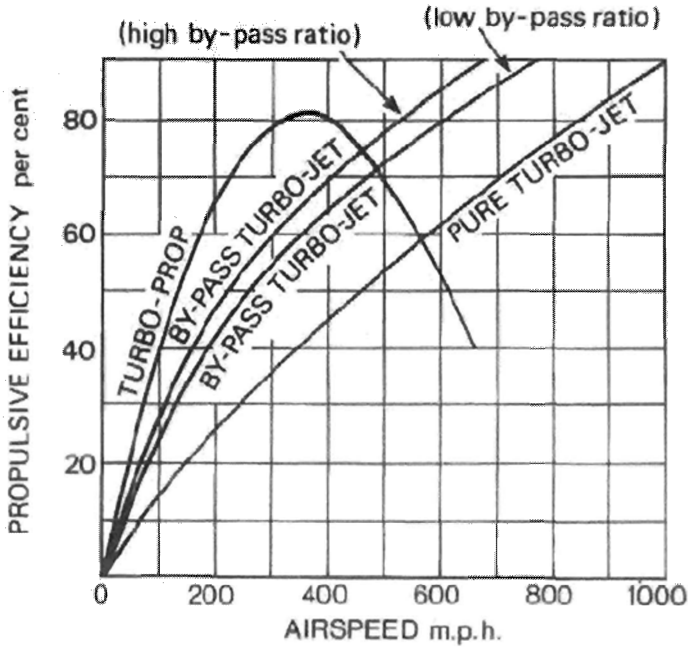

Figure 2.4: Propulsive Efficiency Graphs

The propeller aircraft (either piston or turbine driver peaks out slightly above 85%, after which the propeller loses efficiency. That is, its exhaust wake velocity continues to increase from added fuel energy, but aircraft speed does not increase proportionally. Note that after reaching approximately 375 mph, propulsive efficiency starts to decrease. Aerodynamic drag and tip shock stall are involved here and by 500 mph efficiency decreases to 65%.

The ultra-high bypass turbofan curve peaks at approximately 560 mph (Mach 0.85), after which the fan suffers the same losses in drag and tip speed as the propeller. In order to go to 700 mph (aircraft speed), the exhaust velocity will have to be increased to an uneconomical level.

The high bypass turbofan is the most widely use engine today in both large and small aircraft. Its propulsive efficiency curve peaks out slightly lower than the UHB engine but at approximately the same airspeed.

Subsonic aircraft with low and medium bypass turbofans all operate in the 500 to 600 mph range. Note that the curve shows a lower efficiency value than a high bypass engine in that range. Because of this, high bypass engines are rapidly replacing low and medium bypass engines in many aircraft.

The supersonic low bypass turbofan and turbojet have a theoretical propulsive efficiency peak limit in the 2,000 to 3,000 mph range. Their narrow, low-drag profile allows this range. Any additional energy added (in the form of fuel) to increase speed further would raise the internal engine temperatures to unacceptable levels.

Thermal Efficiency

Thermal efficiency is the ratio of net work produced by the engine to the fuel energy input. As with propulsive efficiency it cannot be measured in the cockpit but can be calculated by utilizing a fuel flow indication

$$\text{Thermal Efficiency} = \frac{\text{Net Power Output of the engine}}{\text{Energy value of Fuel consumed}}$$

Overall Efficiency

It is necessary to combine both of the above efficiencies when looking for a powerplant to suit a particular application.

$$\text{Overall Efficiency} = \text{Propulsive Eff.} \times \text{Thermal Eff.}$$

For example if P_{eff} = 70% and Thermal Eff. = 40% then

Overall efficiency = 70% x 40% = 28%.

Thermal Efficiency Curves

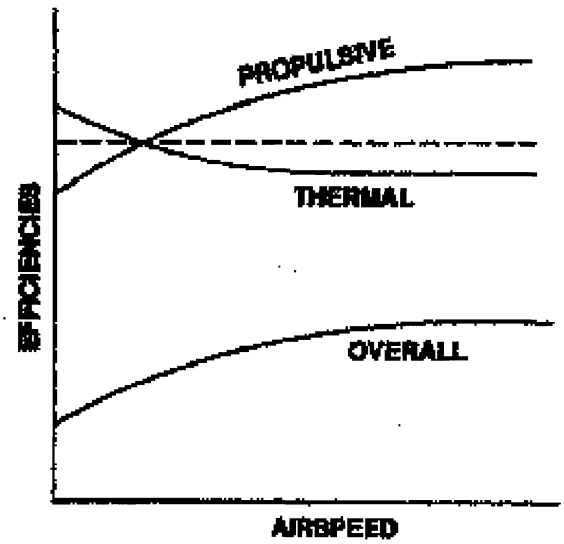

Figure 2.5: Propulsive, thermal and overall efficiencies, variation with speed

Propulsive efficiency increases as airspeed approaches exhaust velocity values.

Thermal efficiency decreases due to added fuel needs at higher airspeeds.

Overall efficiency increases as airspeed increases because propulsive efficiency increases more than thermal efficiency decreases.

Engine Compression Ratio

Engine Compression Ratio in a gas turbine is defined as the ratio between Compressor Outlet Pressure to Compressor Inlet Pressure.

The higher the compression ratio of the engine, the greater the power that can be produced.

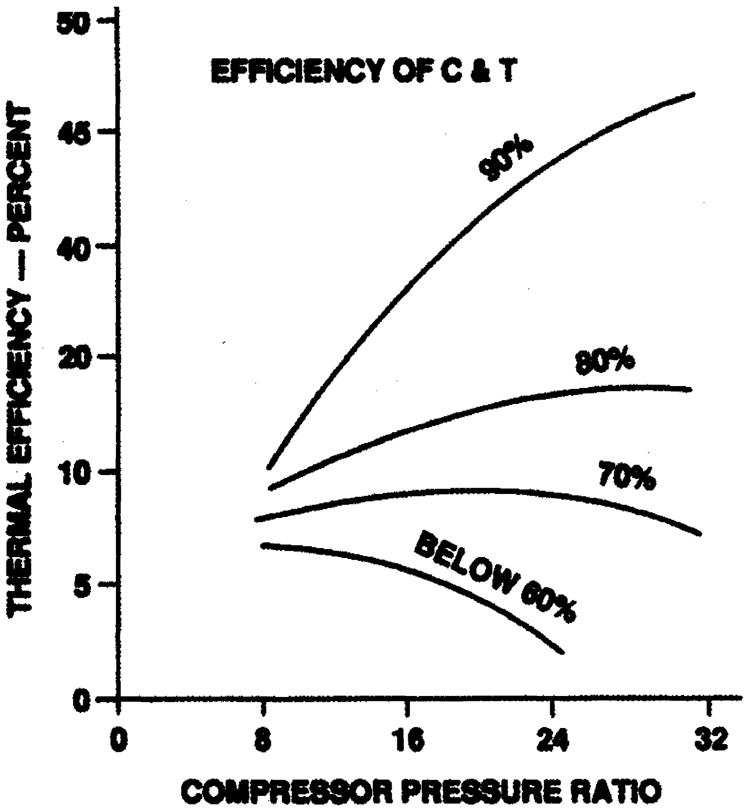

Figure 2.6: Thermal efficiency variation with CPR

Most modern compressor and turbine efficiencies are in the high 80% range. It can be seen from the above that a high compression ratio will produce an increased thermal efficiency.

In other words the ideal compressor efficiency (adiabatic compression) occurs when the compressor produces the maximum pressure with the least temperature rise and the ideal turbine extracts most work for the minimum fuel addition.

Degraded efficiency of the compressor and turbine as shown above at 60 & 70% is due to wear in service, damage or just contamination by dirt etc.

Specific Fuel Consumption

Specific Fuel Consumption (SFC) is sometimes called 'the engine man's efficiency'.

SFC is defined as the ratio of fuel consumed per pound of thrust produced. SFC is inversely proportional to efficiency. In other words the lower the SFC the higher the efficiency.

Units of SFC in a pure Jet engine are - lb/hr/lb thrust

In a Turbo Jet Engine - lb/hr/SHP

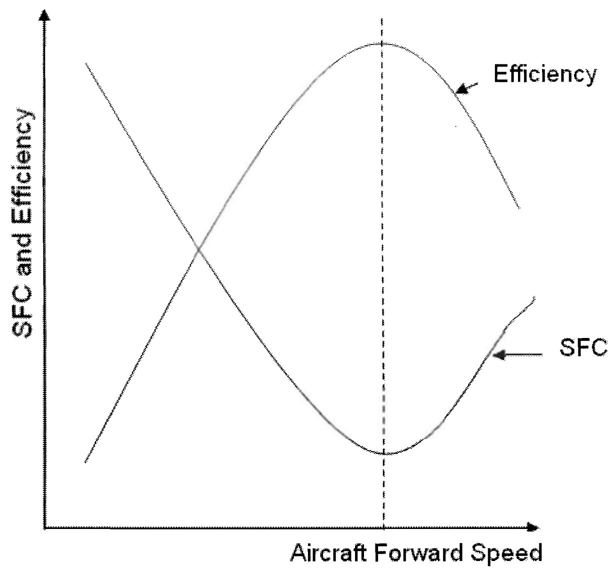

Figure 2.7: SFC and efficiency, variation with forward speed

Note that the SFC starts to increase after falling to a minimum as the aircraft goes faster. This is due to ram effect causing an increase in mass airflow and hence an increase in fuel flow. The engine power limiter will control the maximum fuel flow to prevent over speeding or flat rated power limits.

Ram effect is discussed in Chapter 3 - Intakes

Thrust Factors

The International Standard Atmosphere

ALTITUDE (h)		AMBIENT TEMPERATURE (To)			AMBIENT PRESSURE (Po)		SPEED OF SOUND (ao)		
Feet	Metres	Deg. K.	Deg. C.	Deg. F.	lb./sq. in.	millibars	ft./sec.	knots	m./sec.
−1,000	−304.8	290.13	+16.98	62.6	15.24	1050.4	1120.3	663.3	341.5
0	0	288.15	15.00	59.0	14.69	1013.2	1116.6	661.1	340.3
+1,000	+304.8	286.17	13.02	55.4	14.17	977.1	1112.6	658.8	339.1
2,000	609.6	284.19	11.04	51.9	13.66	942.1	1108.7	656.5	337.9
3,000	914.4	282.21	9.06	48.3	13.17	908.1	1104.9	654.2	336.8
4,000	1219.2	280.23	7.08	44.7	12.69	875.1	1100.9	651.9	335.6
5,000	1524.0	278.24	5.09	41.2	12.23	843.0	1097.1	649.6	334.4
6,000	1828.8	276.26	3.11	37.6	11.78	811.9	1093.2	647.8	333.2
7,000	2133.6	274.28	1.13	34.0	11.34	781.8	1089.3	644.9	332.0
8,000	2438.4	272.30	−0.85	30.5	10.92	752.6	1085.3	642.6	330.8
9,000	2743.2	270.32	−2.83	26.9	10.51	724.3	1081.4	640.3	329.6
10,000	3048.0	268.34	−4.81	23.3	10.11	696.8	1077.4	637.9	328.4
11,000	3352.8	266.36	−6.79	19.8	9.72	670.2	1073.4	635.6	327.2
12,000	3657.6	264.38	−8.77	16.2	9.35	644.4	1069.4	633.2	325.9
13,000	3962.4	262.39	−10.76	12.6	8.98	619.4	1065.4	630.8	324.7
14,000	4267.2	260.41	−12.74	9.1	8.63	595.2	1061.4	628.4	323.5
15,000	4572.0	258.43	−14.72	5.5	8.29	571.7	1057.3	626.0	322.3
16,000	4876.8	256.45	−16.70	1.9	7.97	549.1	1053.3	623.6	321.1
17,000	5181.6	254.47	−18.68	−1.6	7.65	527.2	1049.2	621.2	319.8
18,000	5486.4	252.49	−20.66	−5.2	7.34	505.9	1045.1	618.8	318.5
19,000	5791.2	250.51	−22.64	−8.8	7.04	485.6	1040.9	616.4	317.3
20,000	6096.0	248.53	−24.62	−12.3	6.75	465.6	1036.9	613.9	316.1
21,000	6400.8	246.54	−26.61	−15.9	6.48	446.4	1032.7	611.5	314.8
22,000	6705.6	244.56	−28.59	−19.5	6.21	427.9	1028.6	609.0	313.5
23,000	7010.4	242.58	−30.57	−23.0	5.95	409.9	1024.4	606.5	312.2
24,000	7315.2	240.60	−32.55	−26.6	5.69	392.7	1020.2	604.1	310.9
25,000	7620.0	238.62	−34.53	−30.2	5.45	375.9	1015.9	601.6	309.7
26,000	7924.8	236.64	−36.51	−33.7	5.22	359.9	1011.8	599.1	308.4
27,000	8229.6	234.66	−38.49	−37.3	4.99	344.3	1007.5	596.6	307.1
28,000	8534.4	232.68	−40.47	−40.9	4.78	329.3	1003.2	594.0	305.8
29,000	8839.2	230.69	−42.46	−44.4	4.57	314.8	998.9	591.5	304.5
30,000	9144.0	228.71	−44.44	−48.0	4.36	300.9	994.7	588.9	303.2
31,000	9448.8	226.73	−46.42	−51.6	4.17	287.4	990.3	586.4	301.9
32,000	9753.6	224.75	−48.40	−55.1	3.98	274.5	986.0	583.8	300.5
33,000	10058.4	222.77	−50.38	−58.7	3.80	261.9	981.7	581.2	299.2
34,000	10363.2	220.79	−52.36	−62.3	3.63	249.9	977.3	578.7	297.9
35,000	10668.0	218.81	−54.34	−65.8	3.46	238.4	972.9	576.1	296.5
36,000	10972.8	216.83	−56.32	−69.4	3.29	227.3	968.5	573.4	295.2
36,089	11000.0	216.65	−56.50	−69.7	3.28	226.3	968.1	573.2	295.1
37,000	11277.6	Ambient temperature remains constant from this point up to 65,617 ft.			3.14	216.6	Speed of sound remains constant from this point up to 65,617 ft.		
38,000	11582.4				2.99	206.5			
39,000	11887.2				2.85	196.8			
40,000	12192.0				2.72	187.5			
45,000	13716.0				2.14	147.5			
50,000	15240.0				1.68	115.9			
55,000	16764.0				1.32	91.2			
60,000	18288.0				1.04	71.7			
65,000	19812.0				0.82	56.4			

Figure 2.8: The International Standard Atmosphere

Variation of Thrust with Altitude, Temperature and Airspeed

The figure below shows that thrust improves rapidly with decreasing temperature, given constant altitude, RPM and airspeed.

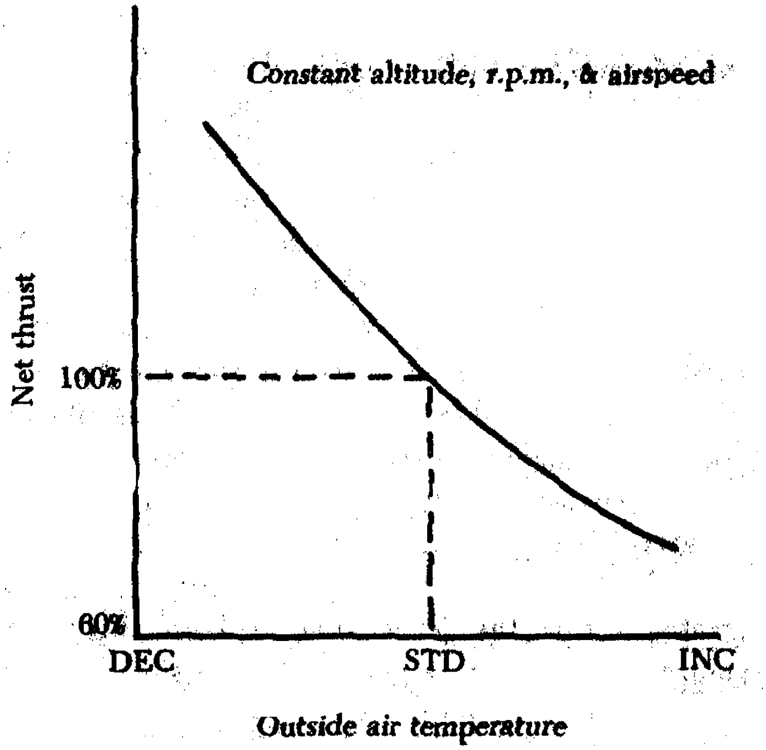

Figure 2.9: Net thrust variation with outside air temperature (OAT)

This is because with decreased temperature one gets increased density, hence the air has greater mass and from the momentum thrust formula thrust will increase.

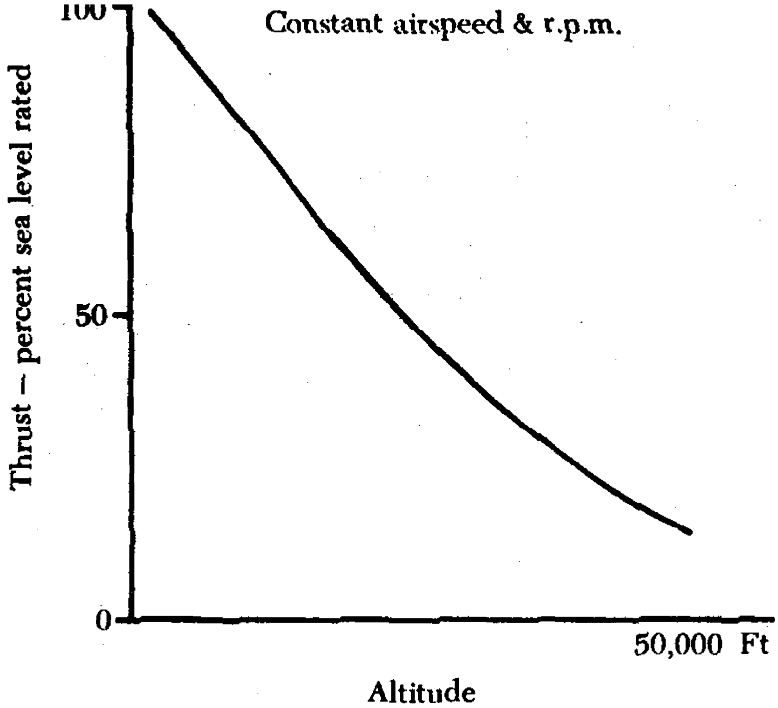

Figure 2.10: Thrust decreases with altitude

The altitude effect on thrust is shown above. Thrust decreases with altitude, given constant airspeed and RPM.

Whilst temperature is decreasing with altitude so is pressure. Since the temperature lapse rate is less than the pressure lapse rate as altitude is decreased, the density is decreased and as a result thrust will decrease.

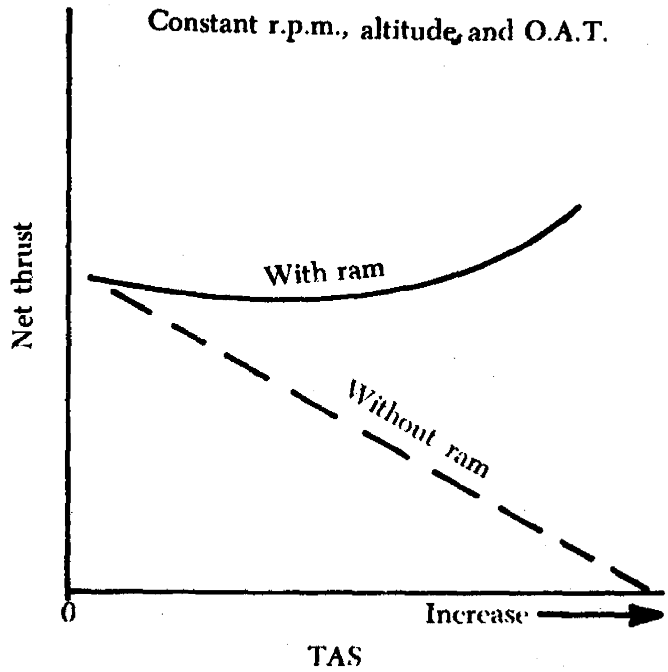

Figure 2.11: Thrust variation with true airspeed (TAS)

The effect of airspeed on thrust depends upon *Ram Effect* being present.

Without ram effect thrust will decrease, with ram effect thrust will start to recover then increase as the speed increases above about 200kts

Increase in forward speed without ram effect will cause the momentum drag term ($\dot{m}V_a$) in the thrust formula $\dot{m}(V_j - V_a)$ to increase thus reducing thrust.

In an intake designed to promote *ram recovery*, that is to increase pressure above existing atmospheric pressure at the engine inlet, ram effect will provide extra compression without further work being needed at the turbine.

In reality there is always some ram effect as the aircraft increases speed so the actual result is a compromise between the two conditions shown above.

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Engine Ratings

Flat Rating

As OAT increase for a given maximum throttle setting the engine thrust increases to a thrust limit. This is known as the flat rated thrust and is usually quoted at the maximum ambient temperature allowed (i.e. 42,000 lb thrust at 59°F) Above this temperature, sometimes known as the kink point or corner point the engine will exceed the maximum exhaust gas temperature limit and will become temperature limited.

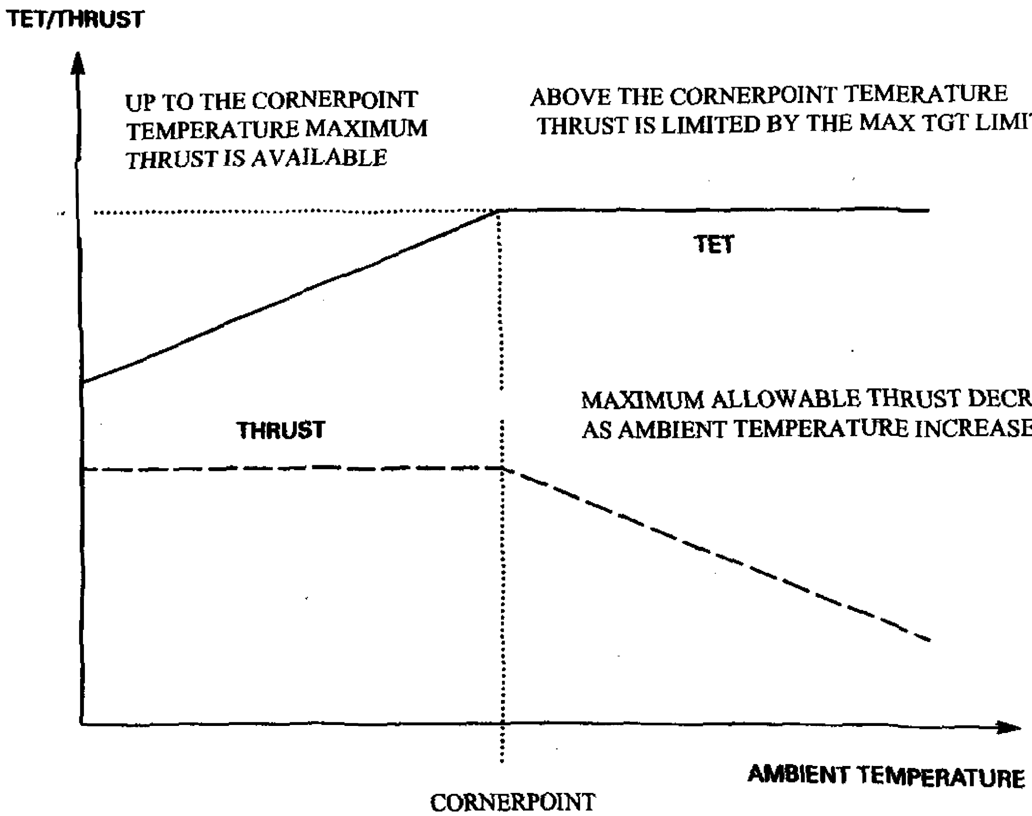

Figure 2.12: Flat Rating Graph

Engine Power Ratings

Turbine engines, both turbojet and turbofan, are thrust rated in terms of either engine pressure ratio or fan speed and turboshaft/turboprop engines are SHP rated in the following categories: Takeoff, maximum continuous, maximum climb, maximum cruise, and idle. For certification purposes, the manufacturer demonstrates to the FAA or CAA that the engine will perform at certain thrust or shaft horsepower levels for specified time intervals and still maintain its airworthiness and service life for the user.

These ratings can usually be found on the engine **Type Certificate Data Sheets**. The ratings are classified as follows:

Takeoff Wet Thrust/SHP
This rating represents the maximum power available while in water injection and is time limited. It is used only during takeoff operation. Engines are trimmed to this rating.

Takeoff Dry Thrust/SHP
Limits on this rating are the same as takeoff wet but without water injection. Engines are trimmed to this rating.

Maximum Continuous Thrust/SHP
This rating has no time limit but is to be used only during emergency situations at the discretion of the pilot, for example, during one engine-out cruise operation.

Maximum Climb Thrust/SHP
Maximum climb power settings are not time limited and are to be used for normal climb, to cruising altitude, or when changing altitudes. This rating is sometimes the same as maximum continuous.

Maximum Cruise Thrust/SHP
This rating is designed to be used for any time period during normal cruise at the discretion of the pilot.

Idle Speed
This power setting is not actually a power rating but, rather, the lowest usable thrust setting for either ground or flight operation.

TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.3 Inlet

Copyright Notice

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.
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Table of Contents

Module 15.3 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 Reference**	**Level**
		B1
Inlet	15.3	2
Compressor inlet ducts		
Effects of various inlet configurations;		
Ice protection.		

Module 15.3 - Inlet

General

Description

The main air intake is often part of the airframe structure, delivering the air to the engine air intake casing.

The intake is designed to convert kinetic energy into pressure reduce the velocity at the compressor inlet to no more than between 0.4 and 0.5 Mach. Any inefficiency in the intake results in a pressure loss at the compressor inlet and reduced compressor outlet pressure.

Purpose

To deliver the air to the compressor with the minimum loss of energy

The intake system should meet the following requirements:-

1 Deliver to the engine an adequate mass flow of air under any engine operating condition.
2 The air must be delivered evenly across the face of the compressor, free from turbulence at approximately M = 0.4.
3 Must make maximum use of **RAM** pressure.
4 Produce minimum airframe drag.

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Ram

Definitions

Total Head Pressure
The pressure of the air when brought to rest in front of the intakes.

Ram Ratio
The ratio of the total pressure (P_t) at the compressor entry to static pressure (P_s) at the intake entry i.e. P_t/P_s (See figure 3.1)

Ram Recovery
To convert as much of the intake air velocity as possible to pressure at the face of the engine. If all available ram pressure is converted, it is known as "TOTAL PRESSURE RECOVERY".

Ram Compression
Ram Compression increases in pressure within the intake at substantial forward speeds.

When an aircraft is stationary, the engine intake is of little interest, in fact, a slight depression exists within it. Ram compression causes redistribution of the energy existing in the air stream. As the air in the intake slows in endeavouring to pass into and through the compressor element against the air, increasing pressure and density which exists therein, so the kinetic energy of the air in the intake decreases. This is accompanied by a corresponding increase in its pressure and internal energies and consequently compression of the air stream is achieved within the intake, thus converting the unfavourable intake lip conditions into the compressor inlet requirements.

Although ram compression improves the performance of the engine, it must be realised that during the process there is a drag force on the engine and hence the aircraft. This drag must be accepted, since it is a penalty inherent in a ram compression process. The added thrust more than makes up for the increase in drag.

The degree of ram compression depends on the following:-

1. The frictional losses at those surfaces ahead of the intake which are "wetted" by the intake airflow.
2. Frictional losses at the intake duct walls.
3. Turbulence losses due to accessories or structural members located in the intake.
4. Aircraft speed.
5. In a turbo-prop engine, drag and turbulence losses due to the propeller, blades and spinner.

Intake Momentum Drag
As forward speed increases, thrust decreases, this is due to the momentum of the air passing into the engine in relation to the aircraft's forward speed.

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Intake Design

The following types of intake can be seen on modern aircraft:-

1 Pitot
2 Divided Entrance
3 Variable Geometry
4 External/Internal Compression

Pitot Intakes

This intake is suitable for subsonic or low supersonic speeds. The intake is usually short and is very efficient because the duct inlet is located directly ahead of the compressor. The duct is **divergent** from front to rear with smooth gradual changes in shape

Efficiency will fall rapidly at sonic speeds due to shock wave formation at the lip. With increased speeds above sonic, this shock wave will move backwards towards the compressor face. If the shock wave enters the compressor, damage may occur and there is a high risk of compressor surge.

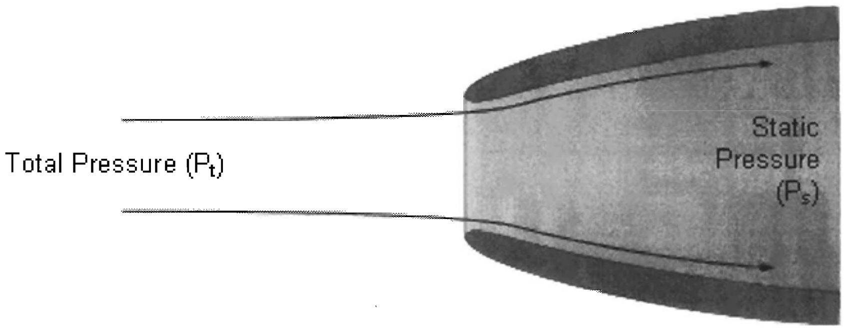

Figure 3.1: A pitot intake

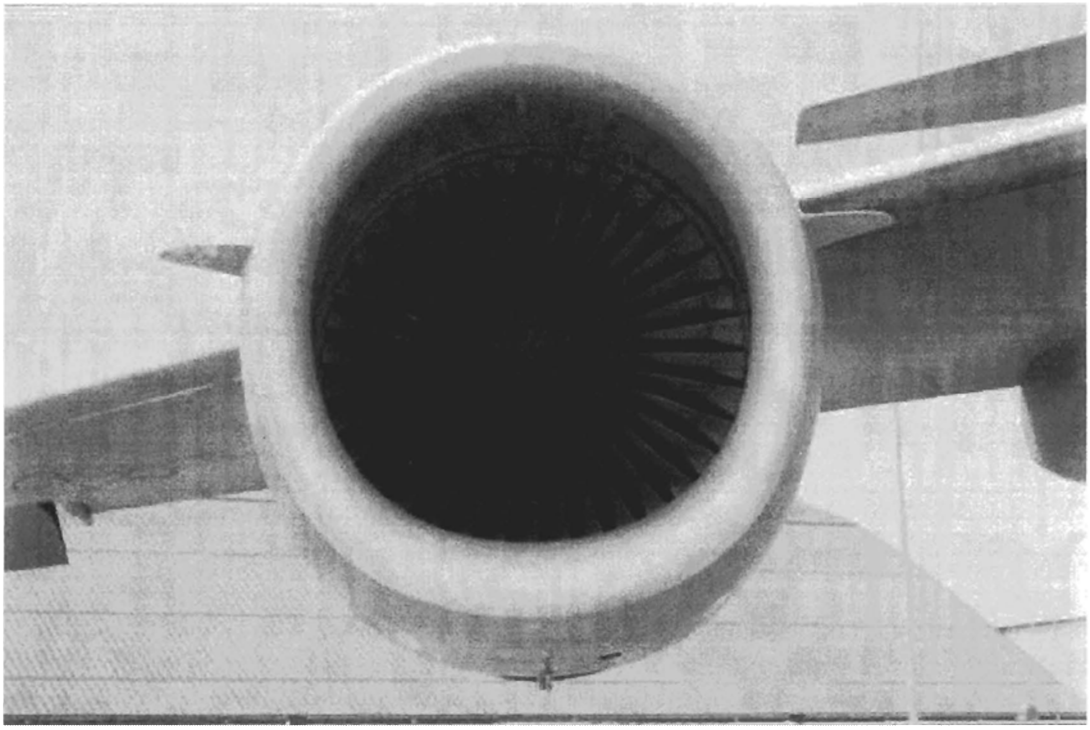

Figure 3.2: A pitot intake

Divided Entrance Intakes

This type is used on some single engined aircraft with a fuselage mounted engine and can be either side scoop or wing root mounted. The side scoop inlet is placed as far forward of the compressor as possible to approach the straight line effect of the single inlet. The wing root inlet presents problems to the designer in the forming of the curvature necessary to deliver the air to the engine compressor.

One major problem with both of these inlet types is a loss of ram pressure occurs on one side of the intake and as a result separated turbulent air is fed to the compressor.

The intake will be divergent from front to rear.

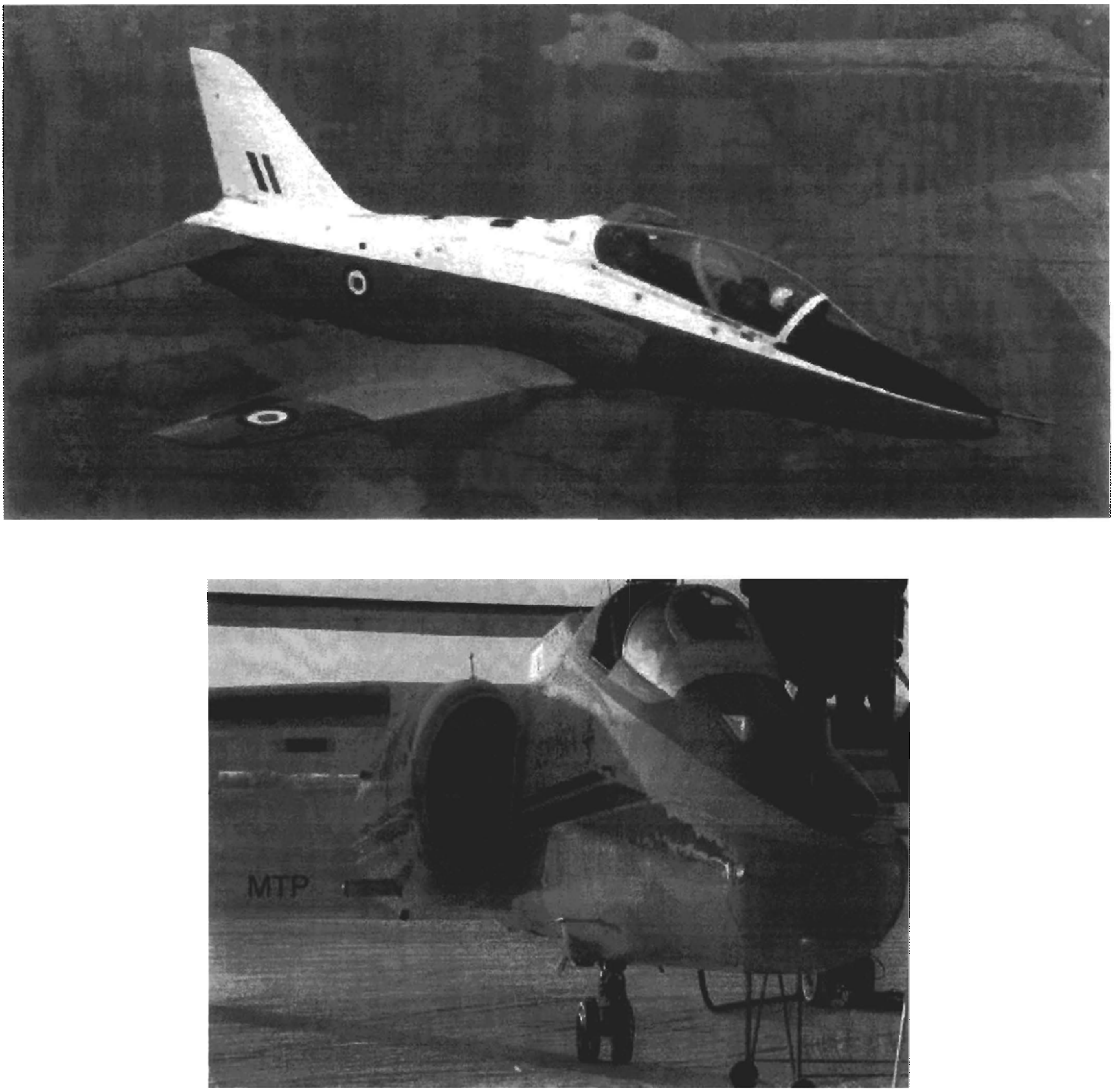

Figure 3.3: Divided entrance intake configurations

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Supersonic Intakes

It is required that the airflow onto the compressor face is **subsonic** regardless of the aircraft speed, (Normally mach 0.4) if the rotating aerofoils are to remain free of shock wave accumulation which would be detrimental to the compression process.

Additional to this, it is often necessary to restrict the amount of airflow entering the compressor at supersonic speeds since the amount of airflow at this speed is simply not required.

At supersonic speeds, a **Convergent-Divergent** intake is found to be most effective, but at subsonic speeds this type of intake is inefficient. The usual method of overcoming this is to use a variable geometry inlet.

The Shock Wave

An inlet shock is very similar to shock waves common to aircraft wings and other aerofoils. A shock wave is defined as an accumulation of sound energy, or pressure, developed when the wave, trying to move away from an object, is held in a stationary position by the oncoming flow of air. One useful aspect of the shock wave is that airflow passing through the high pressure shock region slows down.

Variable Throat Area Inlet

The diagram of the concord inlet (Figure 3.5(a) and (b)) shows firstly an inlet at subsonic speeds. The throat is a maximum size for maximum air inlet. The last diagram (Figure 3.5 (c)) shows the same inlet at supersonic speeds with the throat area reduced. The convergent part breaks the airflow in to a series of weak shocks which slow down the air progressively. Any unwanted air thereafter can be dumped by the spill valve.

Figure 3.4: A supersonic intake (Concorde)

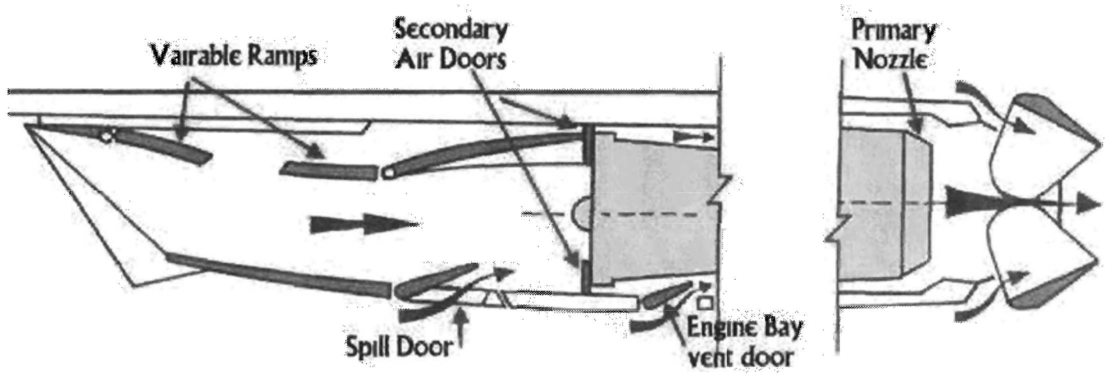

Figure 3.5(a): Variable intake operation (Concorde) - subsonic

At take off the engines need maximum airflow, therefore the ramps are fully retracted and the auxiliary inlet vane is wide open. This vane is held open aerodynamically. The auxiliary inlet begins to close as the Mach number builds and it completely closed by the time the aircraft reaches Mach 0.93.

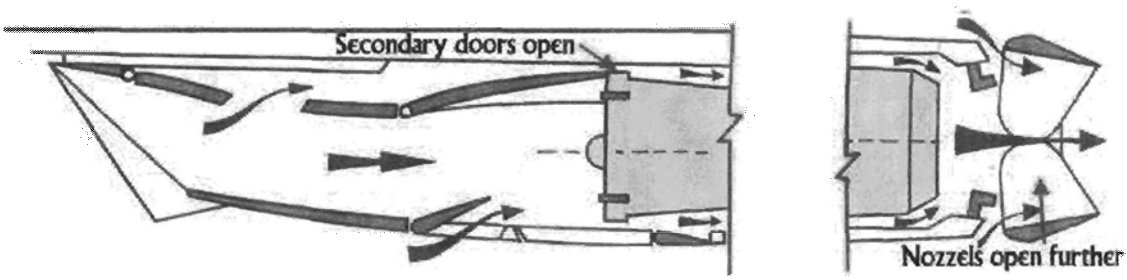

Figure 3.5(b): Variable intake operation (Concorde) - subsonic

Shortly after take off the aircraft enters the noise abatement procedure where the re-heats are turned off and the power is reduced. The secondary nozzles are opened further to allow more air to enter, therefore quietening down the exhaust. The Secondary air doors also open at this stage to allow air to by pass the engine.

At slow speeds all the air into the engine is primary airflow and the secondary air doors are kept closed. Keeping them closed also prevents the engine ingesting any of its own exhaust gas. At around Mach 0.55 the Secondary exhaust buckets begin to open as a function of Mach number to be fully open when the aircraft is at M1.1

The ramps begin move into position at mach 1.3 which shock wave start to form on the intakes.

At take off and during subsonic flight, 82% of the thrust is developed by the engine alone with 6% from the nozzles and 21% from the intakes

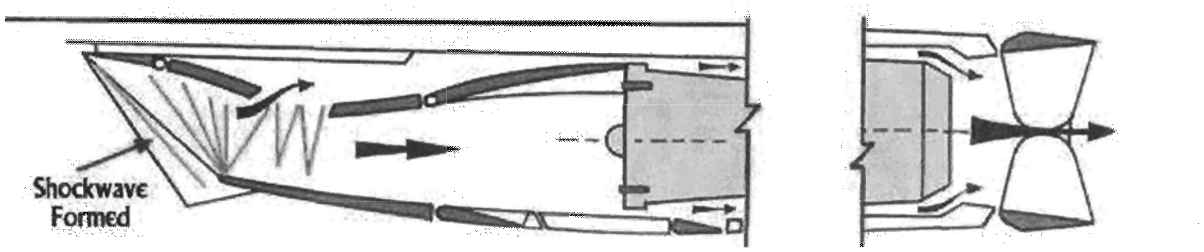

Figure 3.5(c): Variable intake operation (Concorde) - supersonic

At the supersonic cruse speed of mach 2.0 the ramps have moved over half their amount of available travel, slowing down the air by producing a supersonic shockwave (yellow lines) at the engine intake lip.

When the throttles are brought back to start the decent the spill door is opened to dump out excess air that is no longer needed by the engine, this allows the ramp to go down to their maximum level of travel. As the speed is lowered the spill doors are closed and the ramps begin to move back so by M1.3 are again fully retracted.

The ramps can continue in operation till Mach 0.7, should an engine have had to have been shut down.

During the Supersonic cruse only 8% of the power is derived by the engine with the other 29% being from Nozzles and an impressive 63% from the intakes.

External / Internal Intake

At higher supersonic speeds, a more suitable type of intake is the one shown below. This type of intake produces a series of mild shock waves without excessively reducing the intake efficiency.

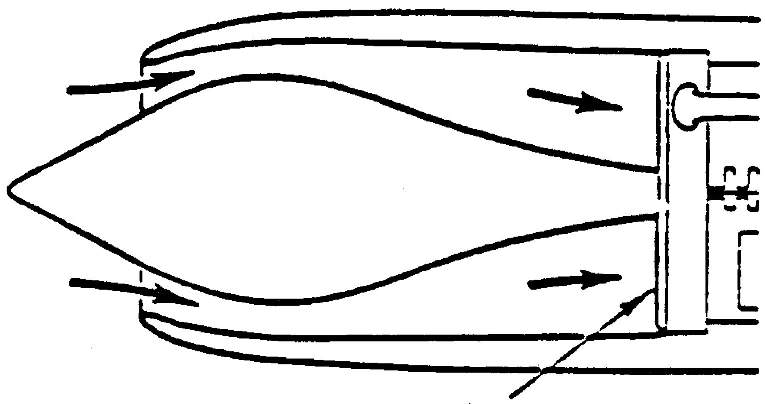

Figure 3.6: External / Internal intake

This intake is sometimes known as a plug intake.

In some applications the plug position is variable dependent upon Mach number.

Intake Ice Protection

Hot Air Anti Icing

Large commercial passenger aircraft use podded engines with pitot intake nacelles. It is normal for this configuration to ensure no ice accretion can occur at the leading edge of the intake. Normally in this configuration the intake lip is prevented from icing by blowing hot air, normally from the HP compressor, through a TAI Manifold also known as a piccolo tube that runs inside the leading edge of the duct. The air exits the duct, either from a dedicated exit port on the side of the intake (GE CF6-80) or into the intake itself through a joggled lip on the inside of the intake. The example shown below is a Rolls Royce 535-E4 as fitted to a Boeing 757. The air supply is usually taken immediately at the HP air outlet. In this way air for anti icing is always available if the engine is running. On some engines this air is also routed through inlet guide vanes and into the LP fan spinner.

The system is activated manually from within the cockpit. An anti-ice pressurisation and control valve is activated and allows HP air to pass to the anti-ice manifold. The valve regulates the pressure, to a figure of about 40 psi or below. Anti icing conditions are deemed to exist at below +10 ^{0}C with visible moisture, that is rain hail snow or fog.

In the event of valve failure it may be manually locked in the open position prior to take off.

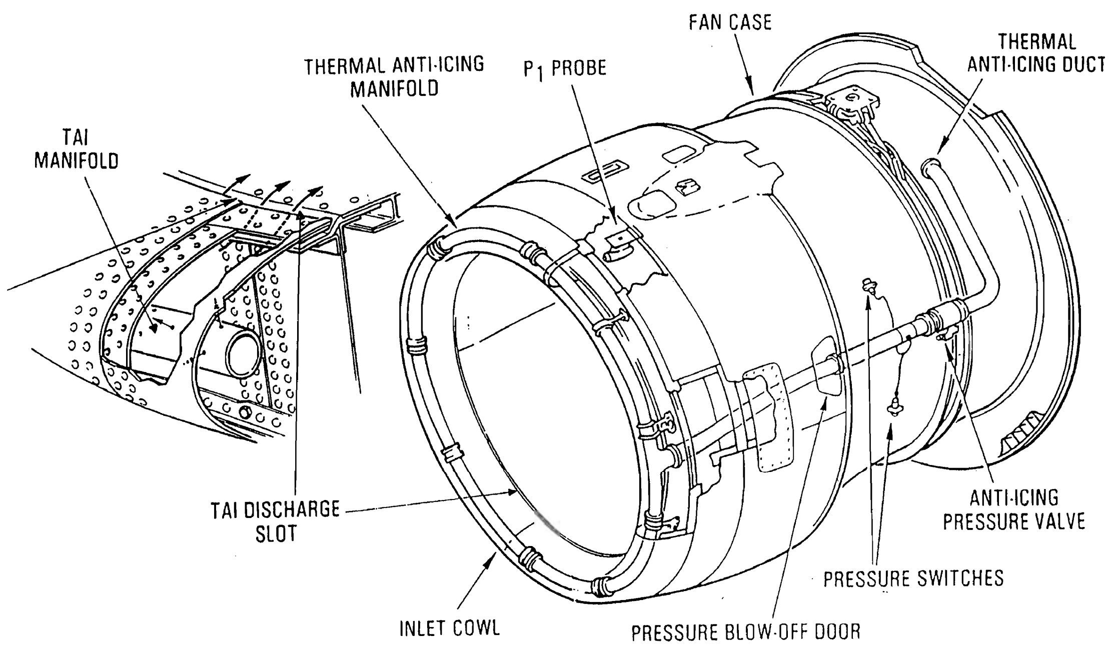

Figure 3.7: Inlet anti-ice system

Electrical Intake De-icing / Anti-icing systems

A disadvantage of ducted air anti ice systems is that a slight power loss occurs when anti icing is used. One way that some manufacturers avoid this power loss is to fix electrical heating elements on the leading edge of the intake. These elements are embedded in a rubber boot. This type of system is more commonly found on turbo-prop intakes.

The electrical system of ice protection is generally used for turbo-propeller engine installations, as this form of protection is necessary for the propellers. The surfaces that require electrical heating are the air intake cowling of the engine, the propeller blades and spinner and, when applicable, the oil cooler air intake cowling.

Electrical heating pads are bonded to the outer skin of the cowlings. They consist of strip conductors sandwiched between layers of neoprene, or glass cloth impregnated with epoxy resin. To protect the pads against rain erosion, they are coated with a special, polyurethane-based paint. When the de-icing system is operating, some of the areas are continuously heated to prevent an ice cap forming on the leading edges and also to limit the size of the ice that forms on the areas that are intermittently heated

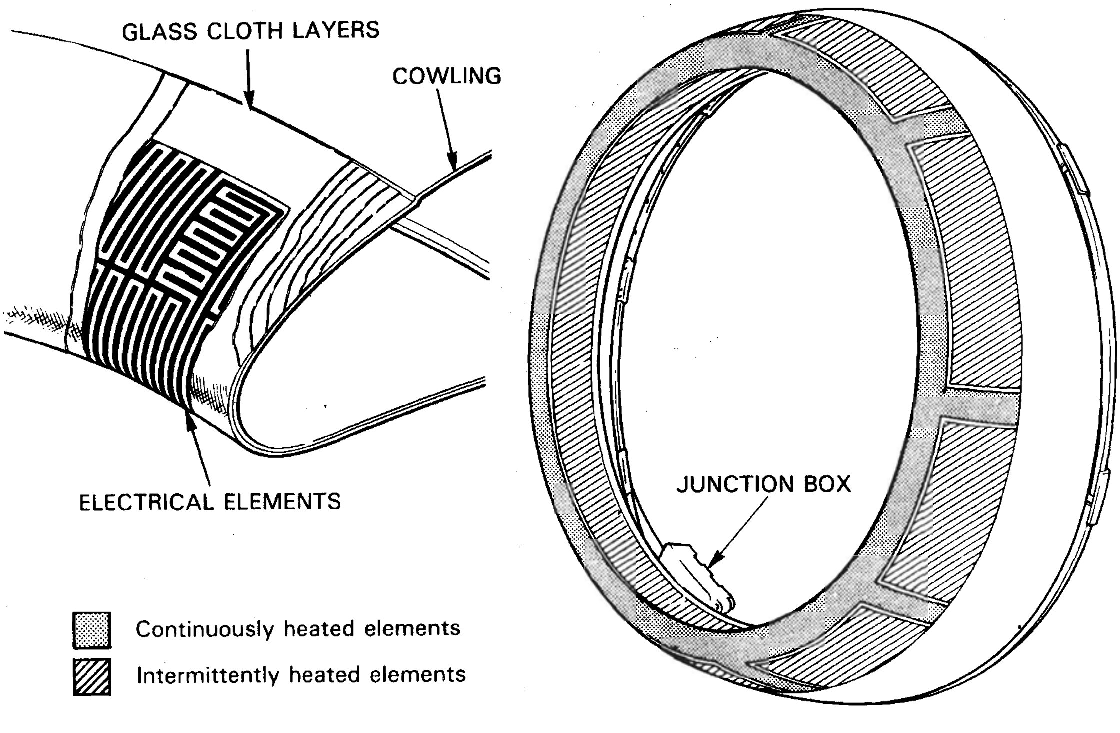

Figure 3.8: Electrically heated intakes

Electrical power is supplied by a generator and, to keep the size and weight of the generator to a minimum, the de-icing electrical loads are cycled between the engine, propeller and, sometimes, the airframe.

When the ice protection system is in operation, the continuously heated areas prevent any ice forming, but the intermittently heated areas allow ice to form, during their ‘heat-off’ period. During the ‘heat-on’ period, adhesion of the ice is broken and aerodynamic forces then remove it.

The cycling time of the intermittently heated elements is arranged to ensure that the engine can accept the amount of ice that collects during the ‘heat-off’ period and yet ensure that the ‘heat-on’ period is long enough to give adequate shedding without causing any run-back icing to occur behind the heated areas.

A two-speed cycling system is often used to accommodate the propeller and spinner requirements; a ‘fast’ cycle at the high air temperatures when the water concentration is usually greater and a slow’ cycle in the lower temperature range

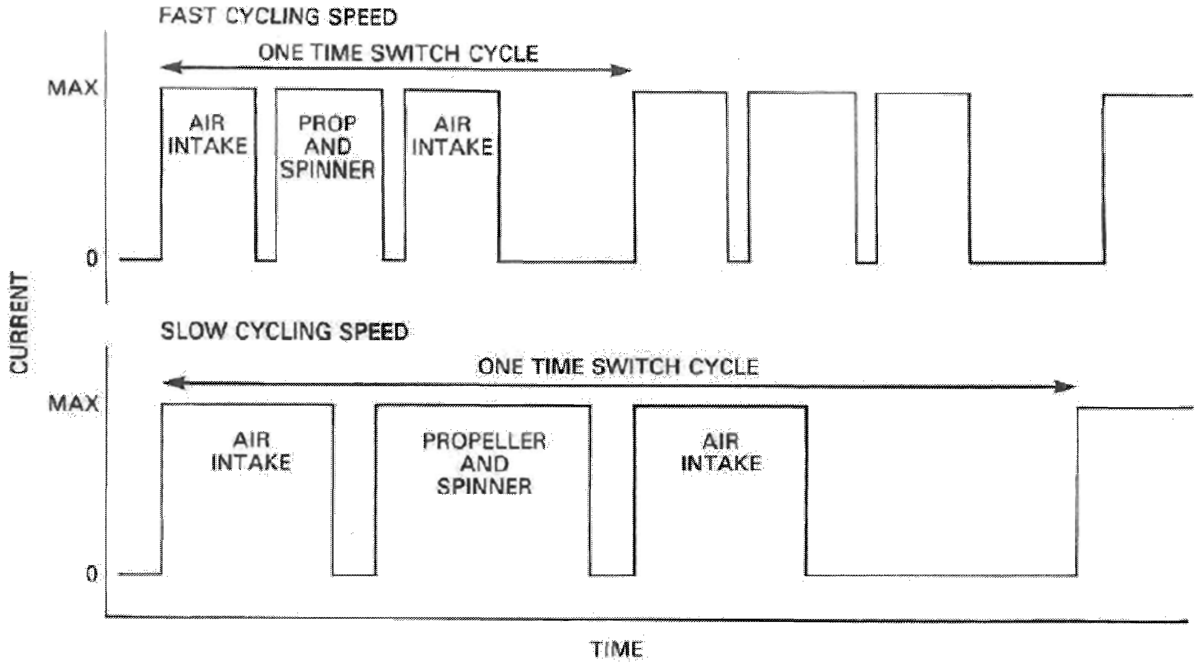

Figure 3.9: Inlet heat cycling

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.4 Compressors

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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.

Table of Contents

Module 15.4 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 Reference	Level
		B1
Compressors	15.4	2
Axial and centrifugal types;		
Constructional features and operating principles and applications;		
Fan balancing;		
Operation:		
Causes and effects of compressor stall and surge;		
Methods of air flow control: bleed valves, variable inlet guide vanes, variable stator vanes, rotating stator blades;		
Compressor ratio.		

Module 15.4 - Compressors

Introduction

The compressor is the means of promoting the mass airflow through the engine and at the same time creating a pressure rise in that air flow. The principle behind the compressor is that the energy of a given mass of air is increased by acceleration in the rotating element and then diffused by the stationary element to reduce the velocity component and increase the static pressure and temperature.

Compressor design is an aerodynamic problem, the factors which affect its performance are the aerofoil section of the blades, the blade pitch angles, the length/chord ratio of the blade and its flexibility under load. Compressors are designed on a compromise between high performance over a narrow speed range or a moderate performance over a wide speed range, any large deviation from design limitations causes changes in aerodynamic flow and instability within the compressor.

Compressor Pressure Ratio

This is the ratio of compressor delivery pressure to compressor inlet pressure;

$$\text{CPR} = \frac{\text{Compressor Delivery Pressure}}{\text{Compressor Inlet Pressure}}$$

The higher the value of CPR the more efficient the engine is likely to be.

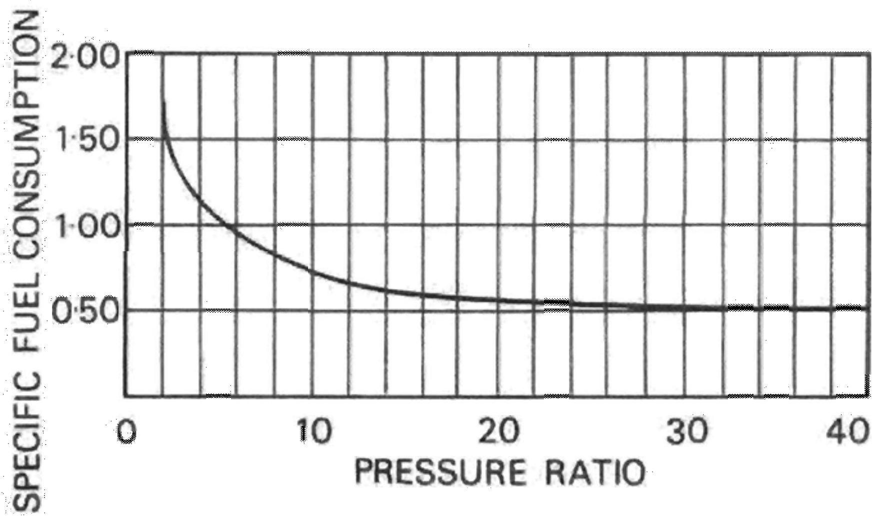

Figure 4.1: SFC decreases with increasing Pressure Ratio

Types of Compressor

The following types of compressors are in use in modern gas turbine engines

1 Centrifugal compressors
2 Axial flow compressors
3 Combination of both

Centrifugal Compressors

These may be found in various forms e.g. single entry single stage, single entry multi-stage and double entry single stage (double sided).

The compressor assembly has three main parts;

the rotating impeller,
the stationary diffuser,
the casing or manifold.

Air enters the impeller at the centre, eye or hub, the high rotational velocities accelerates the air radially outwards between the vanes imparting high velocity (kinetic energy) and higher pressure and temperature to the air. The air then passes into the divergent ducts of the diffuser which converts most of the kinetic energy into a further rise in pressure and heat energy. the air then flows through the manifold into the combustion chambers or into the next stage of compression.

These compressors are approx. 80% efficient and can produce a CPR of up to 10:1

However the large frontal area has made them unsuitable for the main flight engines on large aircraft. A CPR of 5:1 is more normal in, for example, a Rolls Royce Dart Turbo-prop engine, which utilises a dual stage centrifugal compressor.

They are particularly suitable where low cost, ease of manufacture and ruggedness are required.

Advantages and Disadvantages

Advantages

High Pressure rise per stage
Good compression efficiency over a wide range of rotational speed
Simple and cheap to manufacture (usually cast aluminium)
Rugged and resistant to major damage from FOD
Low weight
Low starting power requirements

Disadvantages

Low overall compression ratio
Low power output
Large frontal area for a given mass flow
Limited to 2 stages due to inter-stage losses

Configurations

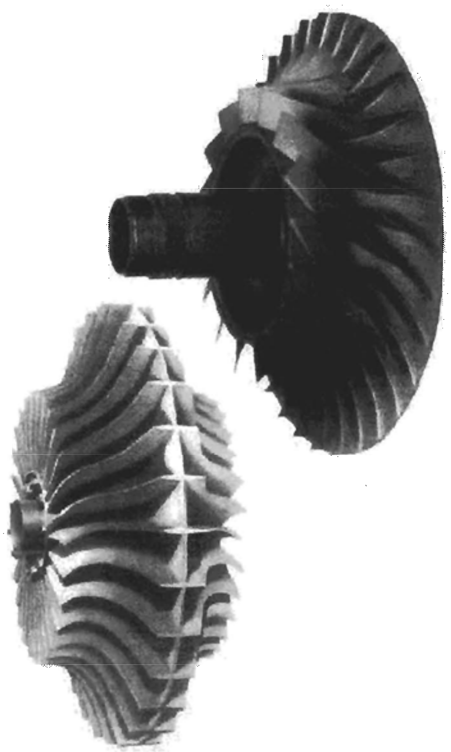

Figure 4.2: Single Entry Single Stage and Dual Entry Single Stage centrifugal compressors

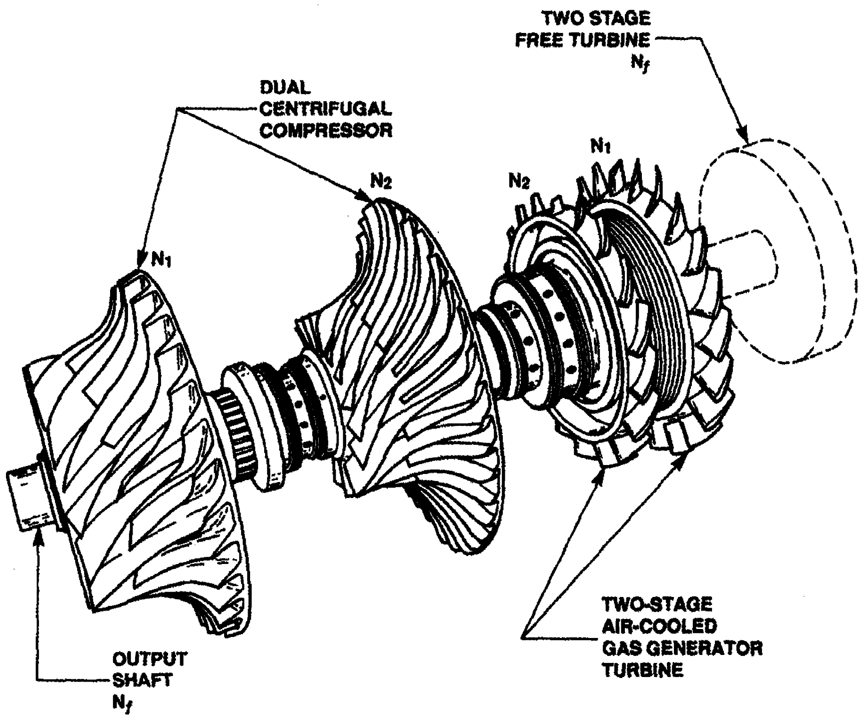

Figure 4.3: Dual Stage Single Entry (shown with a free turbine output shaft)

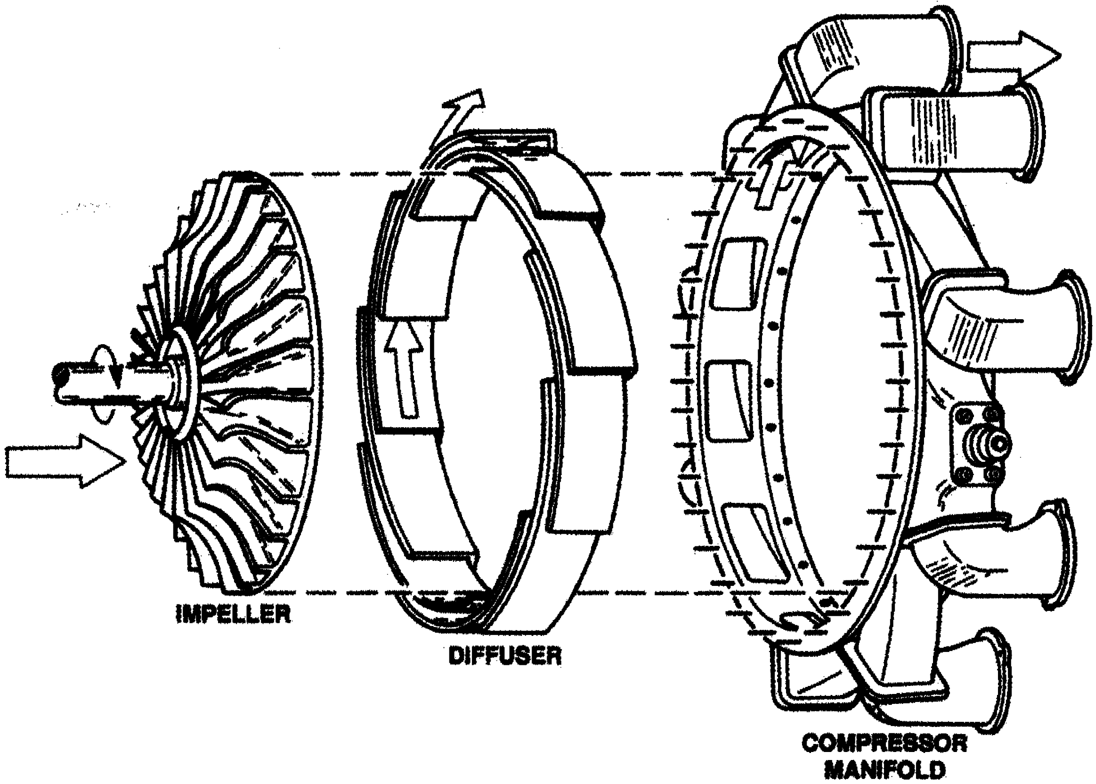

Figure 4.4: Centrifugal Compressor Component Parts

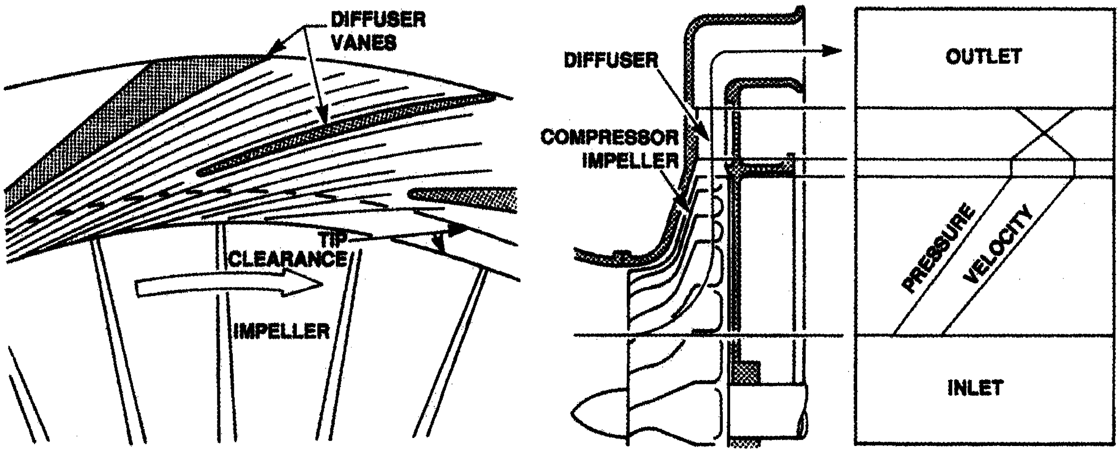

Figure 4.5: Flow Diagram

To maintain the efficiency of the compressor, it is necessary to prevent excessive air leakage between the impeller and the casing; this is achieved by keeping their clearances as small as possible

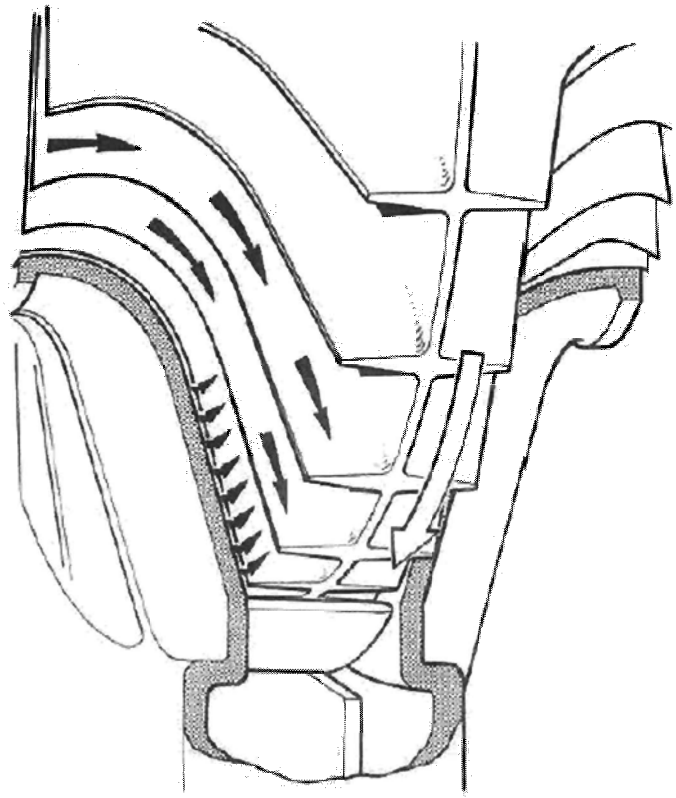

Figure 4.6: Clearance between impeller and casing

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Axial Flow Compressors

General

So called because the airflow moves parallel to the axis of rotation.

The general evolution of the gas turbine engine has been towards the axial flow compressor because it is possible to produce a high compressor pressure ratio (CPR) and mass flow e.g. axial flow compressors are in use with pressure ratios greater than 30:1 and the trend is to go even higher.

In the axial flow compressor the airflow passes through ***stages***; each stage consists of a multi bladed rotor and a multi-vaned stator. The blades and vanes are of precision aerofoil section. Within each stage the airflow is accelerated by the rotors as the blades do work on the airflow, this causes arise in pressure, temperature and velocity. The stator row has divergent spaces between each vane and causes a reduction in velocity with a resulting rise in pressure and temperature. The pressure rise across the stage is multiplied by each succeeding stage. **There is a gradual reduction in the air annulus to maintain the axial velocity of the air,** however, discharge velocity is usually a little lower than the inlet velocity. This avoids the need for excessive diffusion to reduce the velocity to a level suitable for efficient combustion. The overall effect of the compressor is to increase pressure and temperature but to reduce volume.

This type of compressor has a small frontal area, a high compressor pressure ratio and produces an engine with a low specific fuel consumption (SFC).

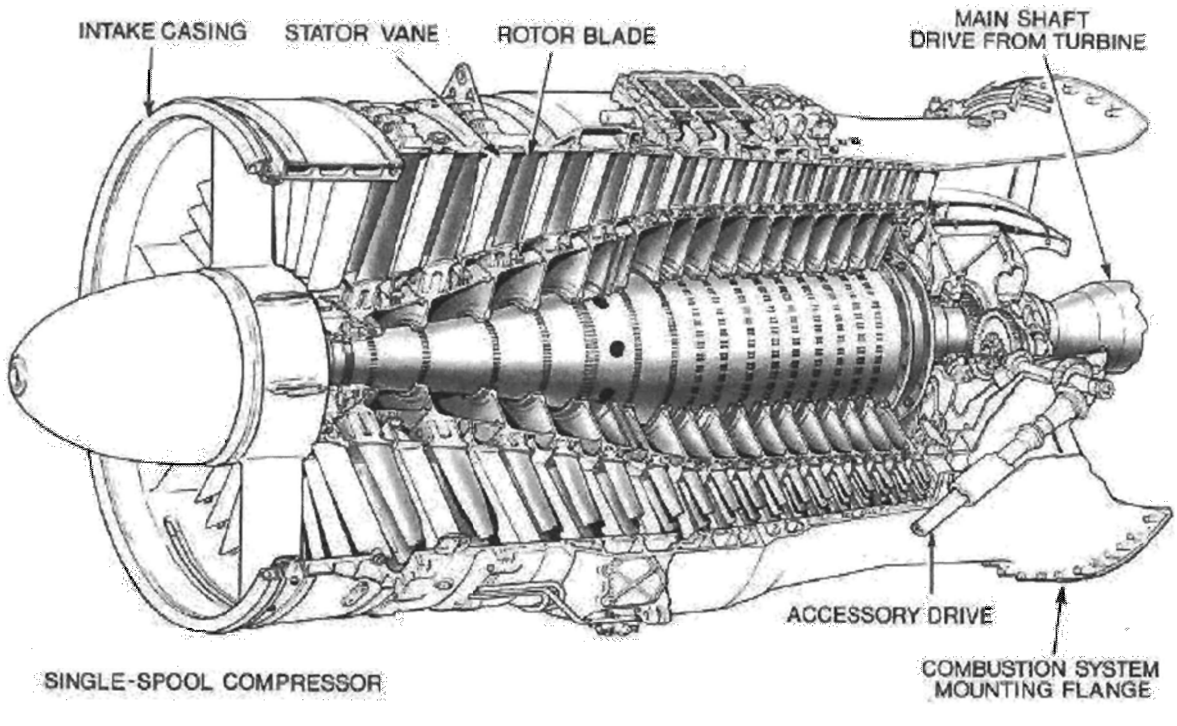


Figure 4.7: A single-spool axial flow compressor

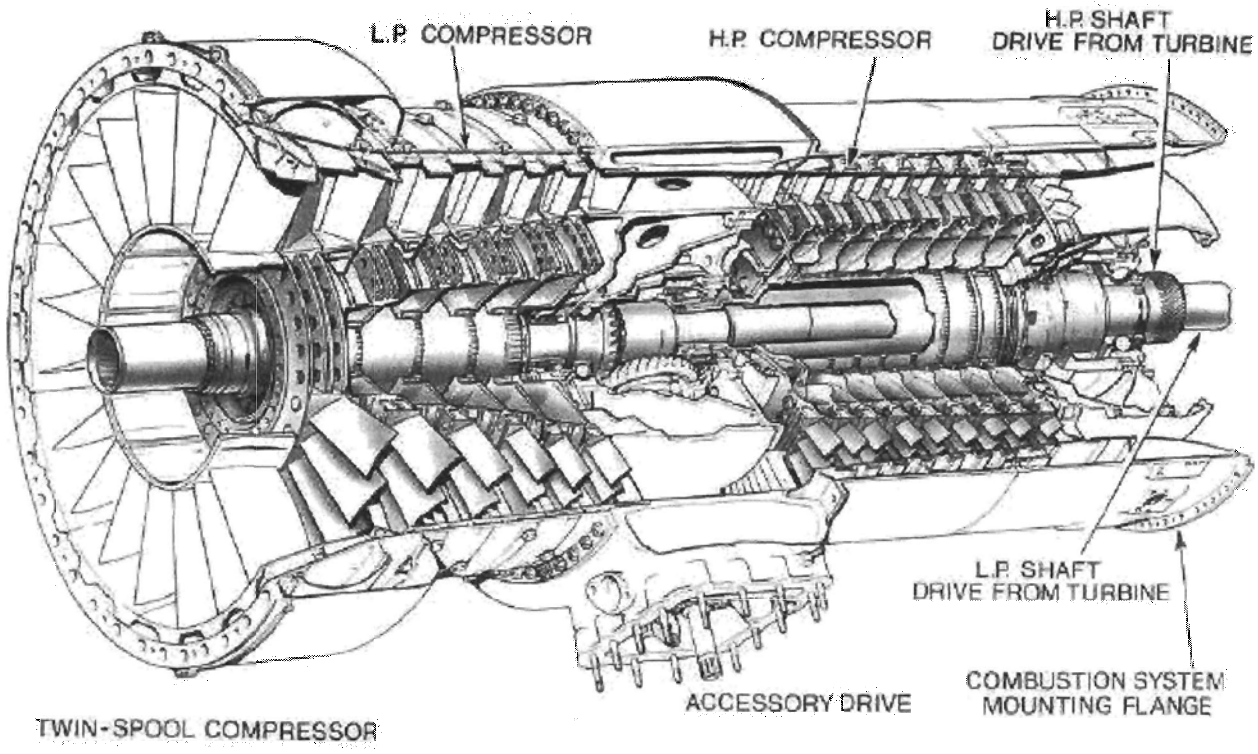


Figure 4.8: A dual-spool axial flow compressor

Advantages

High Compression Ratio
High thrust
Low frontal area to enable fitment in wing mounted nacelles
Low Specific Fuel Consumption

Principle of Operation

The axial flow compressor works on the principle of continuous compression through each stage of the compressor. A stage is defined as a rotor and a stator. All rotor and stator blades form divergent ducts thus causing the continuous pressure rise. Prior to the first stage it is usual to fit intake guide vanes to ensure the airflow is presented to the first stage rotor at the correct angle. It can be seen from the diagram below that the blades decrease in length from front to rear. This is to ensure that the axial velocity of the air remains approximately constant, even though the air is being continually compressed.

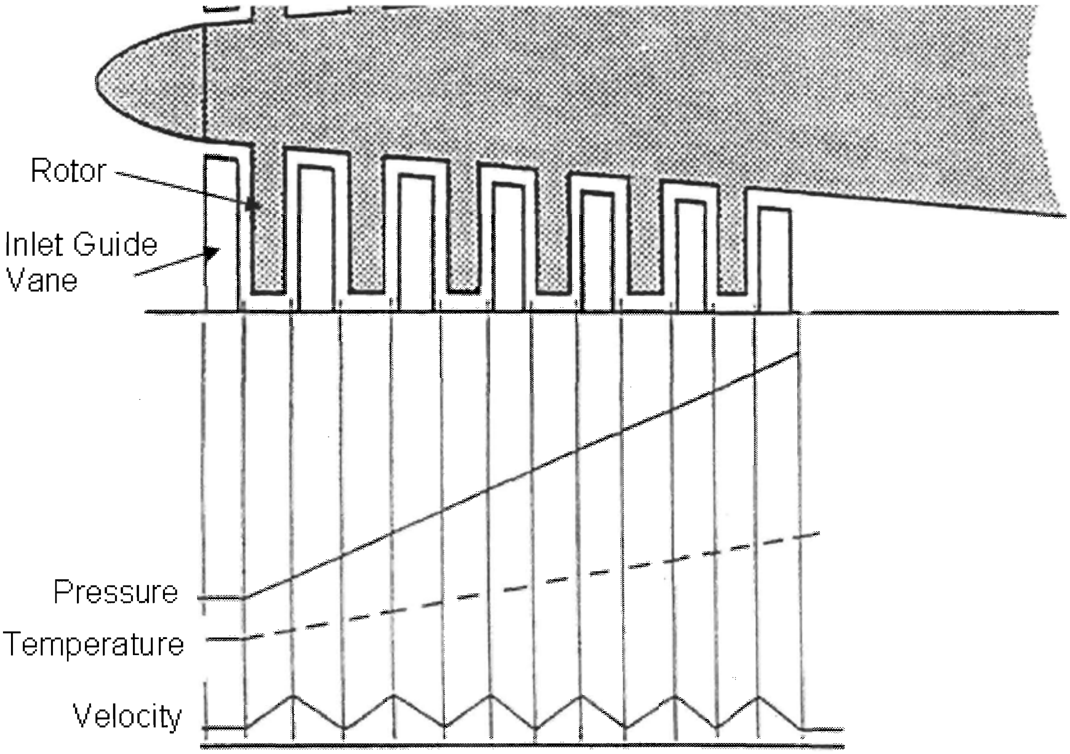


Figure 4.9: Pressure Temperature and Velocity Gradients through a Single Spool Axial Flow Compressor.

Multi-Spool Design

Theoretically a single spool axial flow compressor could be built to incorporate as many stages as necessary to produce the required pressure ratio. Such a compressor would operate very well at one particular speed for which it was designed. At other speeds however, when accelerating or decelerating, the rearmost stages would tend to choke and the foremost stages would be overloaded, this condition would produce a state of instability such as compressor stall/surge. In addition the increased temperatures in the latter stages of a 20 stage single spool compressor effectively reduce the amount per stage of pressure rise to an insignificant amount.

If the compressor is built in two or more sections, the front (LP or N1) and the rear (HP or N2) sections and each compressor is an independent system, driven by separate turbine assemblies through co-axial shafts, a greater flexibility of operation will be experienced. Other airflow devices may not be required at all, or only on the HP system.

The speed of the HP compressor is governed by the Fuel Control Unit (i.e. more fuel, more RPM resulting in a greater air mass flow and greater thrust), but the LP compressor is free to seek its best operating speed, one that will provide a smooth airflow through the system.

The RPM relationship of one compressor to another (N_1 - N_2) at any given moment is called the **Compressor Match.**

The twin spool design also allows for a bypass duct to be constructed around the HP system and combustor thus producing the low bypass turbo fan engine with a bypass ration of up to 3:1.

This type of engine is more efficient than a single spool engine (lower SFC). It is quieter due to the cold air mixing within the jet pipe, and produces greater thrust.

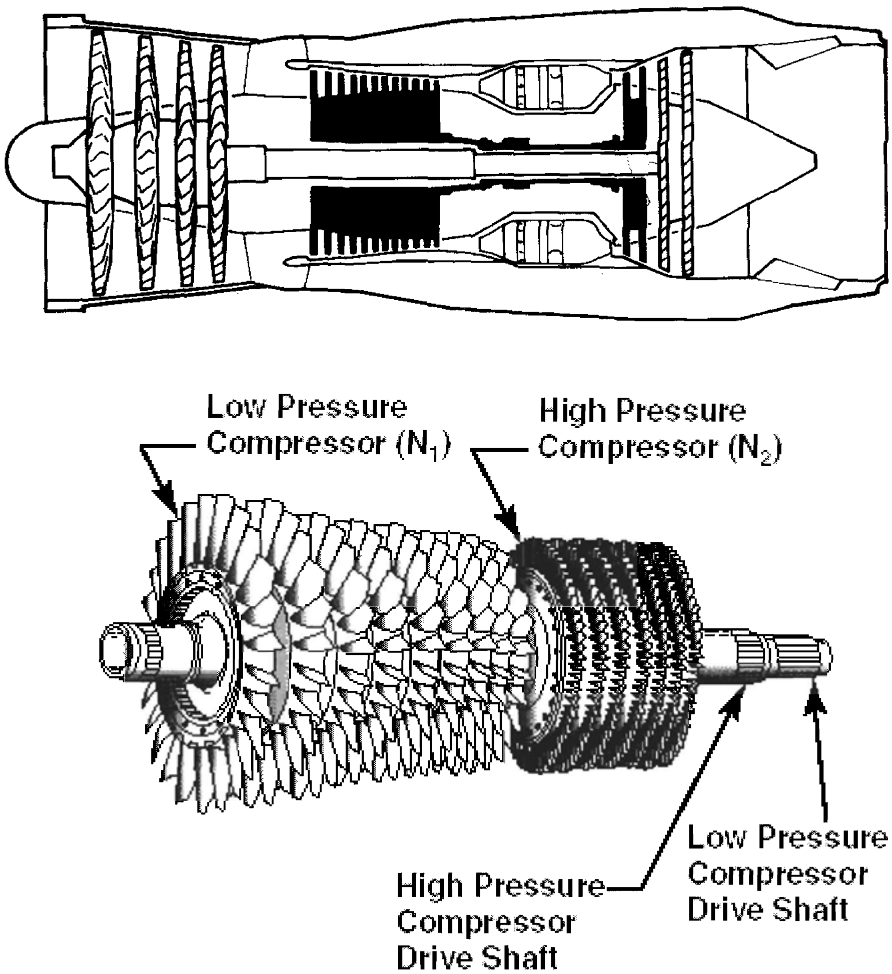


Figure 4.10: Twin Spool Low Bypass Turbo-Jet

High Bypass Compressor Systems (Bypass ratio >4:1)

High Bypass Turbo Fans utilise either a twin spool or triple spool compressor system.

Example - CF6

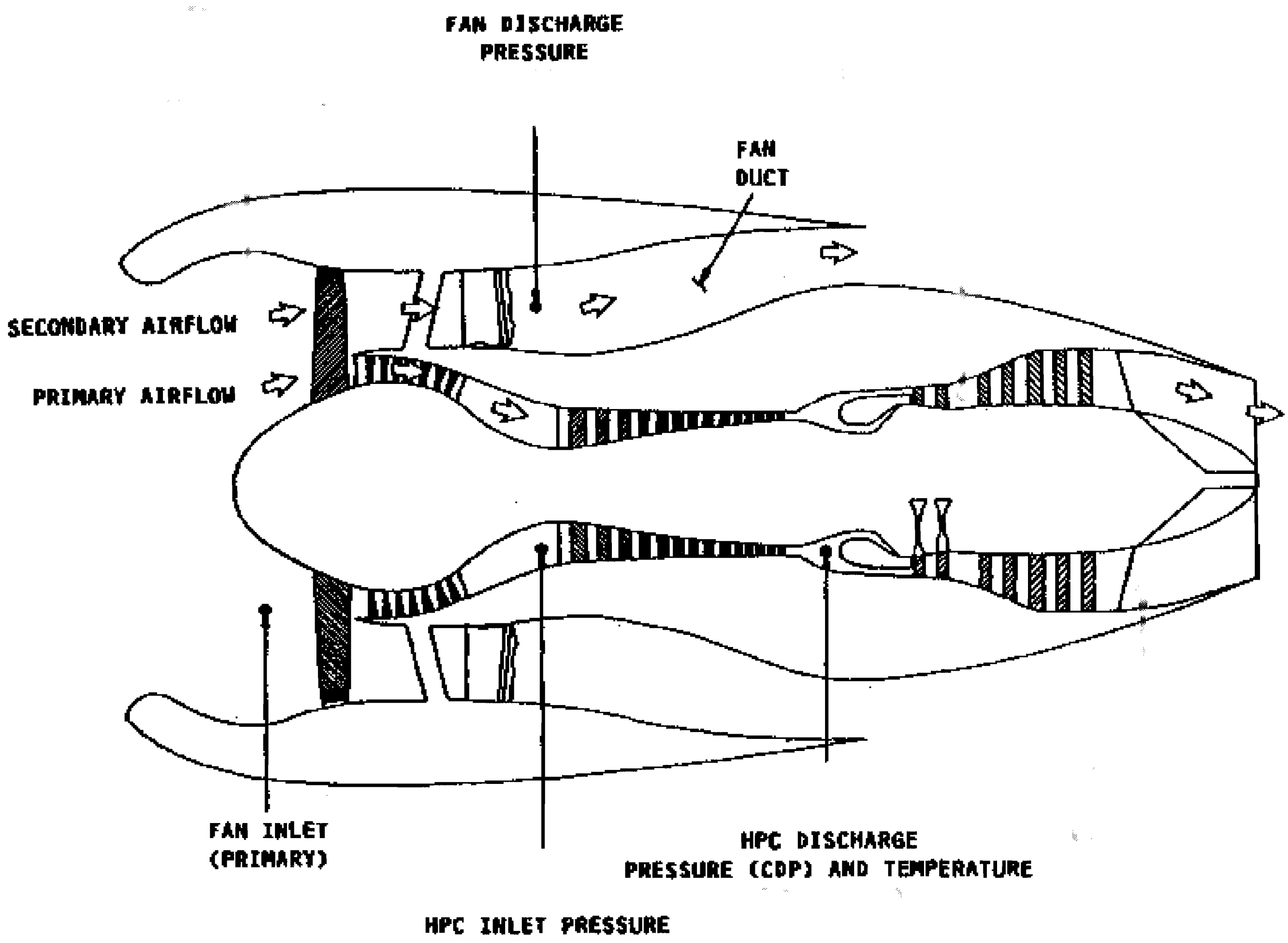


Figure 4.11: Twin Spool High Bypass (CF6-80C2)

The LP Compressor consists of a high aspect ratio LP fan consisting of 38 blades with mid-span shrouds. The fan is treated as stage 1 of the LP Compressor, the remainder consisting of a 4 stage booster. The complete spool is driven by a 5 stage LP compressor. The HP Compressor consists of 14 stages. The HP compressor contains 1 stage of VIGVs and 4 stages of Voss. The spool is driven by a 5 stage LP turbine.

Triple Spool High Bypass (Bypass Ratio >4:1)

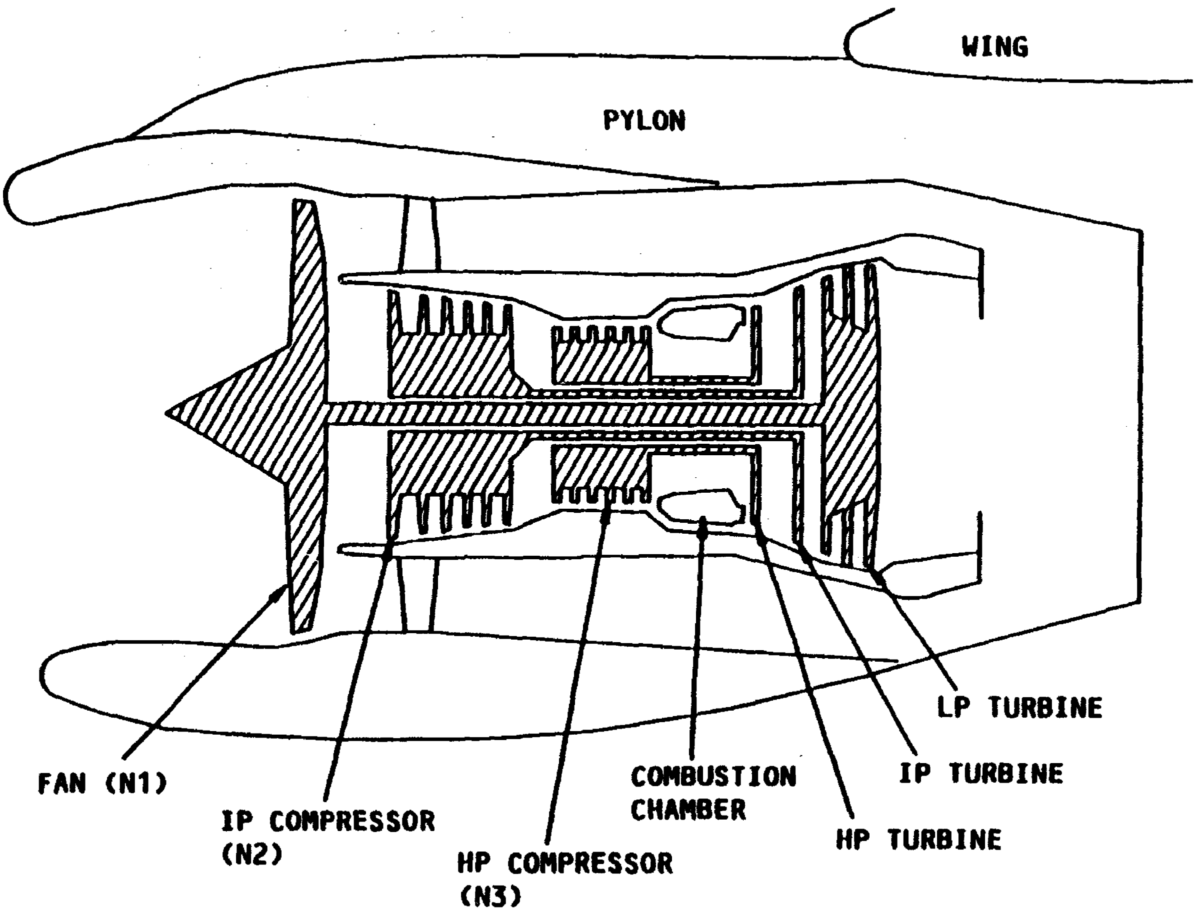


Figure 4.12: Triple Spool High Bypass engine

The triple spool engine shown above uses a 24 bladed wide chord hollow titanium fan disc driven by a 3 stage turbine. The IP or N2 compressor uses a 5 stage compressor driven by a single stage turbine. The HP or N3 system is the same configuration as the IP but note that the HP Turbine will always be closest to the combustor, as the HP spool must run outside the IP and LP shafts.

Whilst high bypass engines are the most efficient for large sub-sonic commercial aircraft, small high bypass turbo fans (RR Tay) are being used in the executive and regional jet markets, providing high efficiency with low noise and low fuel consumption.

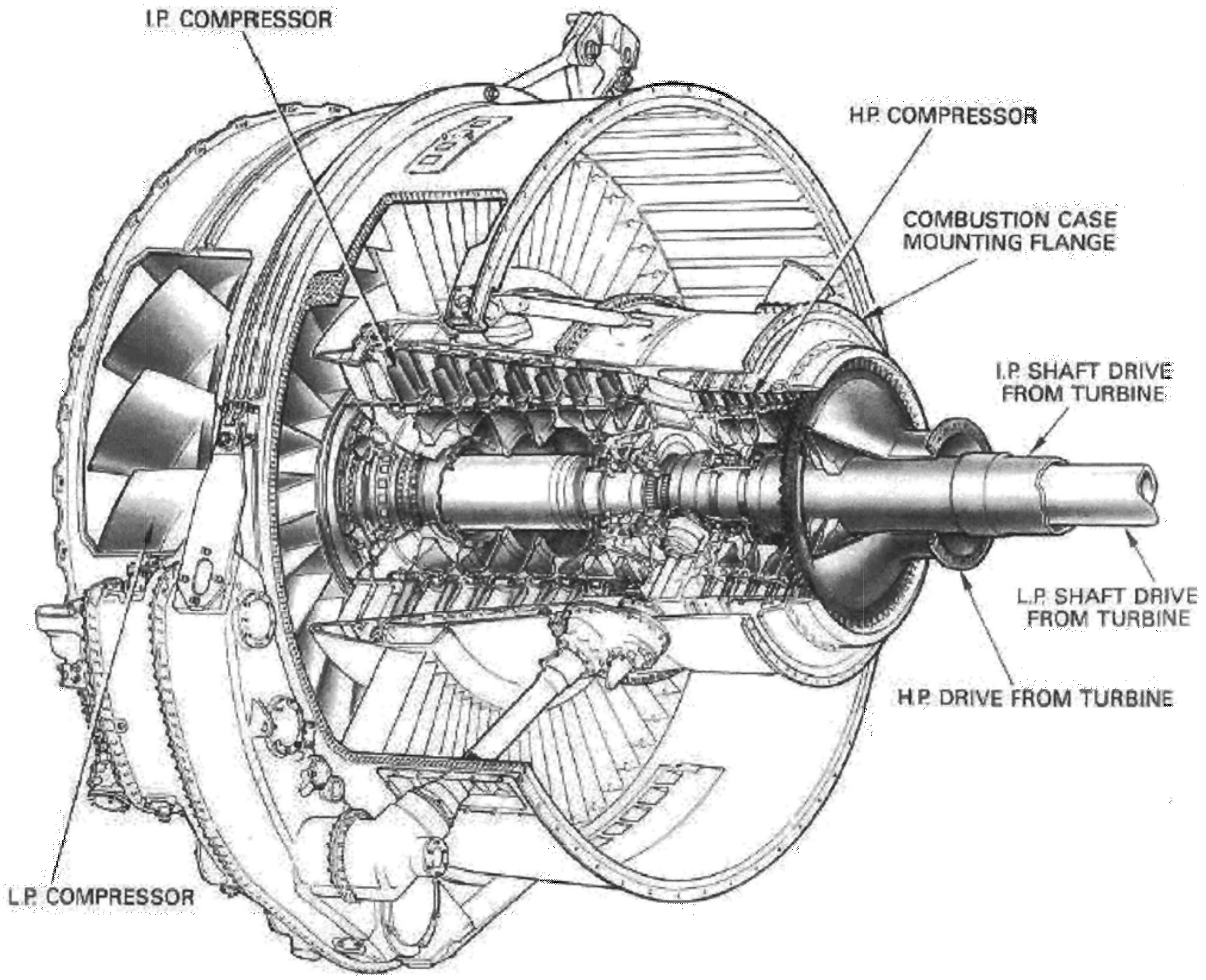


Figure 4.13: A triple-spool high-bypass fan compressor

Construction

Rotor Blades

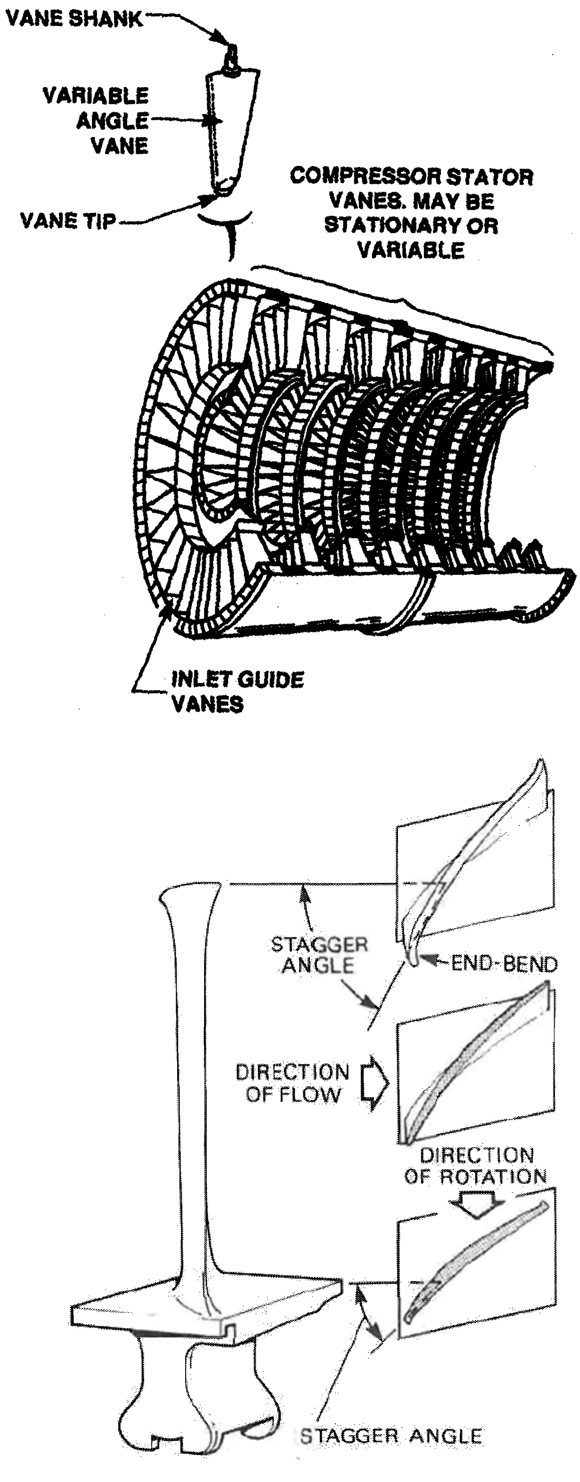


Figure 4.14: Rotor blade construction

Fan blades often have a mid-span support shroud, or clapper. These prevent the blades touching each other. This type of blade is normally made from solid titanium. Rolls Royce produce a super plastic formed titanium fan blade with sufficient rigidity to dispense with the clappers, thus enabling greater performance and less weight for the same size of blade. Further information on fan blades is provided later.

All blades are retained by a keyplate or locktab

Some blades are cut off square at the tip, whilst others have a reduced thickness. These are referred to as profile or squeeler tips. The purpose of this type of tip is to ensure reduced vortexes at the tip and smooth the airflow

On newer engines the tips run within an abradable lining. Thus enabling tighter running tolerances, without wear to the blades. On rundown profile tip blades often make a high pitch noise if in contact with the lining, hence the name squeeler tip.

Air flowing through the compressor creates a slow moving boundary layer both at the root and at the outer wall of the compressor annulus. In order to rejuvenate this air extra camber is introduced to the blade at the root and the tip. This gives the tip a ‘end bend’ appearance.

The increased twist of the blade towards the tips ensures that the velocity profile along the blade is reasonably uniform.

Material:

Early blades:

Low Pressure:	Aluminium
High Pressure:	Steel
Modern Blades:	Titanium

Figure 4.15: A one-piece 'blisk'

For some compressors (especially small compressors) one piece 'blisks' are manufactured with the blades integral with the disk

Stator Vanes

Stator vanes are secured into the compressor casing or into stator vane retaining rings, which are then themselves secured into the compressor casing. It is necessary to lock the blades in their housing to stop them migrating around the casing.

The blades are often shrouded at their inner ends to minimize the vibrational effect of flow variations on the longer vanes.

Stator vanes may be fixed or variable, dependant on the number of stages of compression, the higher number the more chance that the earlier stages will be variable

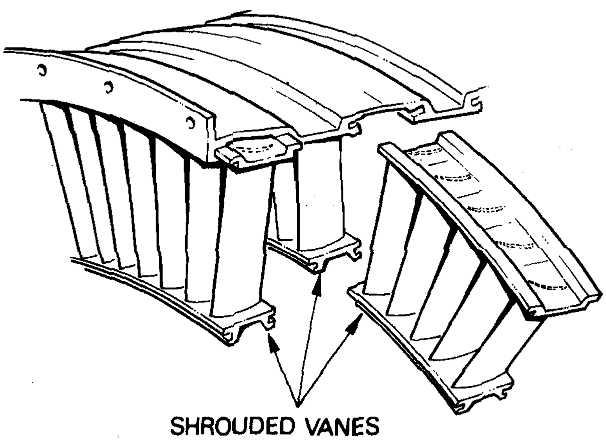


Figure 4.16: Stator vane construction

Materials

Casings- Aluminium

Vanes Steel or Nickel based alloys

(Titanium may be used in the low pressure areas, but not aft of this due to the tendency of titanium to ignite if rubbing occurs)

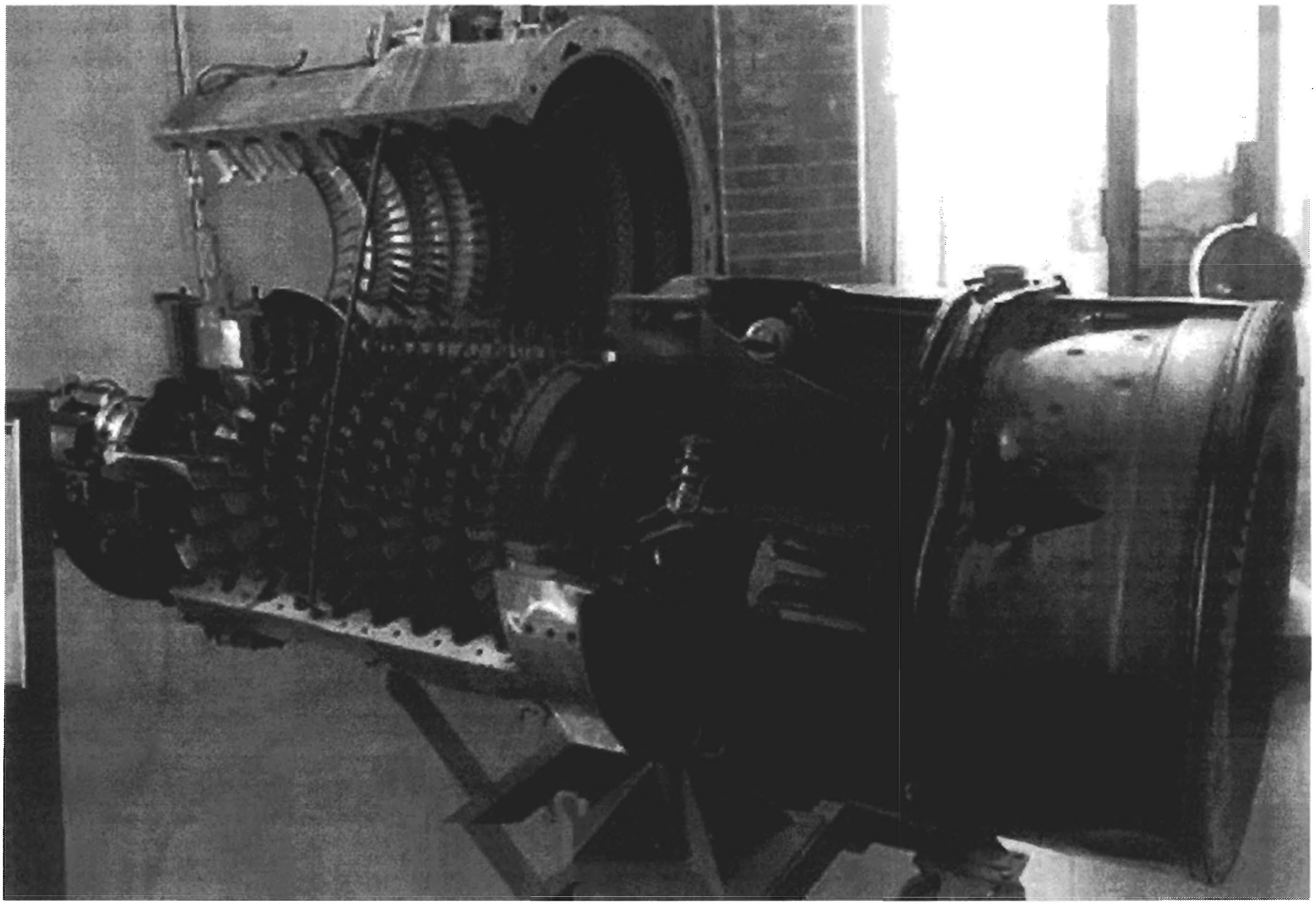


Figure 4.17: Compressor stator and rotor assembly

Securing Methods

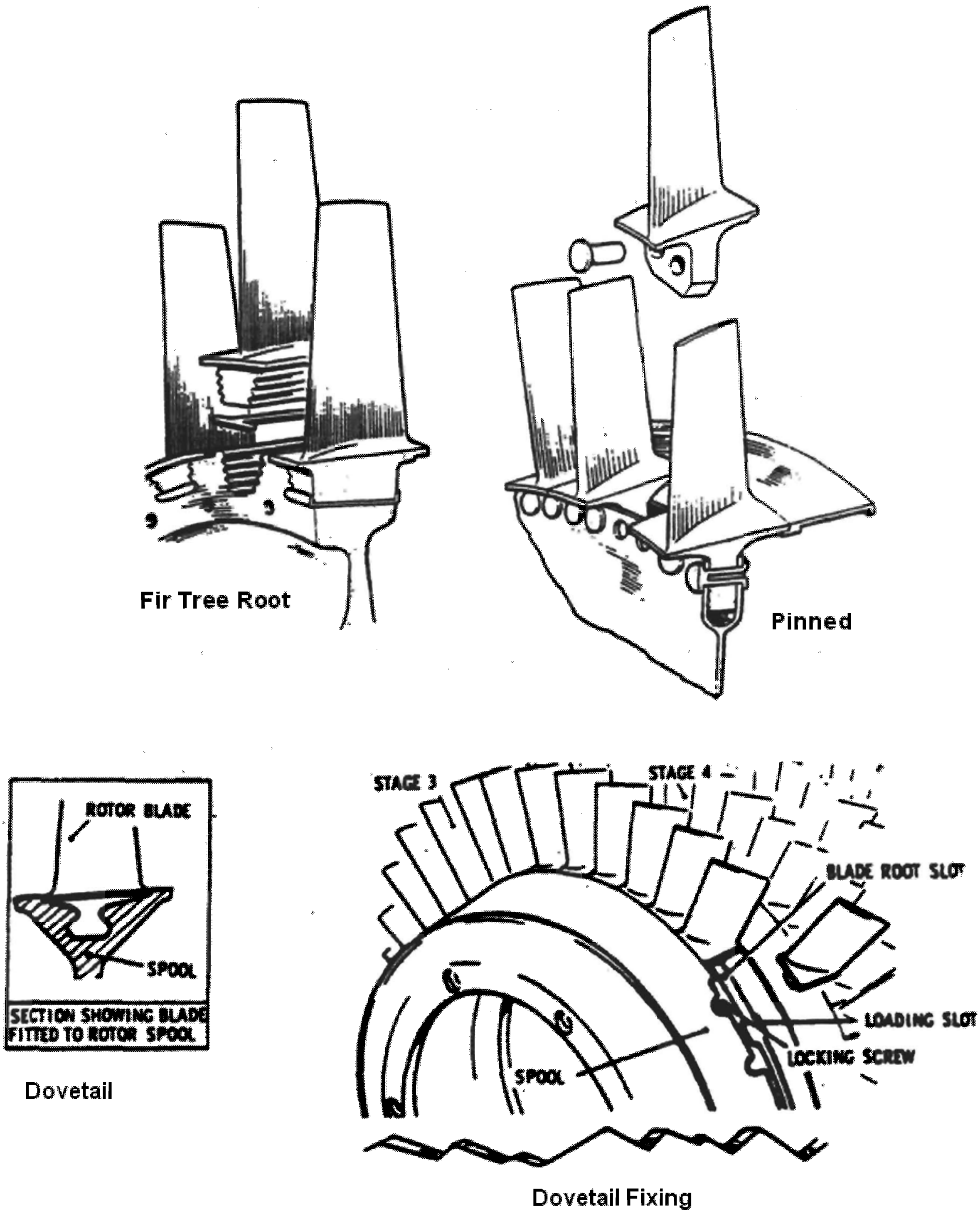


Figure 4.18: Root fixing methods

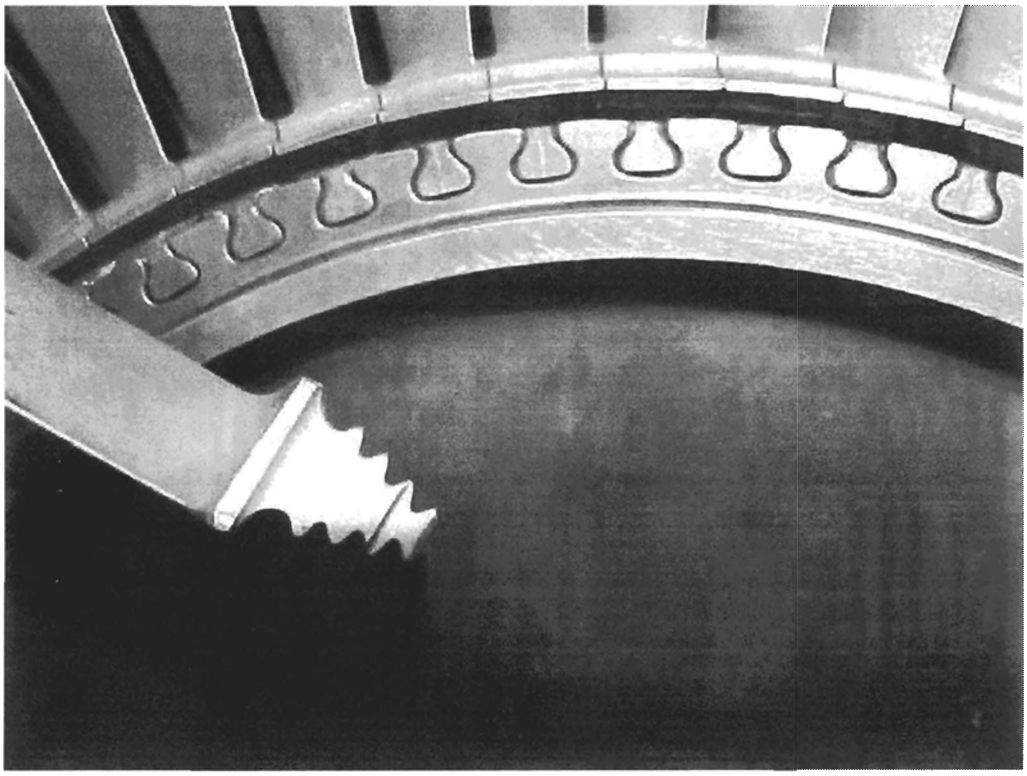


Figure 4.19: Bulb root and fir tree root

Fans

The high bypass ratio fan blade only became a possibility with the availability of titanium, the blade had to be light enough to be contained in the event of blade failure but stiff enough to withstand the bending forces on the blade.

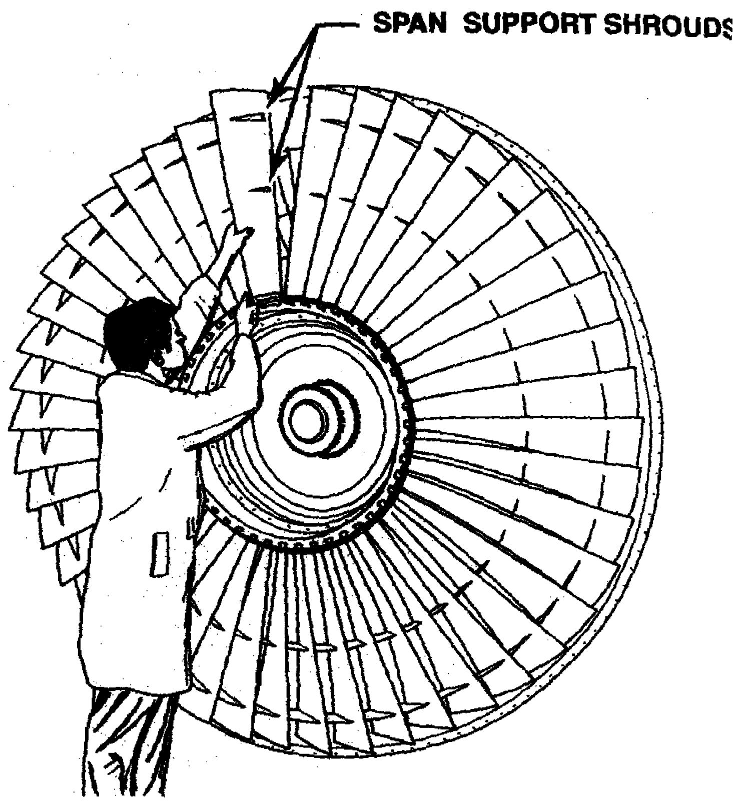


Figure 4.20: A High Aspect Ratio Fan

This high aspect ratio blade (i.e. thin and long) still needed a mid-span support, or clapper to prevent aerodynamic instability. This design has the disadvantage of the clapper disturbing the airflow thus causing pressure losses.

The CF6 overcomes these disadvantages by using a 38 bladed fan to produce 60,000 lb of thrust with a fan pressure ratio of about 1.7:1.

Low Aspect Ratio Fan

The low aspect ratio fan blade features a wide chord and smaller blades. They do not require mid-span shrouds and due to their wide chord are much more efficient than low aspect ratio blades. Rolls Royce produced the first wife chord blades made from super plastic formed diffusion bonded titanium- in other word three pieces of titanium pressed together, with a honeycomb core. The blades are inflated and then sealed to form one piece of material. The air is then evacuated.

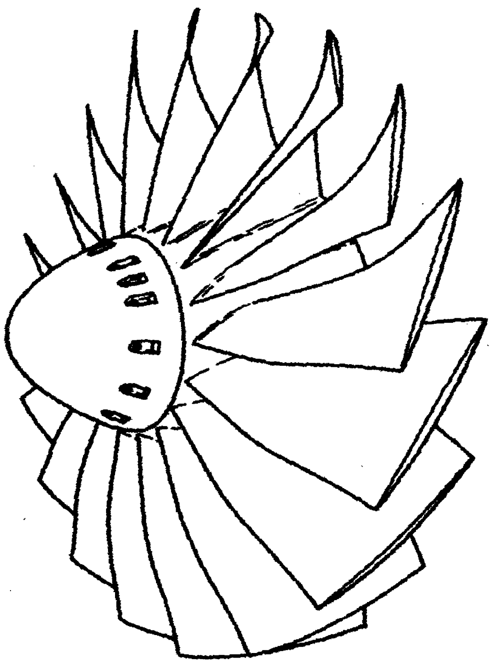


Figure 4.21: A low aspect ratio fan

General Electric use a carbon composite wide chord blade with a metallic leading edge on the GE 90 engine.

The advantages of this type of blade are:

- High performance for low weight
- Lighter containment ring required
- Greater FOD resistant as any FOD is easily diffused into the bypass duct
- Less blades per set (24 on a RR - 535 E4 engine)
- Ease of fitment and removal due to lack of mid- span shroud interference with adjacent blades.

Fan Blade Balancing

Whilst all rotating assemblies require balancing at manufacture, high bypass fans require particular attention whilst in service. The large centrifugal forces on the fan blades require the disc to be balanced to a very high degree. Even minor damage can cause the fan to become unbalanced and compromise the integrity of the rotating assembly and its bearings.

Blades are assembled as a set, a computer programme positioning the blades according to the radial moment weight of each individual blade. The radial moment weight can be found marked either on the bottom of the dovetail or in the case of the blades fitted to the CF6 of the integral shoulder at the base of the blade.

Once the blades are fitted a vibration survey is carried out and if necessary trim balance weights will be fitted to reduce the vibration. Trim balance weights may be either oversize bolts securing the fan spinner, special trim balance bolts fitted at right angles to the spinner securing bolts, or special balance weights that fit on the fan balance ring below the blade root.

In the event of a fan blade being replaced there are three trim balance options:

1 Replace the blade with one within a small tolerance of the original. Balance should not be affected
2 Replace the blade with another of different weight then using a formula from the AMM fit a correcting weight. If the new blade is lighter fit the weight at the blade location. If the blade is heavier fit the weight at the diametrically opposite blade.
3 If the replacement blade is considerably different form the original replace the diametrically opposite blade with an appropriately lighter or heavier blade.

After some considerable time in service the vibration level of the N1 spool can gradually increase. This is probably not due to blade damage or movement, but due to the dry film lubricant on the blade roots wearing. In this instance the fan blades should be removed, the roots cleaned and the dry film lubricant replaced in accordance with the AMM.

Out of balance forces are indicated by their magnitude and direction, direction being given in the form of phase angle from a known datum, usually the number 1 balance hole and magnitude in the form of ‘aircraft units’. This information is displayed on either cockpit EICAS or ECAM systems or specialist balancing test equipment. Limits are given in the Aircraft Maintenance Manual.

In service only fan balancing is possible. Engine removal is required if any other compressor / turbine goes out of balance.

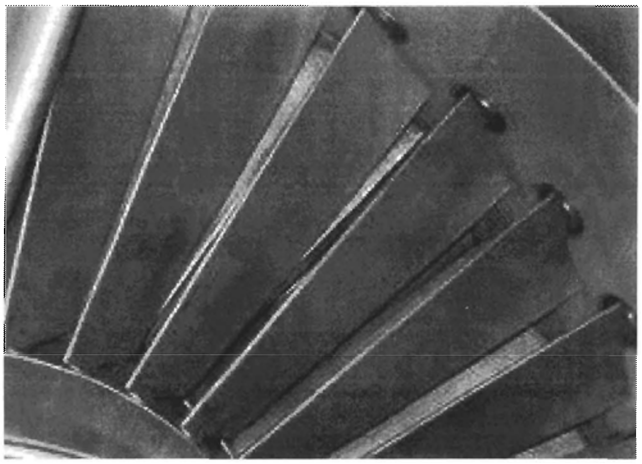
Anti-Surge Devices

To prevent or reduce the risk of stall/surge and to maintain a smooth flow of air through the compressor it is sometimes necessary to use a system of air flow control. The system may include one or more of the following devices;

1 Variable Intake Guide Vanes **(VIGVs)**
2 Compressor bleed Valves **(VBVs)**
3 Variable Stator Vanes **(VSVs)**

Variable Intake Guide Vanes

The purpose of the VIGVs is to direct the oncoming air into the compressor at the correct angle so as to achieve the optimum *angle of attack* of the first stage rotor blades. Since the *angle of attack* changes according to the RPM of the rotor, it is necessary to change the angle of the IGVs accordingly.



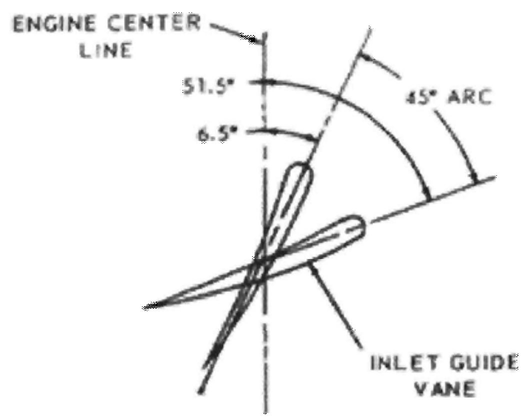


Figure 4.24: Variable Inlet Guide Vanes

A rise in air intake temperature delays the start of the VIGVs opening, and vice versa. The reason for this is that cold air moves more 'sluggishly' than warm air.

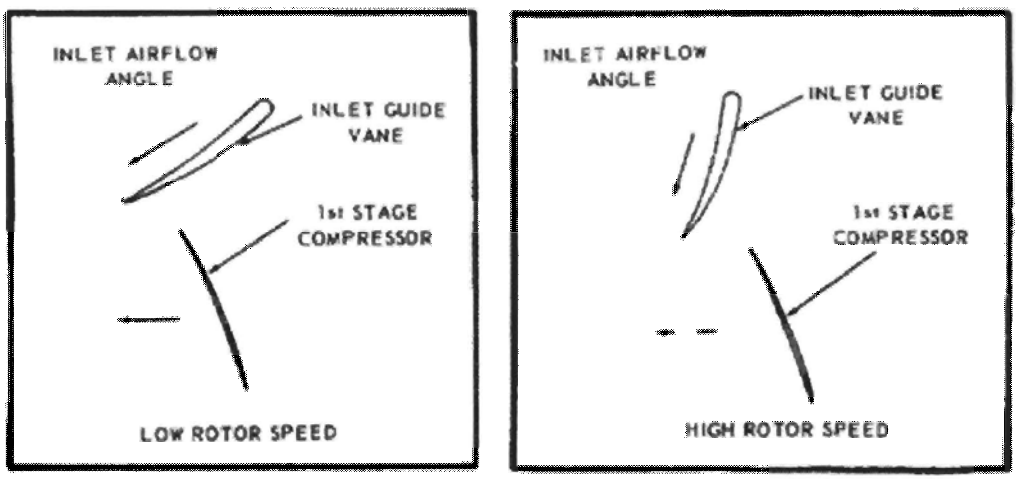


Figure 4.25: Inlet Guide Vanes at low and high rotor speeds

They are hydraulically operated by fuel pressure and sensitive to **Engine Rpm** and **Air Intake Temperature**.

The vanes are normally set to some angle relative to the engine axis (closed) at low engine speed, and move to almost parallel to the engine axis (open) at high engine speed.

The VIGVs are positioned by the inlet guide vane actuator pilot valve, located in the fuel control, which monitors N_1 speed and compressor inlet temperature (T1). While setting the desired position of the VIGVs, the actuator relays their position back to the fuel control through an external feedback control rod to nullify the fuel pressure signal so that at any steady-state N_1 speed between 80 and 95 percent, the inlet guide vanes will assume a constant position. The VIGV actuator is mounted on the right side of the compressor housing assembly. The actuator is controlled by main fuel pressure from the fuel control. Two fuel lines carry the fuel from the fuel control to the VIGV actuator. This fuel pressure acts upon the piston inside the actuator to move the VIGVs. The VIGVs are positioned by the inlet guide vane actuator control rod through a synchronizing ring.

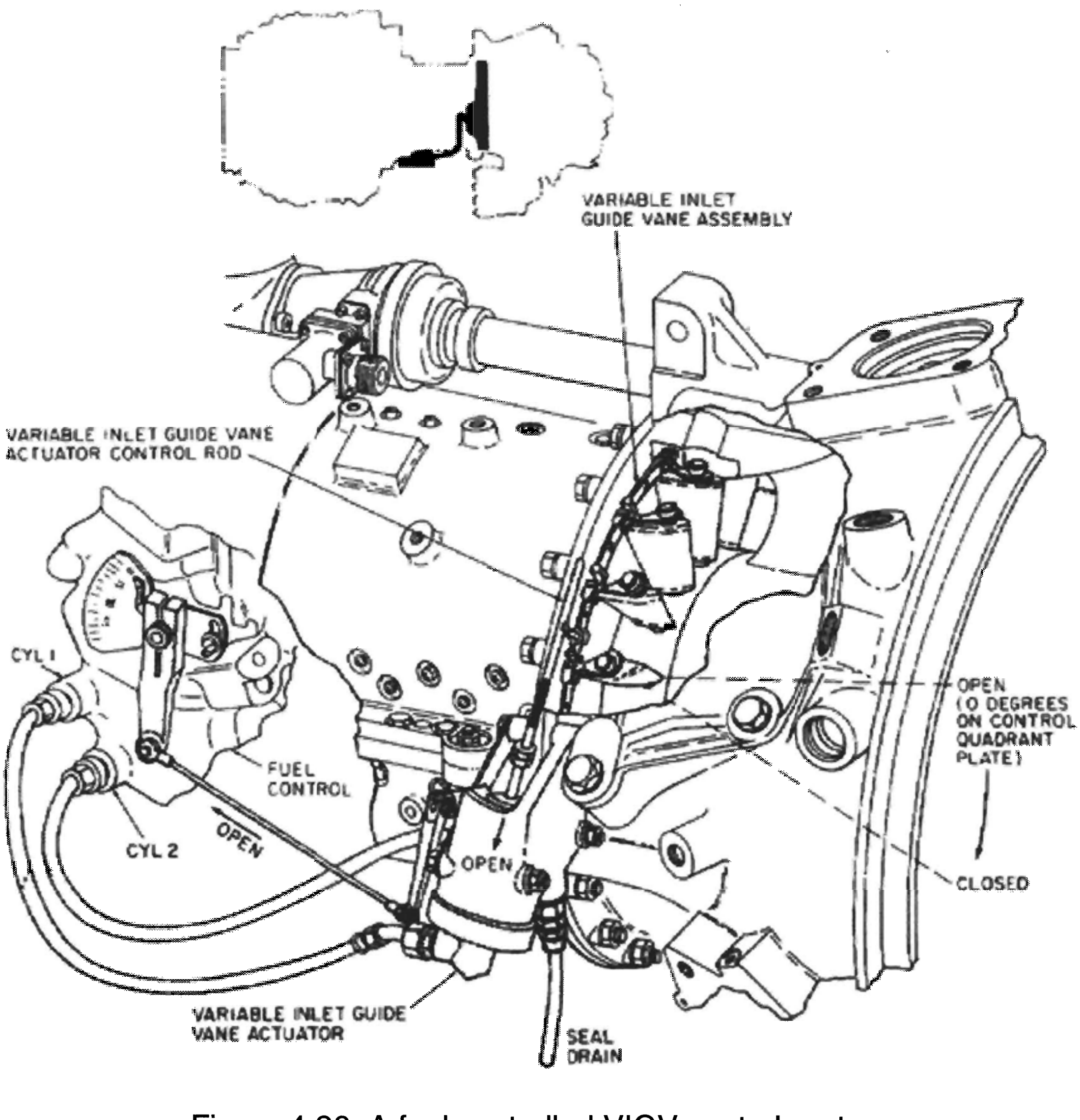
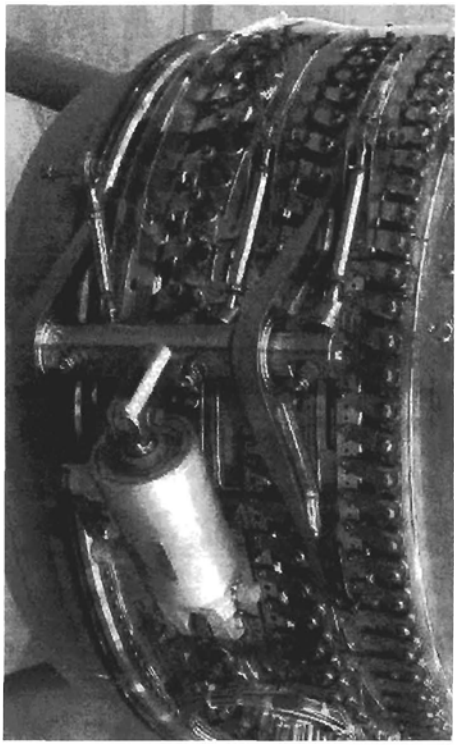


Figure 4.26: A fuel controlled VIGV control system

Variable Stator Vanes



For maximum efficiency, the angle of the stator blade should give optimum *angle of attack* throughout the whole RPM range. With variable angle stator systems, the vanes are hydraulically actuated and controlled, usually by fuel pressure from the FCU. The blades are controlled in relation to engine RPM and air intake temperature.

At low RPM the blades are in their CLOSED position. As RPM rises they pivot towards the OPEN and are fully open at max RPM. Low intake temperature causes the blades to open at a lower RPM and vice versa.

VSVs and VIGVs if fitted to the same compressor system normally operate to the same schedule and are controlled and actuated by the same system

Figure 4.27: Variable stator vane mechanism

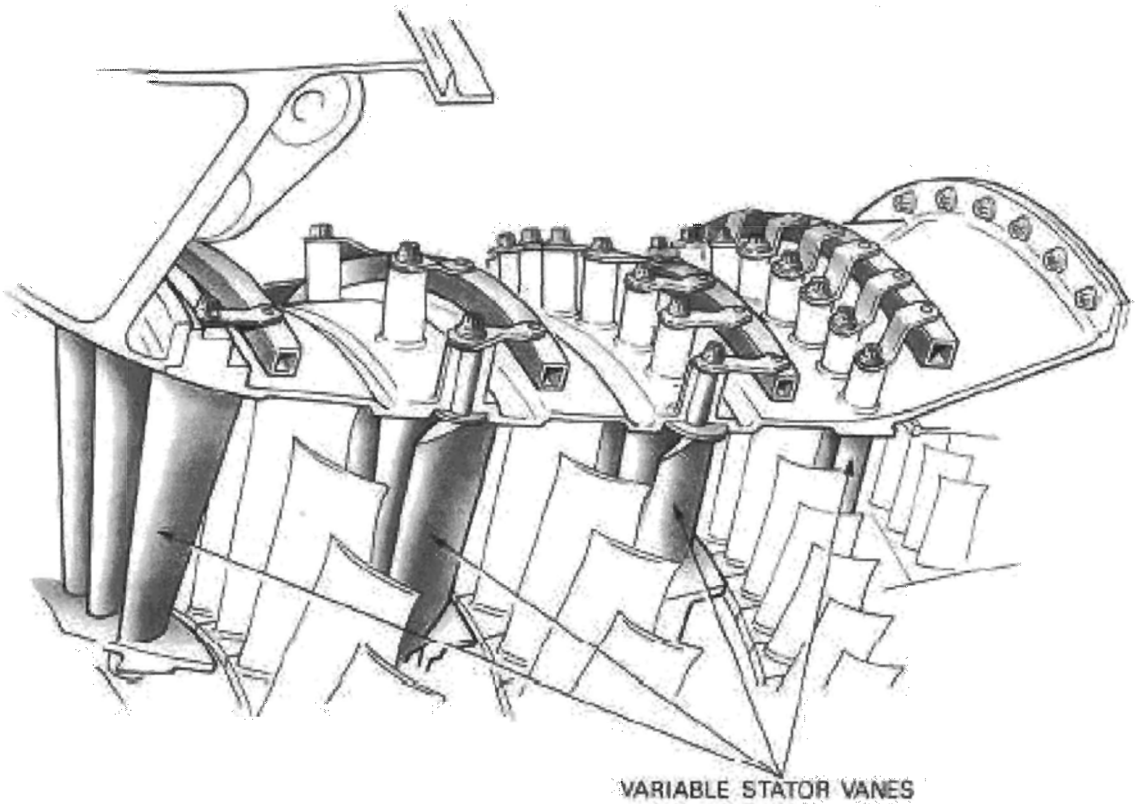


Figure 4.28: Variable stator vane mechanism

Compressor Bleed Valves

These are operated automatically by fuel or hydraulic pressure to bleed off excess compressor air from part way along the compressor during low compression situations.

The valves are open at low engine RPM and closed at high engine RPM. They have the effect at low engine speeds of increasing the flow through the early compressor stages and preventing "choking" of the rear stages. This assists in maintaining a smooth airflow under all running conditions. Modern High bypass engines have a control system that opens bleed valves if a surge is detected to reduce the pressure in the compressor and thus stop the surge.

When a bleed valve is stuck open the engine will run up to 30°C hotter than it should due to the reduced airflow through the engine.

Example - CF6-80 FADEC Airflow Control System

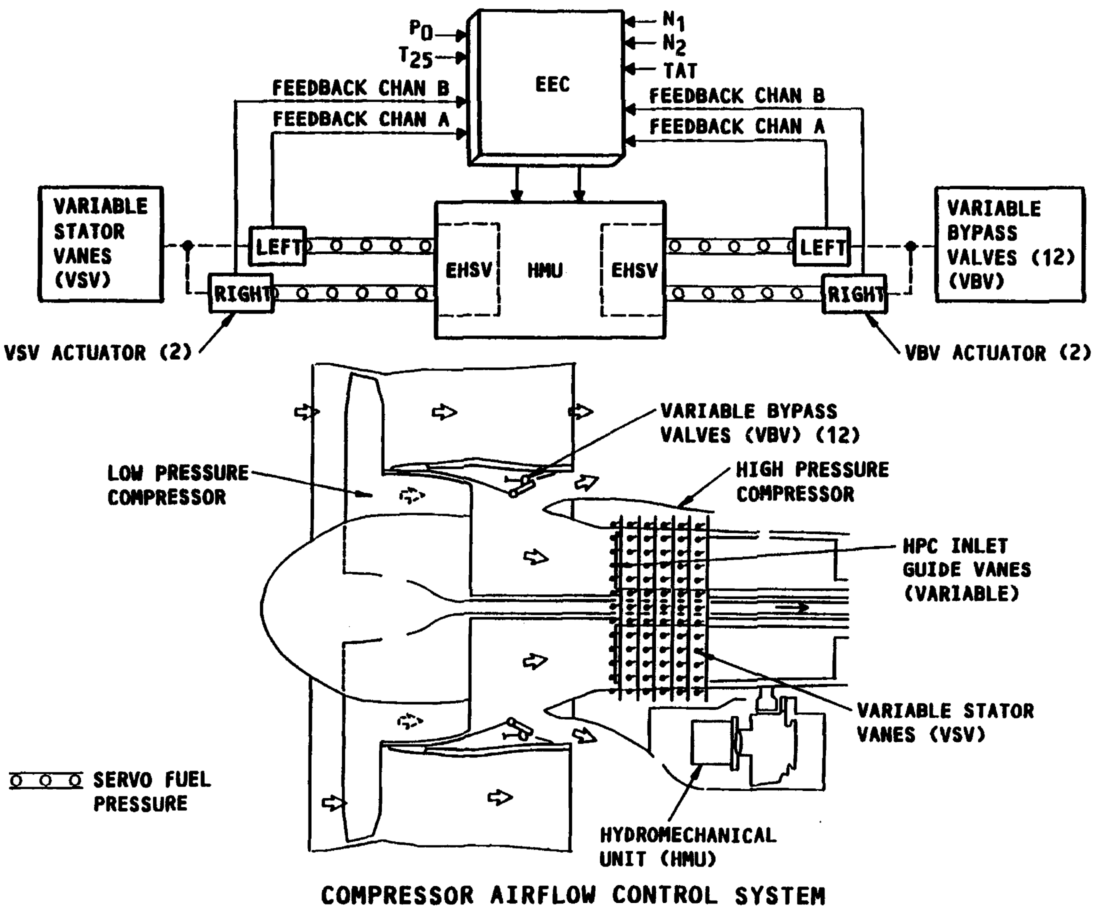


Figure 4.29: CF6-80 Airflow Control System

Note that the **Variable Bypass Valve** as shown in the diagram above is the American terminology for **Variable Bleed Valve.**

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Combination Compressors

To take advantage of the several good points of both the centrifugal and the axial flow compressors and to eliminate some of their disadvantages, the combination axial/centrifugal compressor was designed. This application is currently being used in many small turbine engines installed in business jets and helicopters.

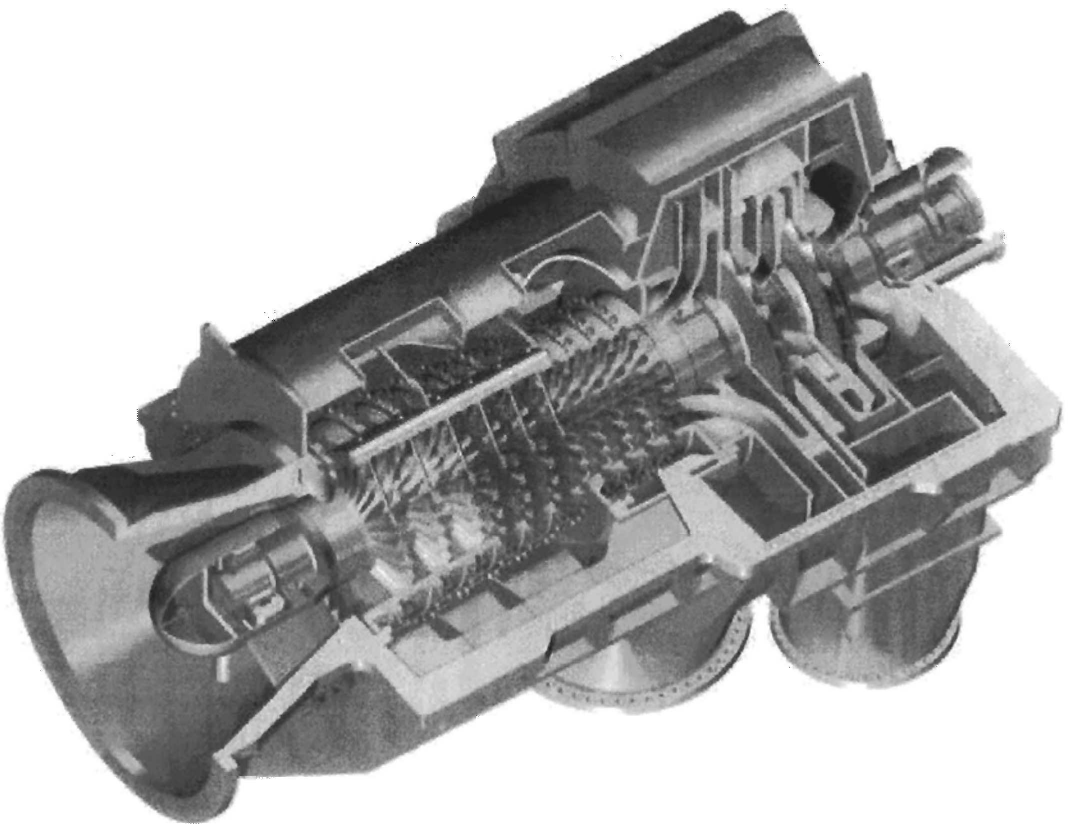

Figure 4.30: A combination compressor system

It produces a high mass airflow in its axial section for a small cross sectional area, due to the high axial velocity present. The centrifugal section creates a good compression ratio over a wider operating range, which is much better than would be possible with an axial compressor by itself. The combination compressor is also well suited to engines with a ***reverse flow annular combustion chamber*** since it provides the first change in direction and the smaller diameter axial flow compressor can accommodate the combustion chambers around it.

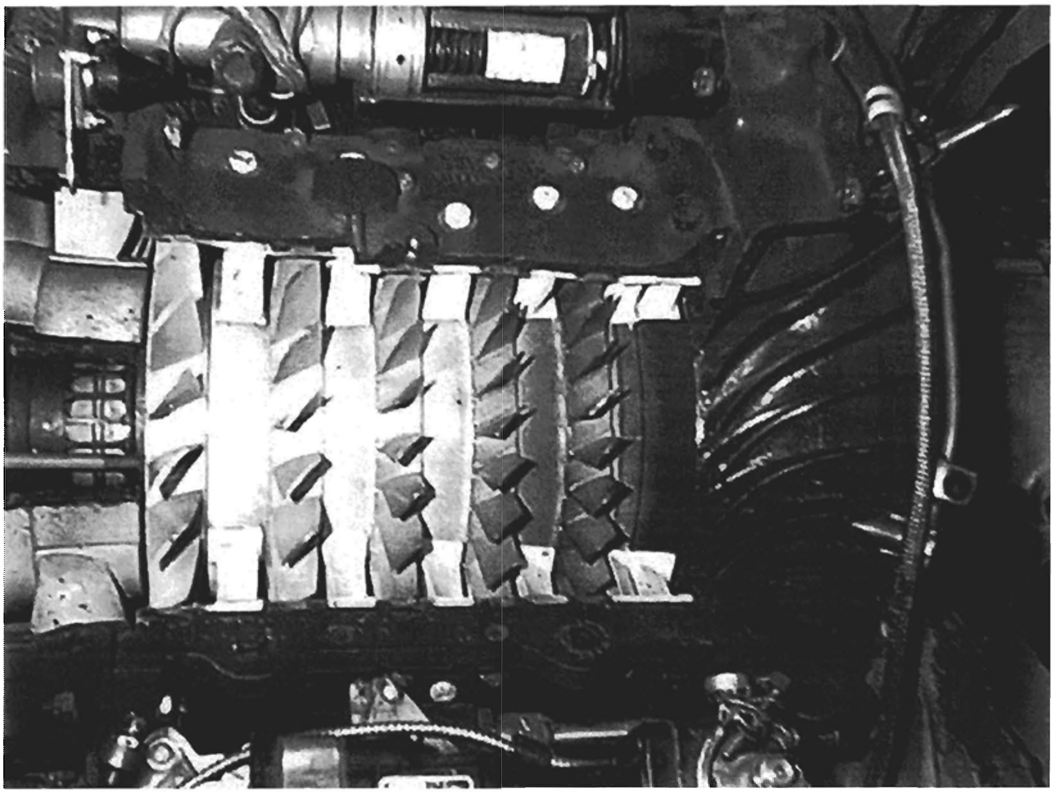

Figure 4.31: A combination compressor assembly

TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.5 Combustion Section

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.
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LEVEL 1

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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.

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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.
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Table of Contents

Module 15.5 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 Reference**	**Level**
		B1
Combustion Section	15.5	2
Constructional features and principles of operation.		

Module 15.5 - Combustion Section

Introduction

The combustion system has to burn large quantities of fuel, with large volumes of compressed air and then release the heat energy so that the air is expanded and accelerated rapidly, to give a smooth stream of uniformly heated gas at all conditions required by the turbine.

Components

The combustion chamber system consists of the following components;

Perforated flame tube(s)
Outer air casing(s)
A burner system
Igniter plugs

A number of different chamber layouts are in current use but all function in basically the same manner.

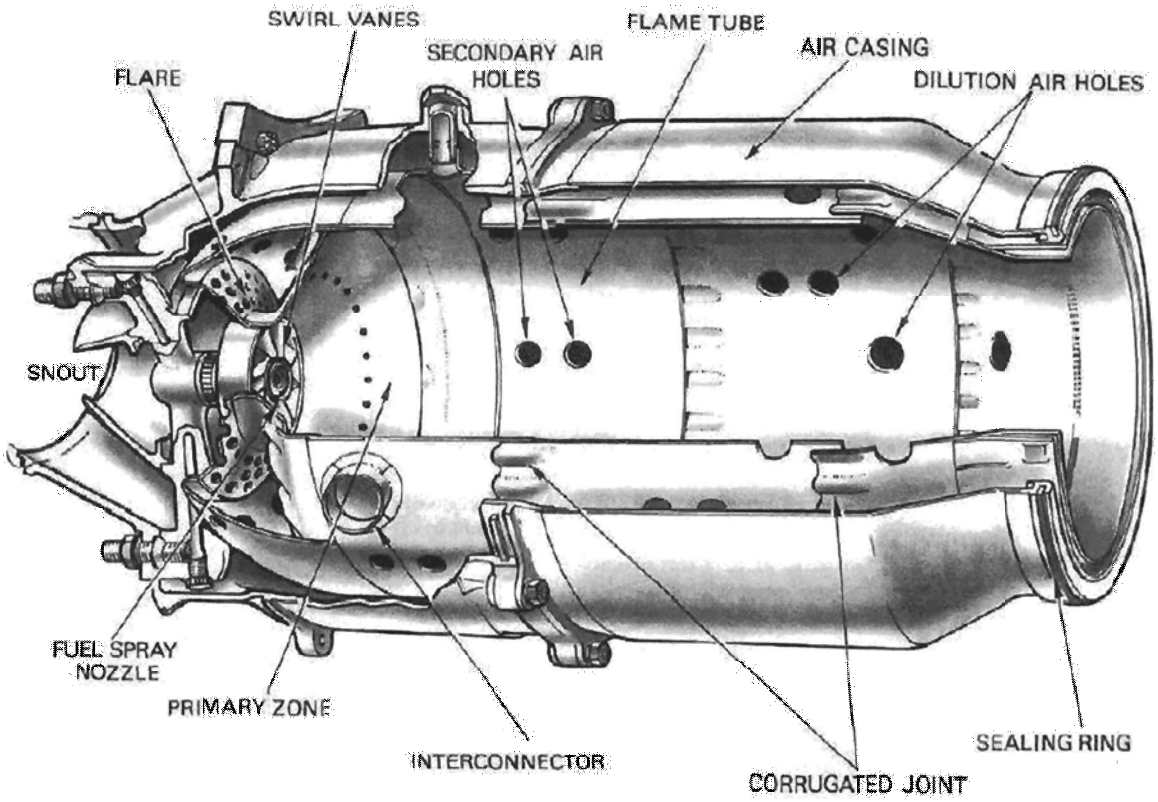

Figure 5.1: Combustion chamber components

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Combustion Process

Air from the compressor enters the combustion chamber system at up to 150 m/s and is diffused to raise the static pressure and lower the velocity to about 24 m/s. This velocity is still too high since the speed of burning kerosene is only a few m/s and a region of low axial velocity has therefore to be created in the e chamber to ensure that the flame will remain alight.

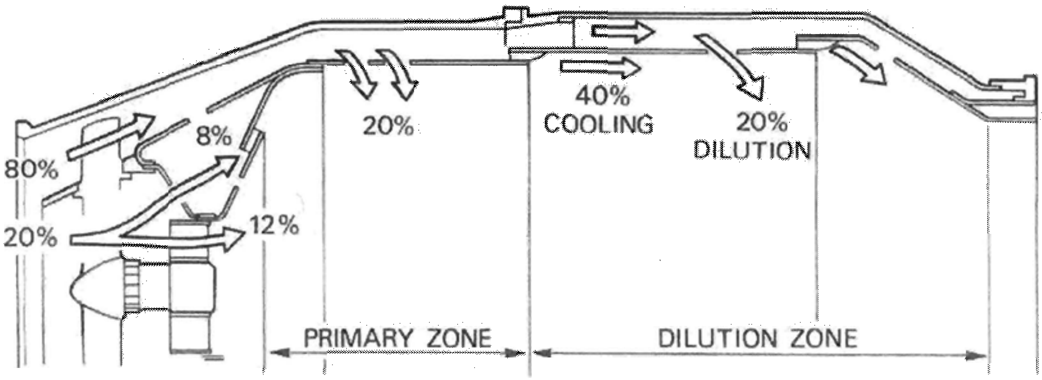

Figure 5.2: Combustion zones

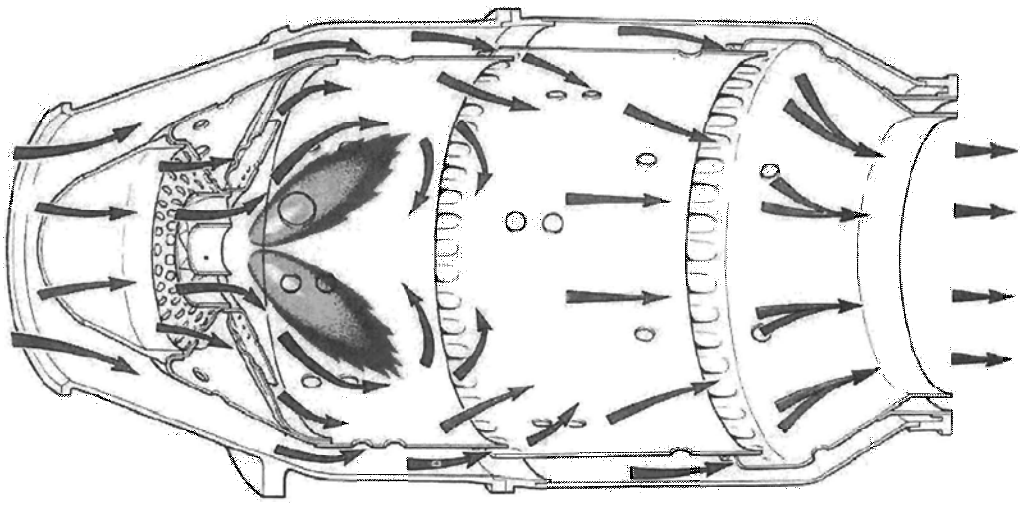

Figure 5.3: Combustion chamber gas flow

The overall air/fuel ratio of a combustion chamber can vary between 45:1 to 130:1 but since kerosene only burns efficiently at about 15:1, the **fuel is burned with only part of the air entering the chamber in what is usually called the PRIMARY combustion zone.**

Part of the mass airflow is taken by the **snout**, passes through the **perforated flare** and through the **swirl vanes** into the primary combustion zone, to give the correct air/fuel ratio in the primary combustion zone. **This swirling air promotes an upstream flow of LOW AXIAL VELOCITY and the desired RECIRCULATION.** The remaining air flows into the annular space between the flame tube and the air casing and this is fed through holes in the wall of the flame tube to join the air from the swirl vanes and flare. These airflows interact, creating a region of low velocity recirculation in the form of a **TORROIDAL VORTEX (similar to a smoke ring) which stabilises and anchors the flame to the front of the burner assembly.**

The conical fuel spray or vapour from the burner intersects the recirculation air vortex at its centre, thus assisting the mixing of the air and the fuel.

The airflow in the primary zone, known as the **burning total** reaches a temperature of approx 2000^0C which is far too hot for entry to the **Nozzle Guide Vanes** of the turbine. The hot gasses are therefore diluted by the remainder of the airflow entering the flame tube and the air casing. Of this air some is used for cooling the chamber walls and the rest is the **dilution total.**

Combustion Chamber Cooling

Due to the very high temperatures involved, the walls of the chamber must be cooled and/or protected from the effects of heat in any of the following ways;

- Corrugated strip cooling
- Machined cooling strip
- Splash cooling strip
- Transpiration cooling
- Ceramic coatings

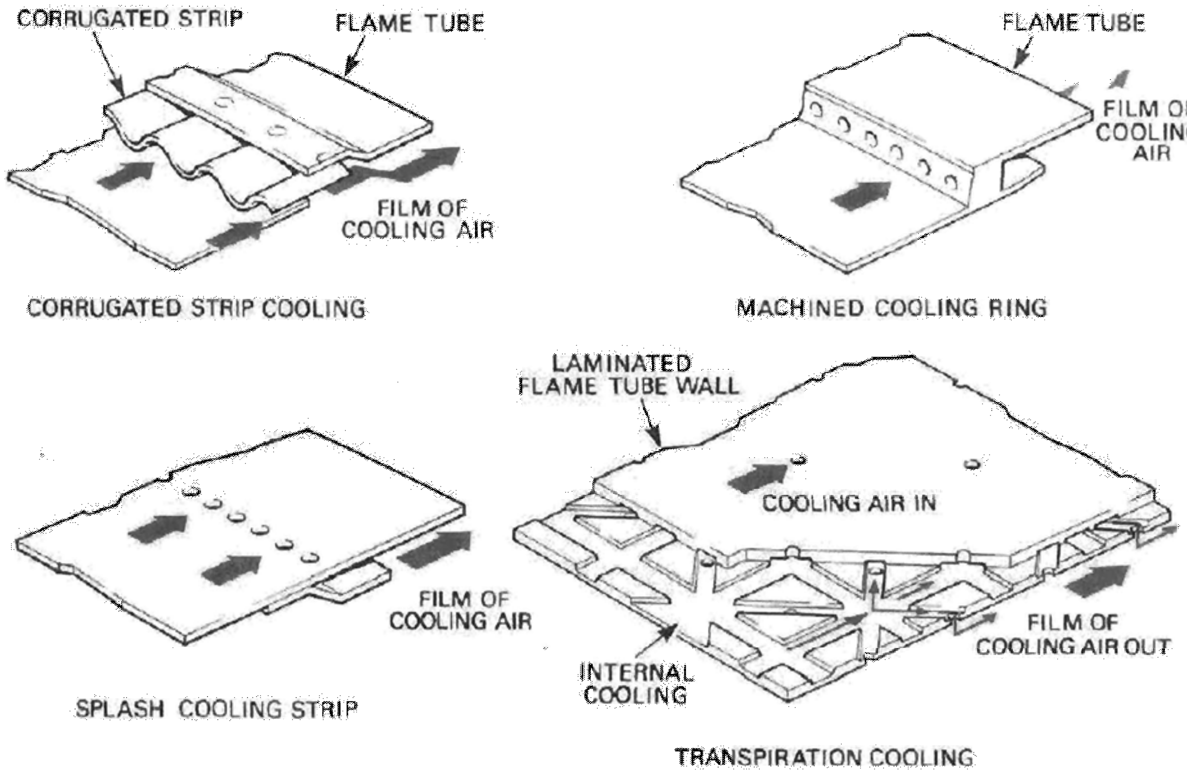

Figure 5.4: Combustion chamber cooling methods

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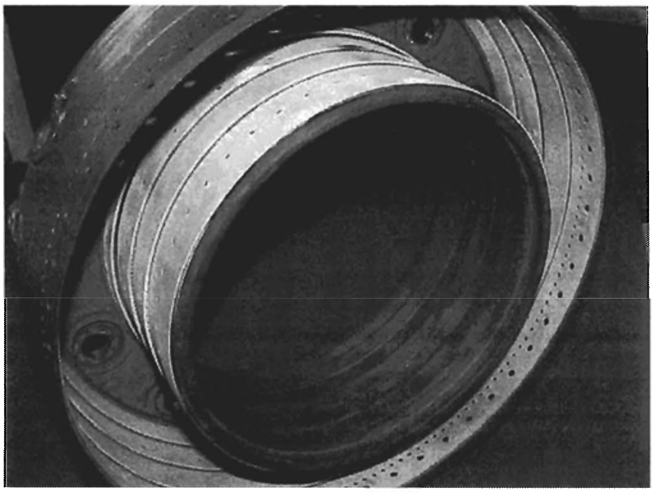
Carbon Formation

Some engines tend to produce exhaust smoke at take-off conditions. This indicates that carbon particles are being formed in over-rich regions of the primary zone in conditions of low turbulence, at high temperature and pressure. However, smoke represents an almost negligible loss in combustion efficiency of less than 0.3%. In modern high by-pass ratio engines it has been almost eliminated by detailed redesign of the airflow pattern in the primary zone of the combustion chamber.

Materials

The air casing walls and the flame tube must be capable of resisting the very high gas temperatures in the primary zone. In practise, this is achieved by the use of the best heat resisting materials available and by cooling the inner walls of the flame tube as an insulation from the flame.



The combustion chamber must also withstand corrosion due to the products of combustion, creep failure due to temperature gradients and fatigue due to vibrational stresses.

The main material normally chosen is a **nickel based alloy** with the use of ceramic coatings internally on the flame tube becoming more common in recent years.

Figure 5.5: Ceramic coated flame tube

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Design Requirements

The combustion system must provide the following;

- Light up and light round at sea level on start up.
- Stable combustion at all engine speeds, (i.e. over a wide range of air/fuel ratios 45:1 at idling to 120:1 at max. power) and during acceleration and deceleration.
- Enough temperature rise in over-fuelling conditions to accelerate the engine from start to max. speed.
- Satisfactory mechanical condition i.e. freedom from distortion, cracking, oxidation and fretting.
- A temperature distribution at exit which will give a satisfactory life for the turbine assembly.
- Burn the fuel at maximum RPM (fast moving stream of air) with 100% combustion efficiency and have an exhaust free from smoke.
- Negligible carbon deposits.
- Minimum drop in total pressure from the compressor delivery pressure.
- Light up and light around at high altitude when the engine is windmilling.
- Minimum weight, volume, length and cost. Long life between overhauls, with ease of removal/replacement.

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Types of Combustion Systems

Multiple Can Combustion Chamber

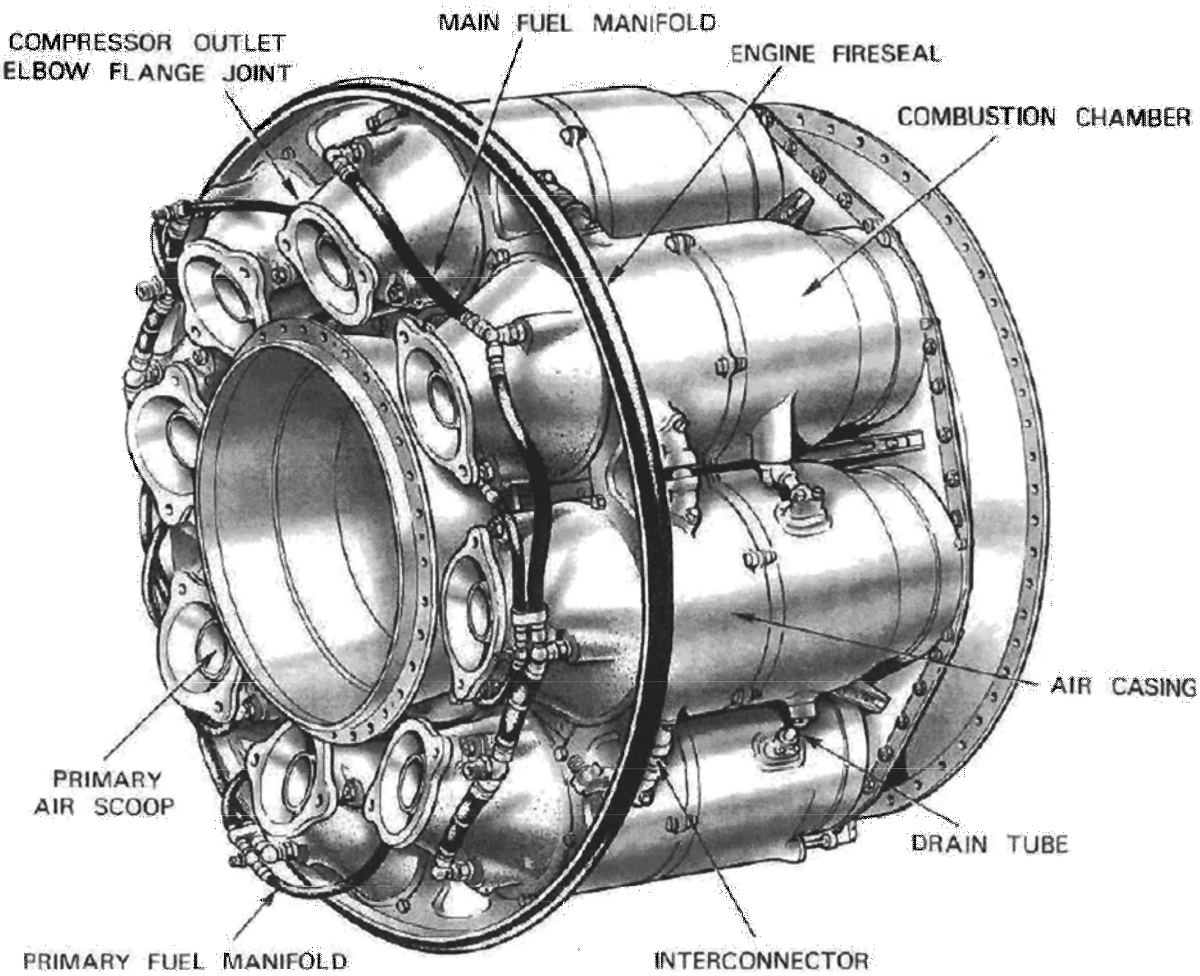

Figure 5.6: Multiple can combustion chamber components

This is the earliest type of system. It consists of a number of separate chambers each with its own air casing, flame tube and burner, all interconnected together. **The INTERCONNECTORS allow pressure fluctuations to stabilise and starting to be achieved with the use of only two igniter plugs**. The chambers are arranged evenly around the outside of the engine casing. This type will provide good airflow control and ease of maintenance, however mass flow is limited and it tends to be heavy.

Tubo-Annular Combustion Chamber

This type of system has a number of flame tubes fitted inside a common air casing.

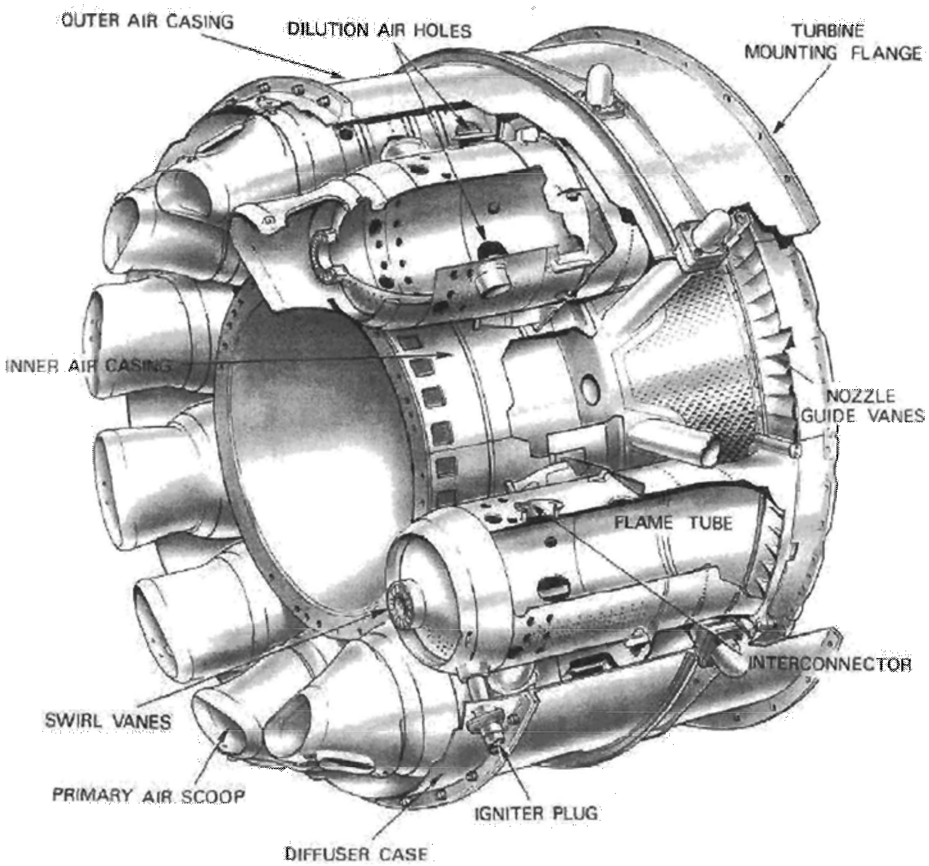

Figure 5.7: Tubo-annular combustion chamber components

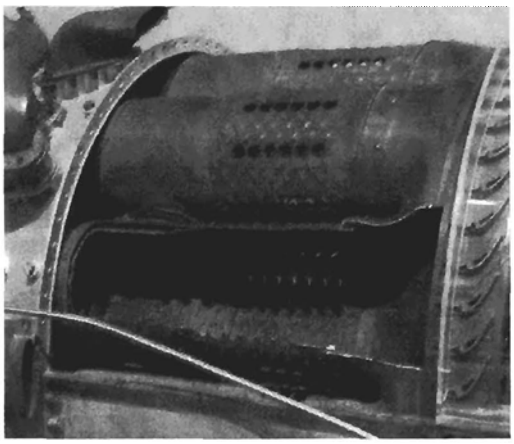

Figure 5.8: Tubo-annular combustion chamber

The system is lightweight, easy to manufacture, overhaul and test. The American name for this system is **CAN-ANNULAR**

Annular Combustion Chamber

This combustion chamber consists of a single flame tube completely annular in form which is contained within inner and outer air casings. The airflow through the flame tube is similar to that already described. For the same power output, the length of the chamber is shorter than that for the tubo-annular system (for the same diameter) thereby saving both weight (shorter shafts) and production costs. The propagation of the combustion flame is also improved in this system.

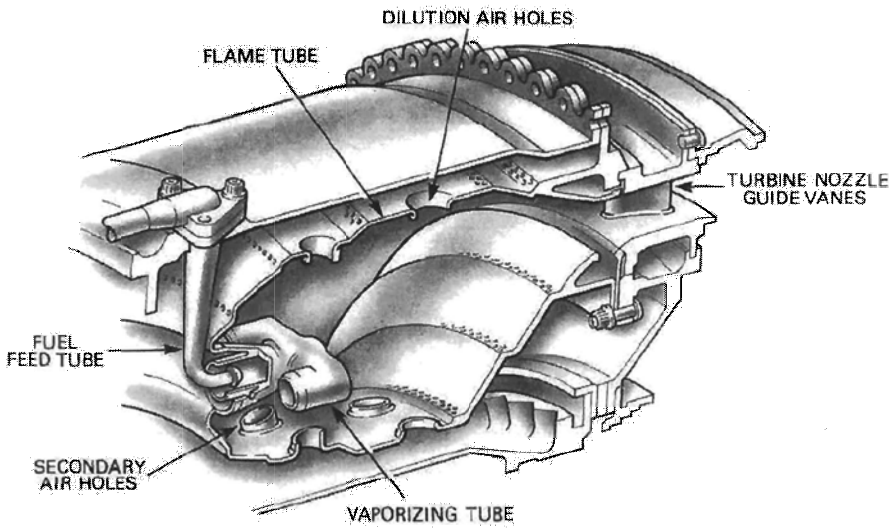

Figure 5.9: Section through an annular combustion chamber

This type of combustion chamber consists of a single flame tube, completely annular in form, which is contained in an inner and outer casing.

The airflow through the flame tube is similar to that already described, the chamber being open at the front to the compressor and at the rear to the turbine nozzles.

The main advantage of the annular chamber is that, for the same power output, the length of the chamber is only 75 per cent of that of a tubo-annular system of the same diameter, resulting in considerable saving of weight and production cost. Another advantage is the elimination of combustion propagation problems from chamber to chamber.

In comparison with a tubo-annular combustion system, the wall area of a comparable annular chamber is much less; consequently the amount of cooling air required to prevent the burning of the flame tube wall is less, by approximately 15 per cent. This reduction in cooling air raises the combustion efficiency to virtually eliminate unburnt fuel, and oxidizes the carbon monoxide to non-toxic carbon dioxide, thus reducing air pollution.

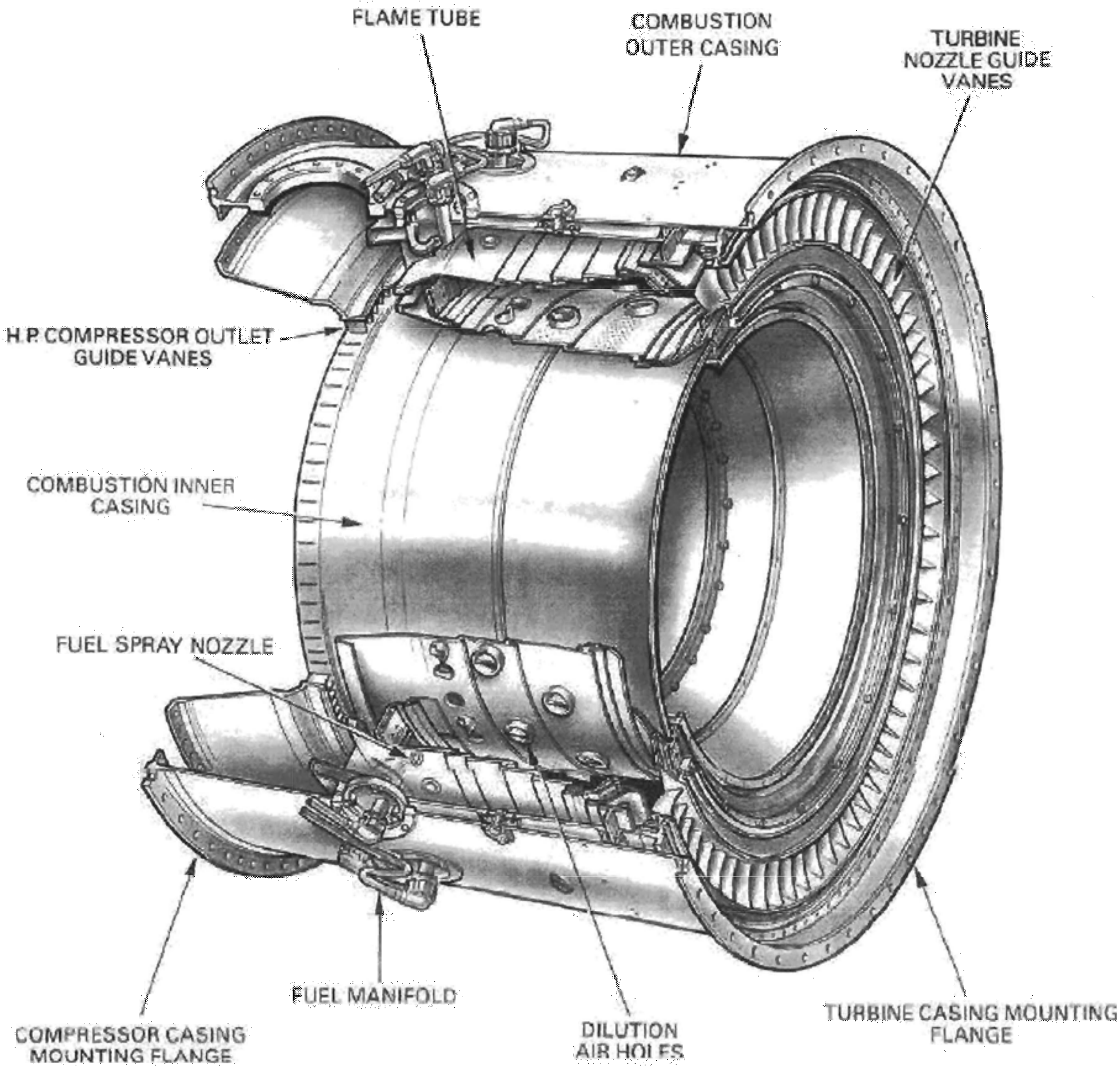

Figure 5.10: Section through an annular combustion chamber

This is now the most common combustion system in use.

Reverse Flow Combustion System

In a number of small modern engines the combustion system is in effect reversed in layout. Compressor airflow passes between the flame tube and the air casing to the rear of the system where it enters the flame tube in the normal way. The hot gases leaving the flame tube at the front are then turned through 180^0 to pass into the turbine assembly in the normal way.

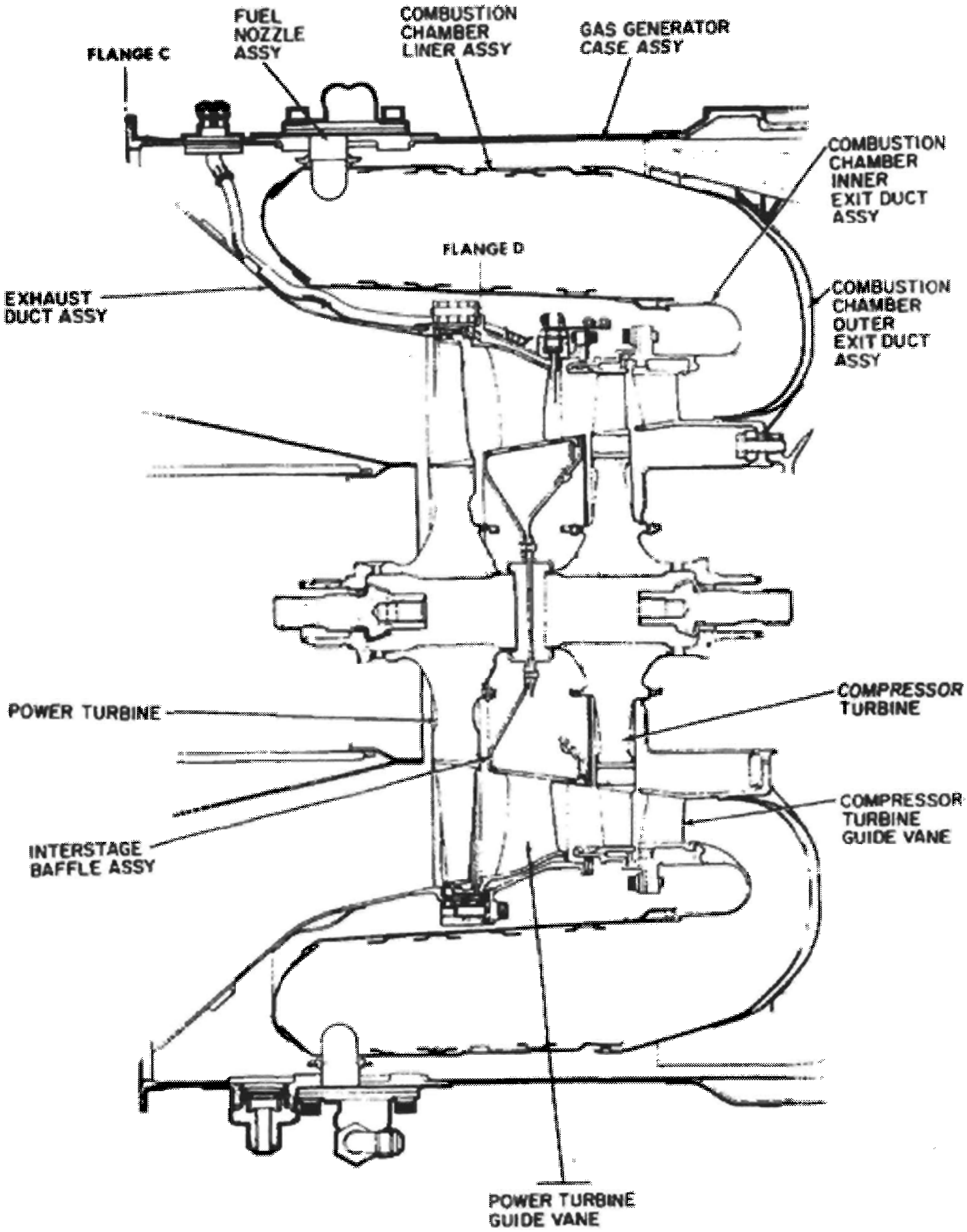

Figure 5.11: A reverse flow combustion chamber

The system has the advantage of enabling the length of the engine to be reduced, which may save weight and cost.

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.6 Turbine Section

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Table of Contents

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Objective	EASA 66 Reference	Level
		B1
Turbine Section	15.6	2
Operation and characteristics of different turbine blade types;		
Blade to disk attachment;		
Nozzle guide vanes;		
Causes and effects of turbine blade stress and creep.		

Module 15.6 - Turbine Section

Introduction

The turbine drives the compressors, accessories and where applicable, the propeller or power output shaft by absorbing a high proportion of the energy of the gas stream, and converting it into torque. The gas leaves the turbine at a lower velocity, temperature and pressure proportional to the energy given up in the turbine.

To produce the driving torque required in a shaft a turbine may consist of several stages, each stage comprising of a fixed ring of Nozzle Guide Vanes followed by a turbine disc holding the rotating blades around its edge. The disk includes the shaft attachment, normally a bolted flange. The number of turbines depends on the number of shafts. Power is proportional to turbine blade area and for a given power, a turbine may be one large single stage, or a smaller diameter multi-stage unit, with all stages connected to a common shaft

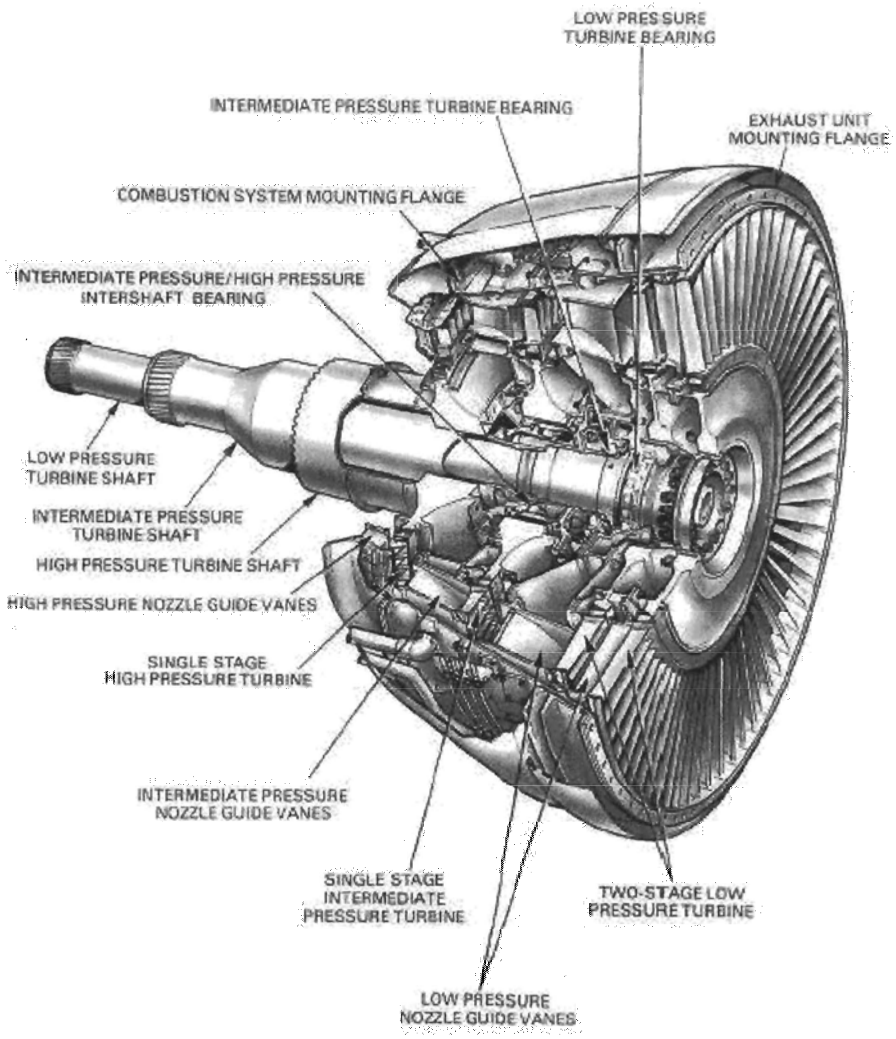

Figure 6.1: A typical turbine section assembly

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Types of Turbine

The following types of turbine may be used in a gas turbine engine

Impulse Turbines
Reaction Turbines
Impulse/Reaction Turbines
Radial Inflow Turbines

Impulse Turbines

The impulse turbine transfers the energy of the gas flow to the turbine wheel by impulse (or impact). **The nozzle is convergent**, the inlet area being larger than the discharge area. as the gases leave the nozzle they are accelerated, resulting in a decrease in pressure and temperature. The accelerated gases are directed by the Nozzle Guide Vanes onto the turbine blades (buckets) at the best angle of attack to cause rotation. **The cross sectional flow area of the rotor is constant,** consequently there is no significant change in gas temperature, pressure or speed across the rotor.

Note: There is a velocity change across the impulse rotor due to a change in gas direction with NO CHANGE in gas speed. The force producing the change in velocity has a REACTION force which acts on each turbine rotor blade.

The torque produced will be the sum of the forces on all the blades times the effective disc radius.

In addition to contributing to the production of torque, the acceleration of the gases from the impulse turbine nozzle also lowers the temperature of the gases. In some cases this becomes an important factor in reducing the blade operating temperature, so allowing higher turbine inlet temperatures. An alternative approach is to use the lower blade temperature to prolong blade life.

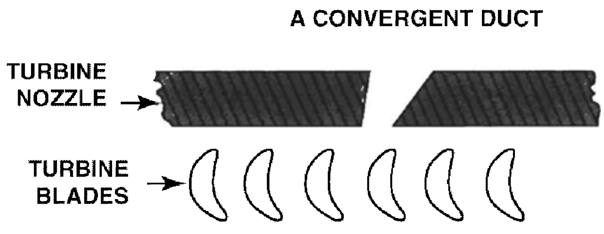


Figure 6.2: Impulse turbine vanes form convergent ducts

Reaction Turbines

In the reaction turbine the primary nozzle function is to direct the gases at the proper angle onto the turbine rotor blades. **The nozzle has a constant flow area** and gases flow through the nozzle with relatively constant pressure, temperature and speed. **On the rotor, the cross sectional flow area is smaller at the discharge than at the rotor inlet**

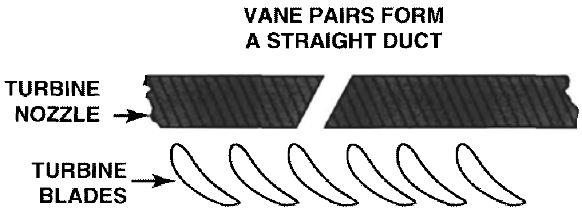
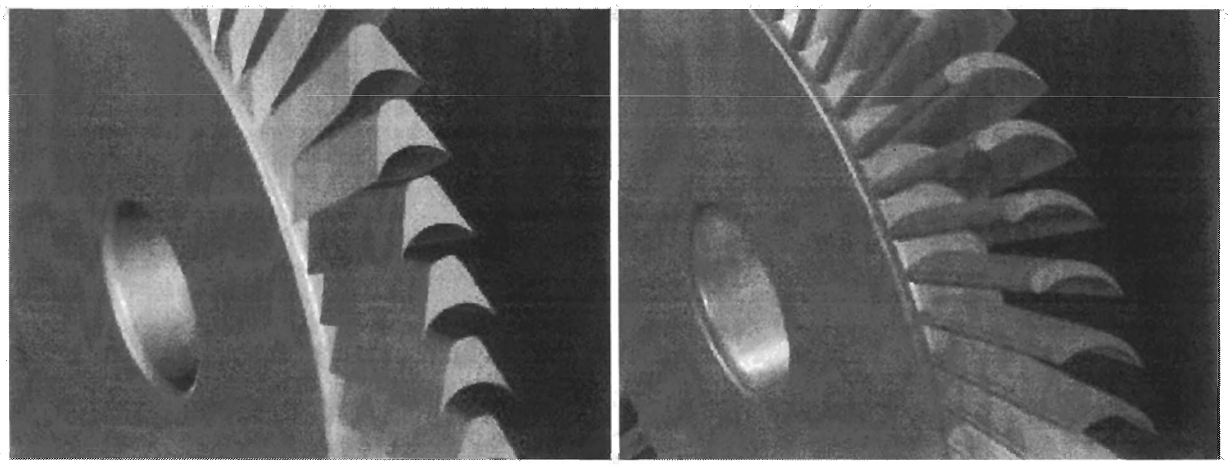


Figure 6.3: Reaction turbine vanes form parallel ducts

As the gas flows through the reaction turbine rotor, the gas stream is turned, speed increased, pressure and temperature decreased. The acceleration of the gases through the turbine rotor creates an equal and opposite **reaction** which applies a force on each blade and this total force multiplied by the effective radius of the disc produces the torque to drive the shaft.



Pure Impulse Blades **Pure Reaction Blades**

Figure 6.4: Pure impulse and pure reaction blades

Impulse-Reaction Turbines

Gas turbine engines used for aircraft propulsion utilise both impulse and reaction. The typical blade design is shown below.

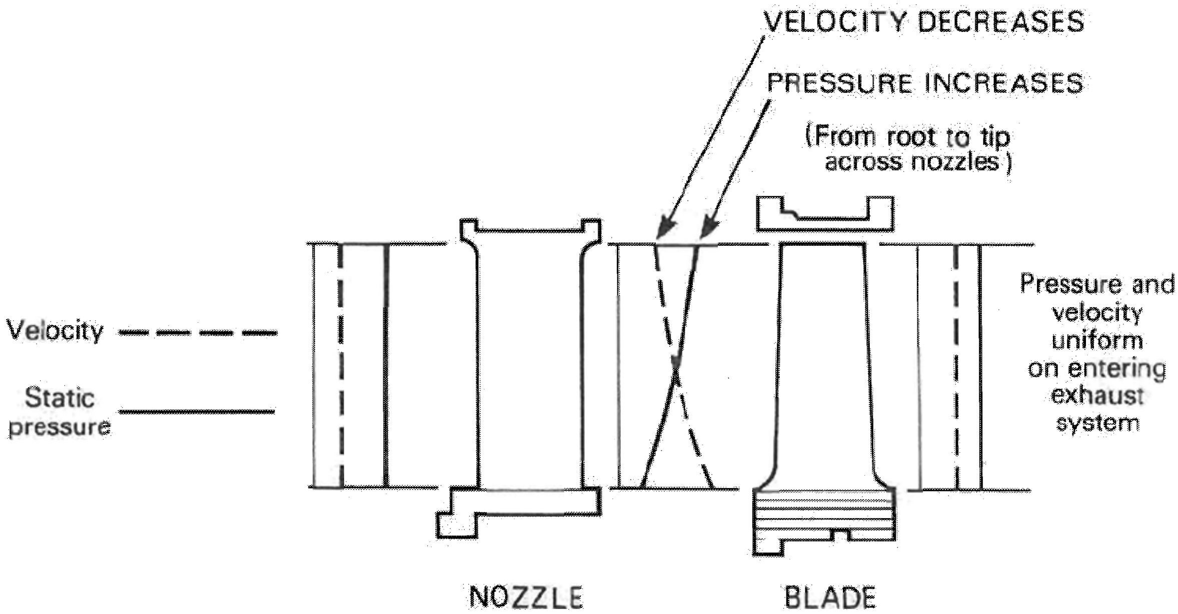


Figure 6.5: Impulse to reaction blading from root to tip

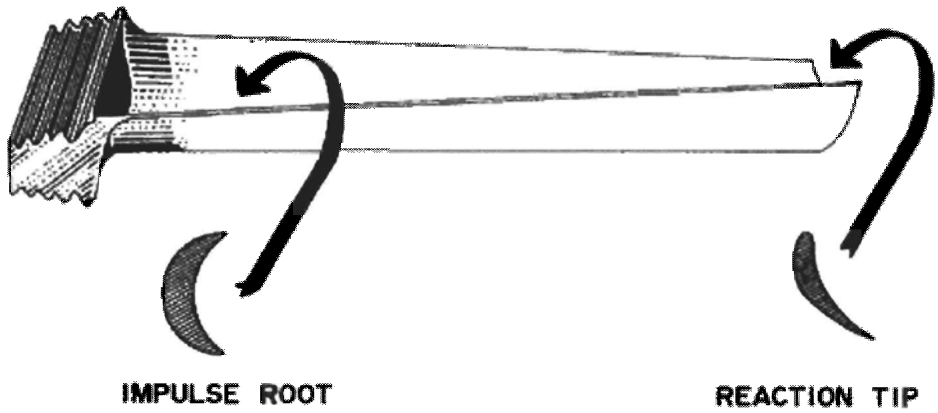


Figure 6.6: Impulse to reaction blading from root to tip

The Nozzle Guide Vanes form convergent ducts and give a whirl component to the gas flow, creating a vortex flow. This results in a higher gas pressure and lower velocity at the tip and the reverse near the blade roots. The gas flow is then fed onto the rotor blades which are often known as **vortex blades**. **The rotor blades are twisted and of impulse form at the root and reaction at the tip. The reason for the twist is to make the gas flow from the combustor do equal work at all positions along the length of the blade,** and to ensure that the flow enters the exhaust system with a uniform axial velocity.

Impulse-Reaction Blade Twist

More impulse at the root moving towards reaction at the tip.

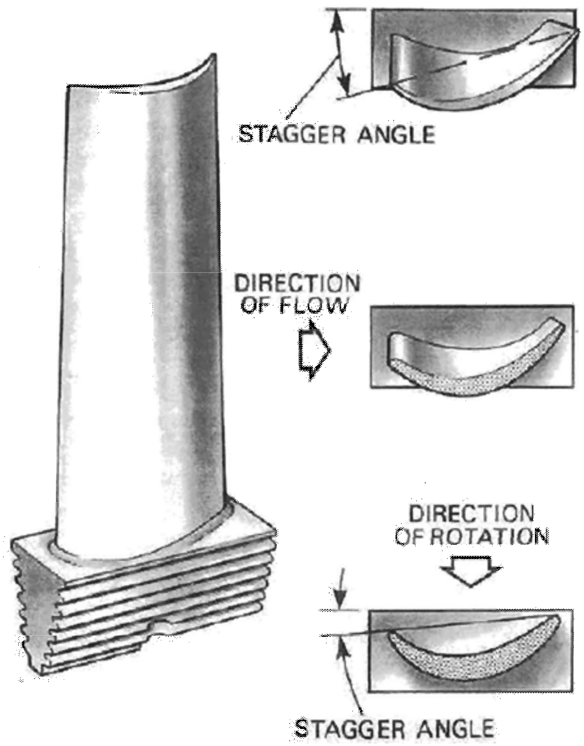


Figure 6.7: Blade stagger angle

Radial Inflow Turbines

This type of turbine is similar in appearance to a centrifugal compressor. The exhaust gas is fed to the rotor at the tip from the nozzle, which accelerates and directs the gases. The turbine rotor usually has curved convergent passages and it thus functions by a combination of impulse and reaction.

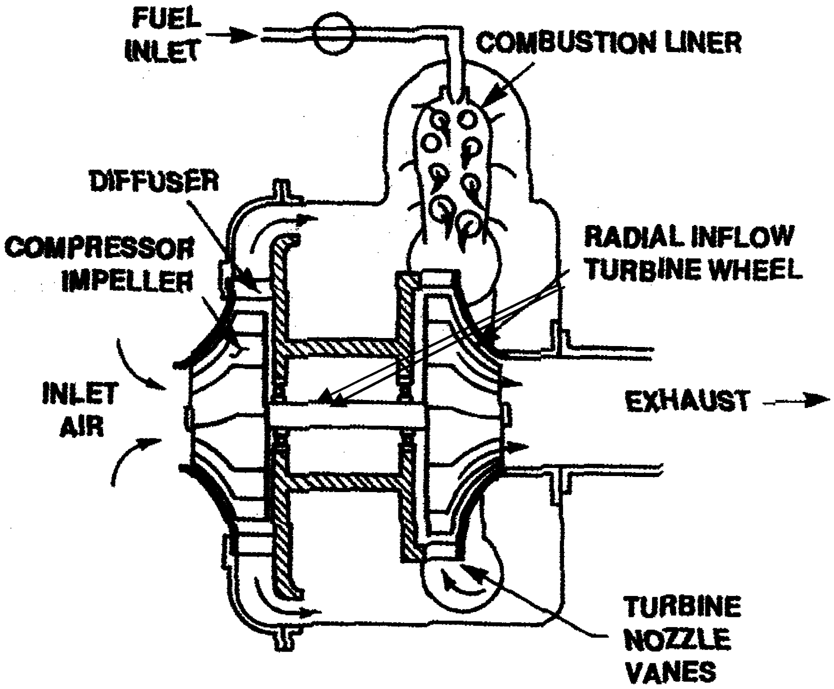


Figure 6.8: A radial inflow turbine assembly

Applications for the radial flow turbines are limited to APUs and superchargers for piston engines, due to short service life due to high centrifugal load and temperatures. This type of turbine is not used for in flight engines.

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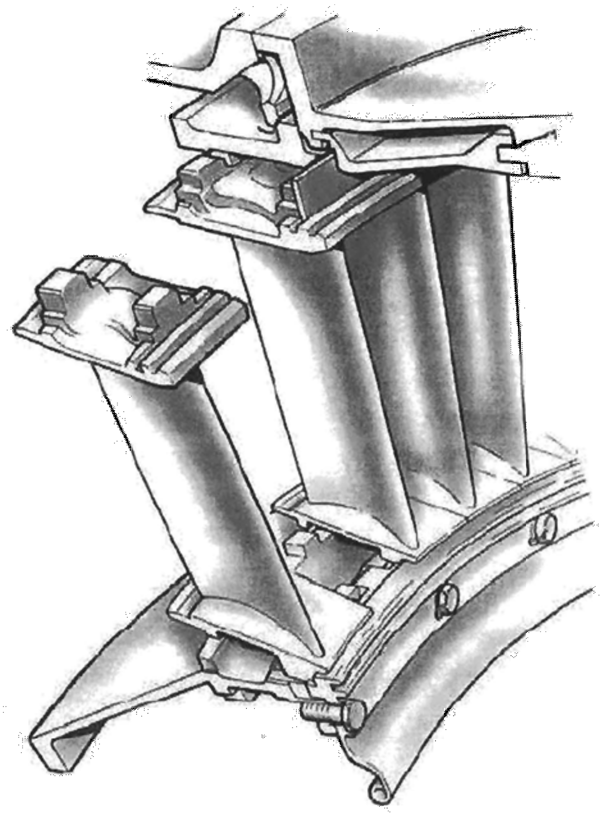
Turbine Construction

Nozzle Guide Vanes



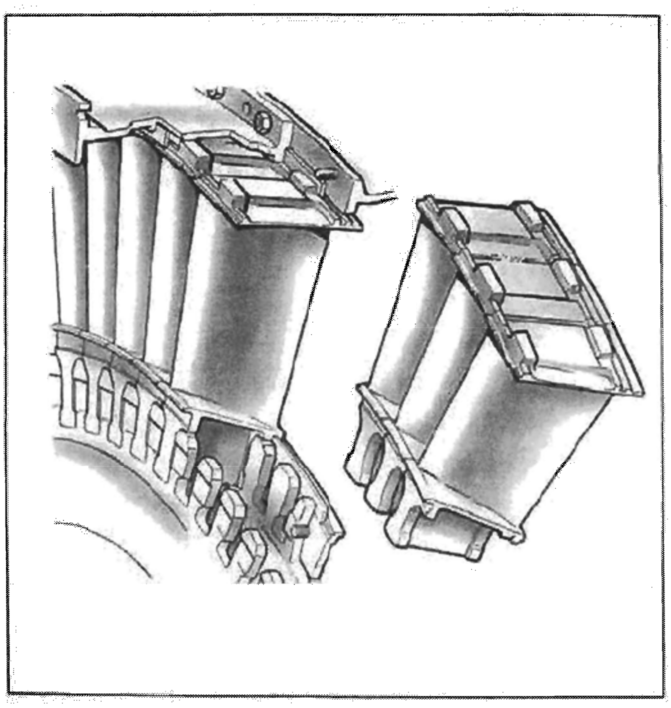


Figure 6.8: Typical turbine assemblies

Nozzle Guide Vanes are mounted as shown above. They are located in casings so that they can expand on heating. They are usually hollow and are cooled by passing compressor bleed air through the blade.

As they are static, NGVs require heat resistance as their most important property. They are made from nickel alloys but extra measures are still required to prevent overheating. These are **ceramic coating** and **air cooling.**

Turbine Discs

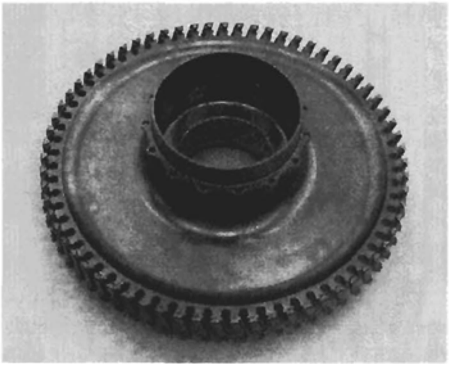


Figure 6.9: A turbine disc

A turbine disc has to rotate at high speed in a relatively cool environment and is subjected to large rotational stresses. The limiting factor which affects the useful disc life is its resistance to fatigue cracking. In the past, turbine discs have been made using ferritic and austenitic steels but nickel based alloys are currently used. Increasing the alloying elements in nickel extend the life limits of a disc by increasing fatigue resistance. Alternatively, expensive powder metallurgy discs, which offer an additional 10% in strength, allow faster rotational speeds to be achieved.

Turbine Blades

A brief mention of some of the points to be considered in connection with turbine blade design will give an idea of the importance of the correct choice of blade material. The blades, while glowing red-hot, must be strong enough to carry the centrifugal loads due to rotation at high speed. A small turbine blade weighing only two ounces may exert a load of over two tons at top speed and it must withstand the high bending loads applied by the gas to produce the many thousands of turbine horse-power necessary to drive the compressor. Turbine blades must also be resistant to fatigue and thermal shock, so that they will not fail under the influence of high frequency fluctuations in the gas conditions, and they must also be resistant to corrosion and oxidization. In spite of all these demands, the blades must be made in a material that can be accurately formed and machined by current manufacturing methods.

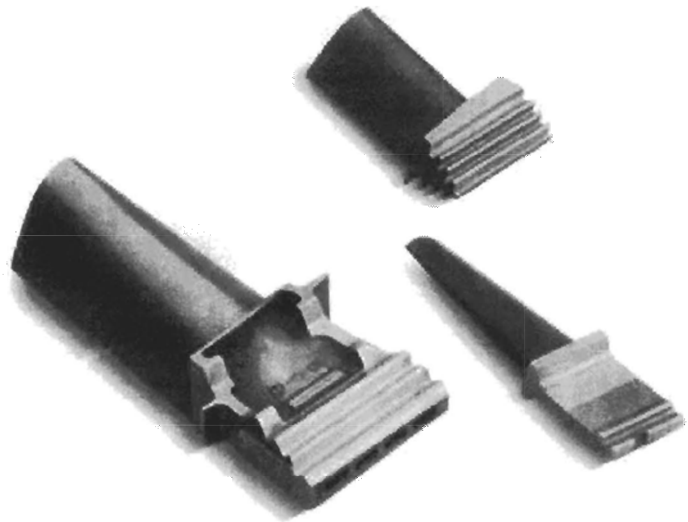


Figure 6.10: Typical turbine blades

From the foregoing, it follows that for a particular blade material and an acceptable safe life there is an associated maximum permissible turbine entry temperature and a corresponding maximum engine power. It is not surprising, therefore, that metallurgists and designers are constantly searching for better turbine blade materials and improved methods of blade cooling.

Turbine Blade Creep

Over a period of operational time the turbine blades slowly grow in length. This phenomenon is known as creep and there is a finite useful life limit before failure occurs.

The early materials used were high temperature steel forgings, but these were rapidly replaced by cast nickel base alloys which give better creep and fatigue properties.

Close examination of a conventional turbine blade reveals a myriad of crystals that lie in all directions (equi-axed). Improved service life can be obtained by aligning the crystals to form columns along the blade length, produced by a method known as Directional Solidification. A further advance of this technique is to make the blade out of a single crystal. Each method extends the useful creep life of the blade and in the case of the single crystal blade, the operating temperature can be substantially increased.

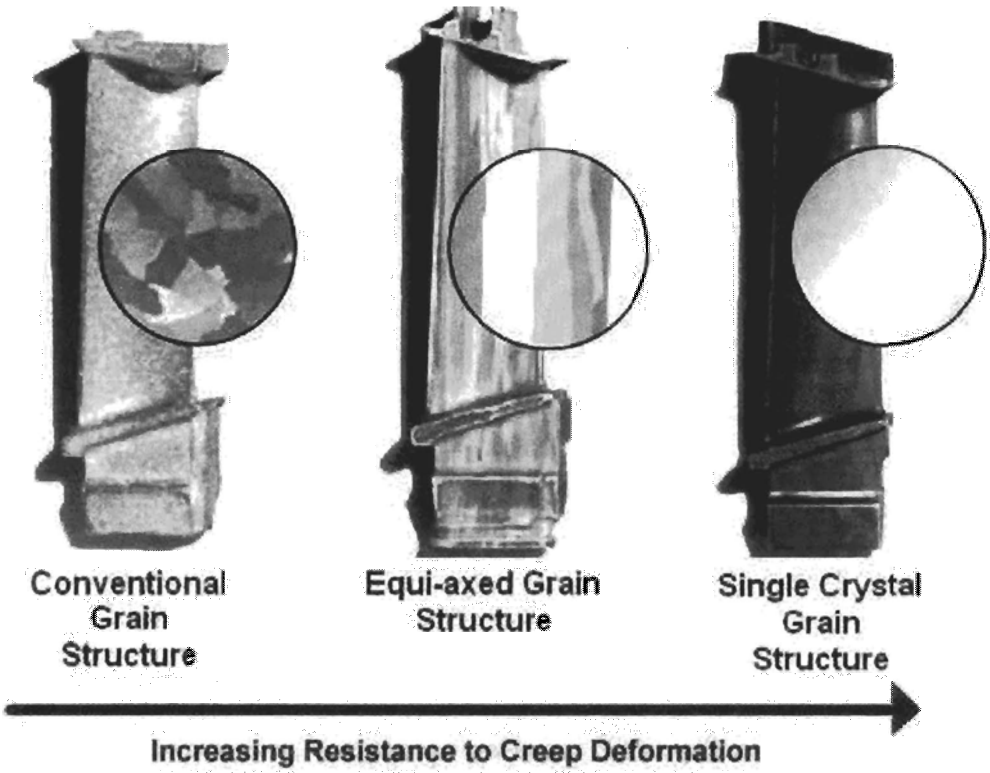


Figure 6.11: Turbine blade grain structure development

The turbine blade is subjected to both high temperatures and centrifugal forces. It is a character of all metals that in these conditions that changes will occur due to creep. The blade will stretch. These changes are irreversible and there are usually three main stages;

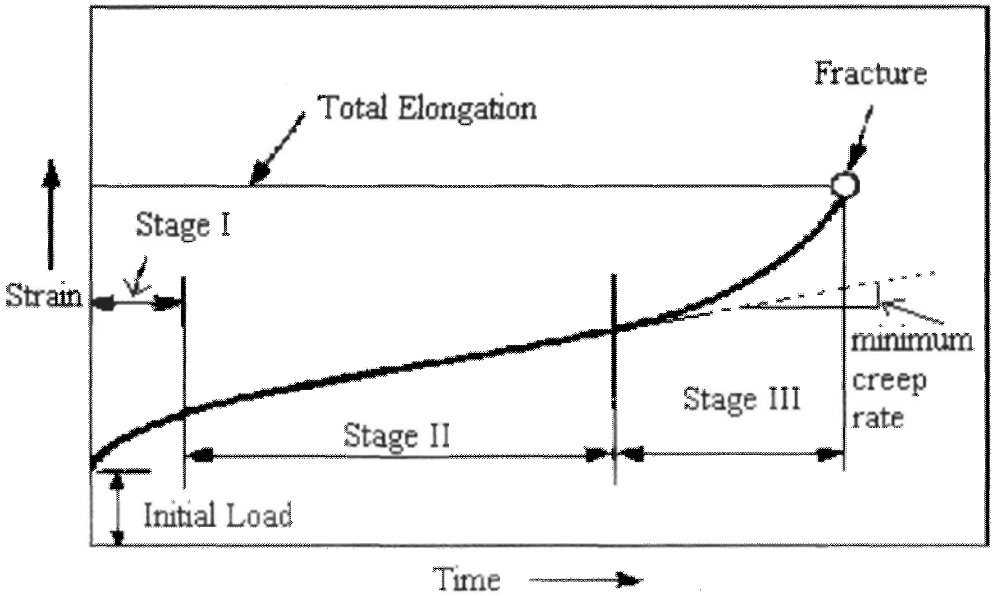


Figure 6.12: Turbine creep

Stage I	**Primary creep -** There is a rapid extension at a decreasing rate.
Stage II	**Secondary creep -** There is a constant rate of extension.
Stage III	**Tertiary creep -** There is extension of the blade at a rapidly increasing rate culminating in blade failure.

The end of the secondary phase will be the time that limits the blade **safe life**.

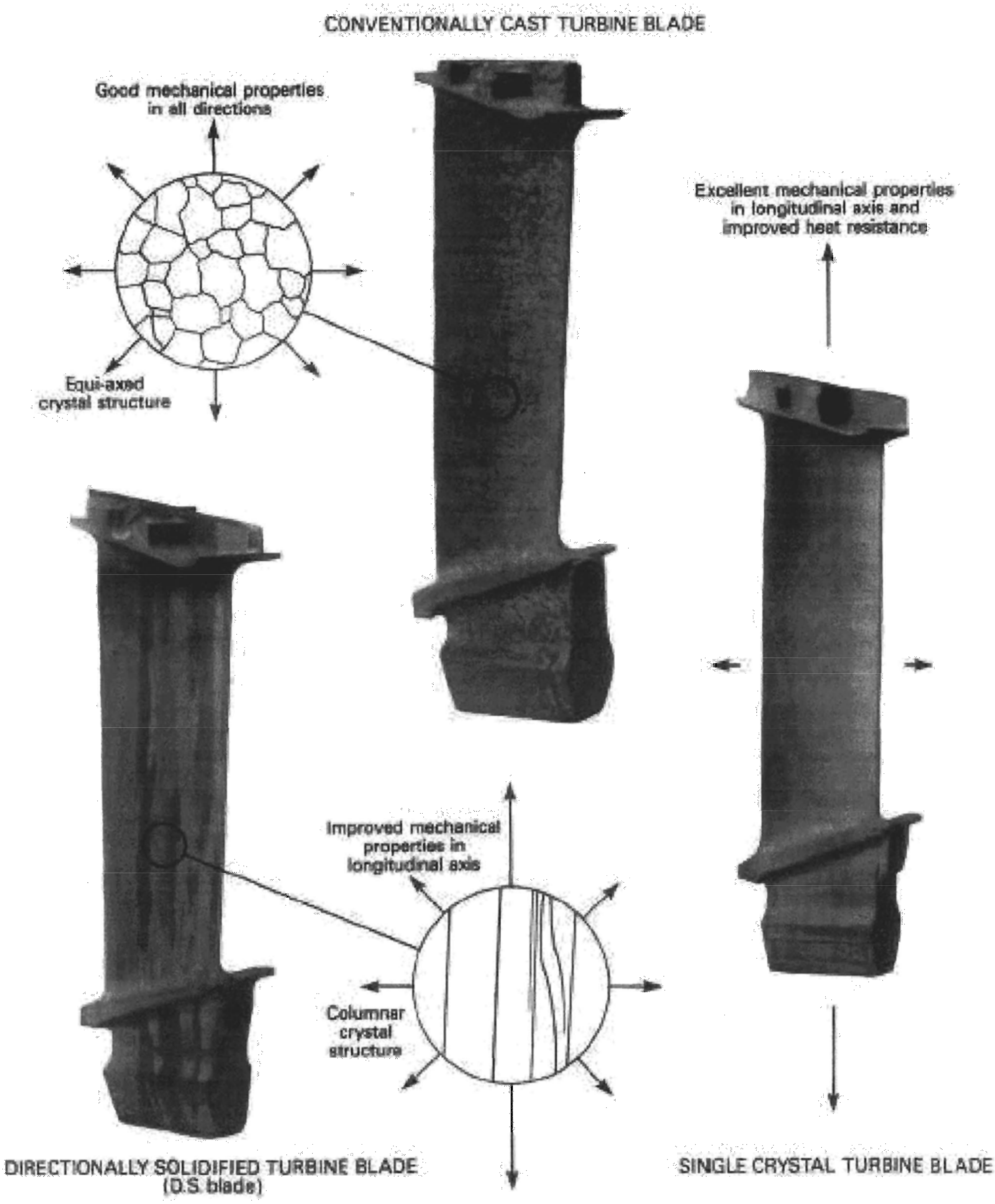


Figure 6.13: Turbine blade grain properties

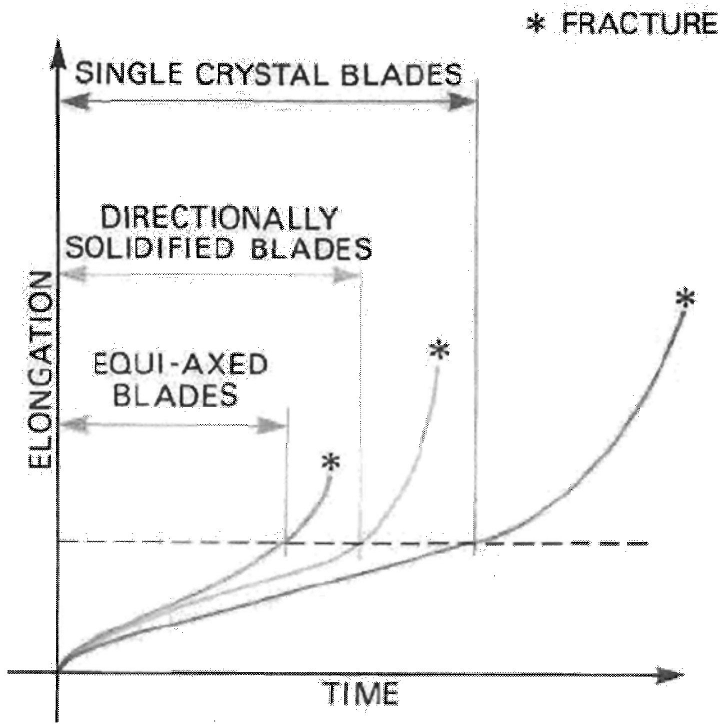


Figure 6.14: The effect of improved grain structure on fatigue life

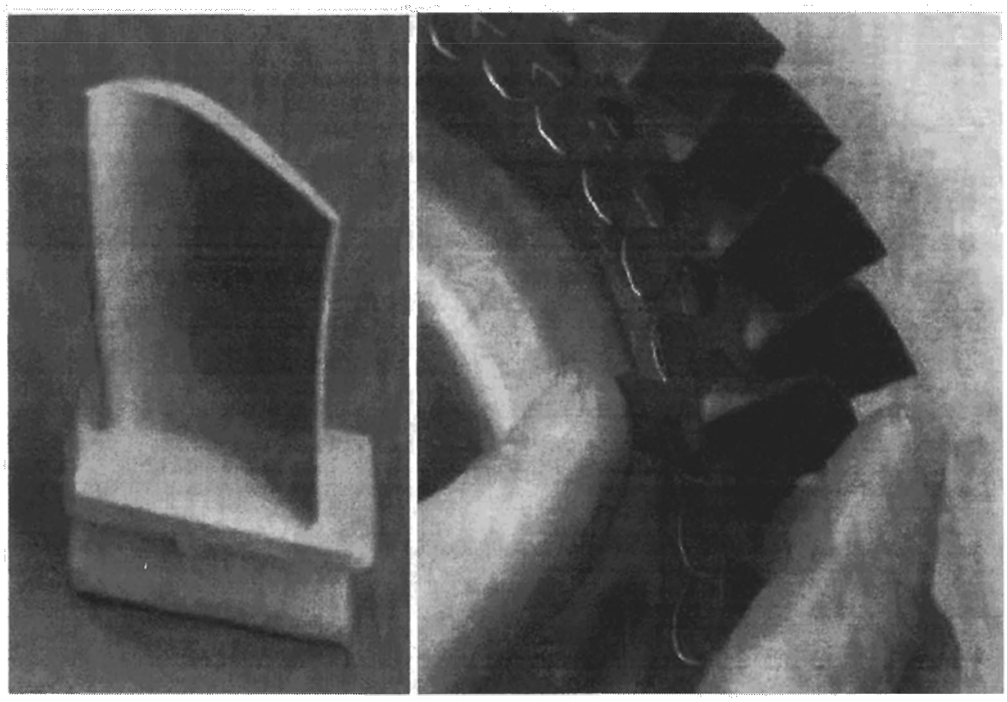


Figure 6.15: Ceramic turbine blades

Turbine Blade Cooling

In order that turbines can survive in an environment where gas temperatures can be higher than the melting temperature of steel, it is essential that both the NGVs and turbine rotor blades of most turbine assemblies are extensively cooled internally using compressed air from the engine compressor. The following variations of cooling techniques are used;

Internal cooling by impact
Film cooling
Multi-pass cooling
Transpiration cooling
Platform film cooling

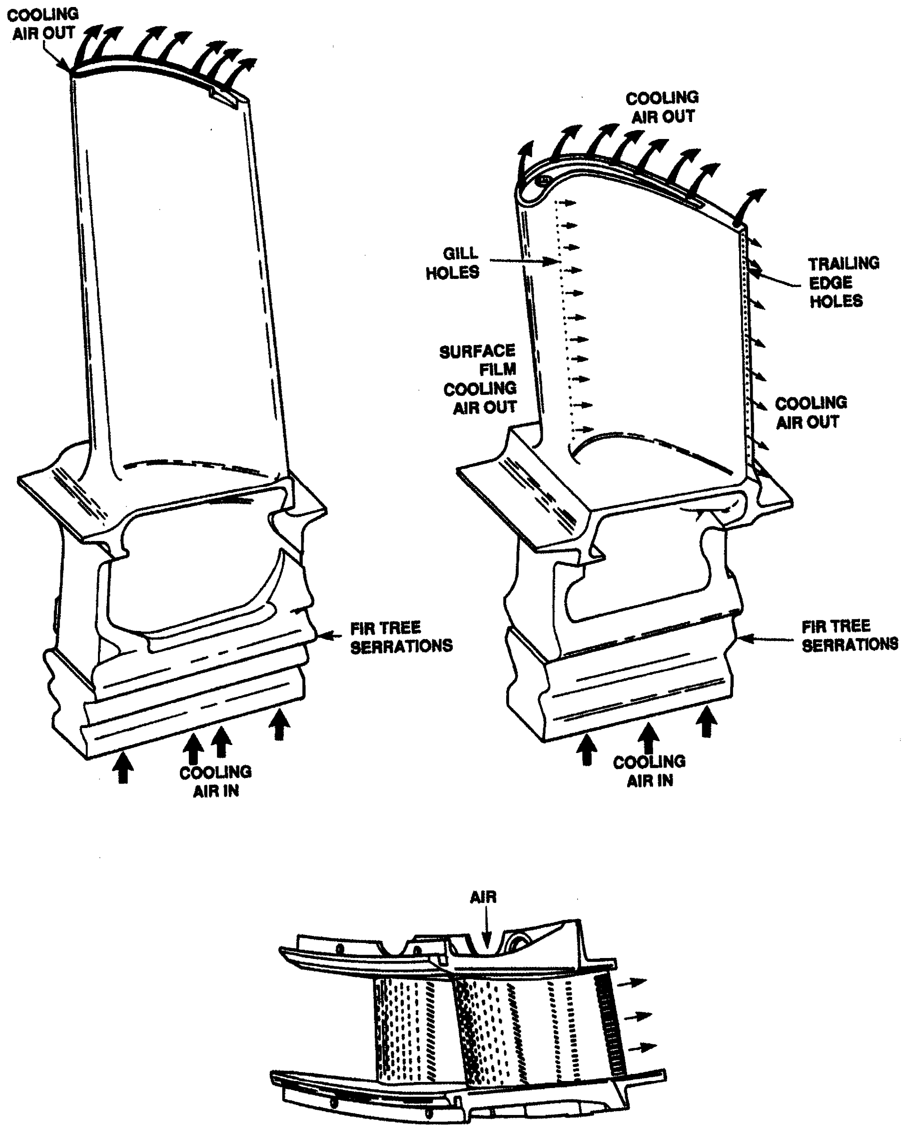


Figure 6.13: Levels of blade cooling

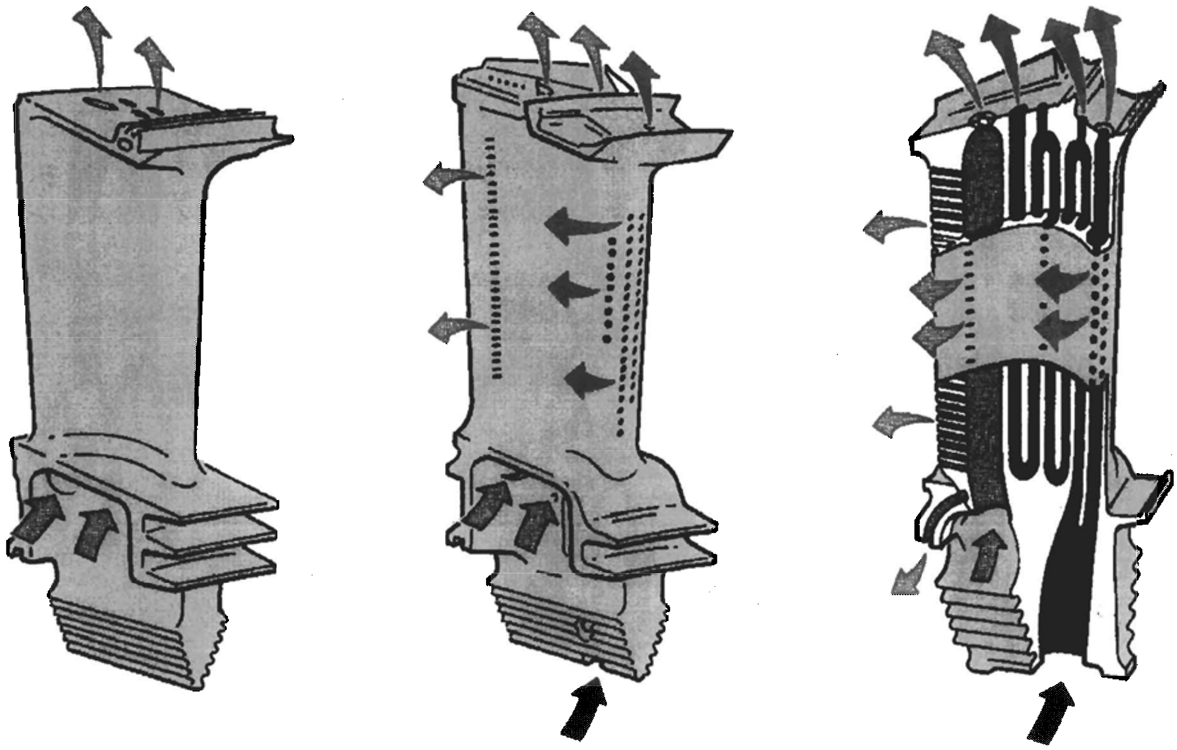


Figure 6.14: Blade cooling passages

Shrouded and Knife Edge Turbine Blades

Some turbine blades are shrouded at the top to reduce gas vortices at the blade tips and as a result improve the blades resistance to vibration. The shrouds normally interlock, but they have the disadvantage of limiting the blades safe maximum RPM due to increased centrifugal force.

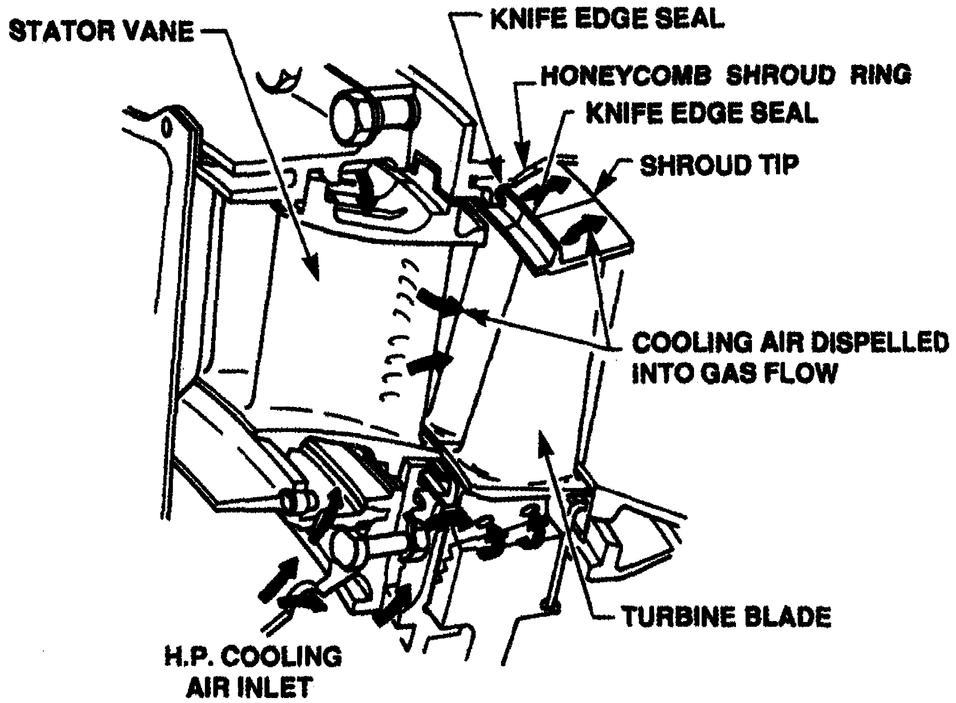
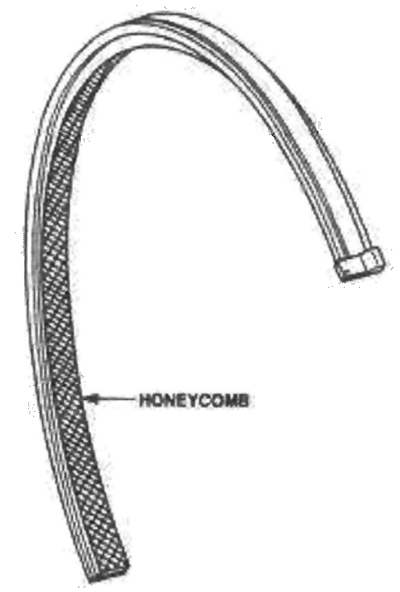


Figure 6.15: Shrouded turbine assembly

Knife edge seals also prevent tip losses. They usually fit in close tolerance to a shroud ring mounted in the outer turbine case



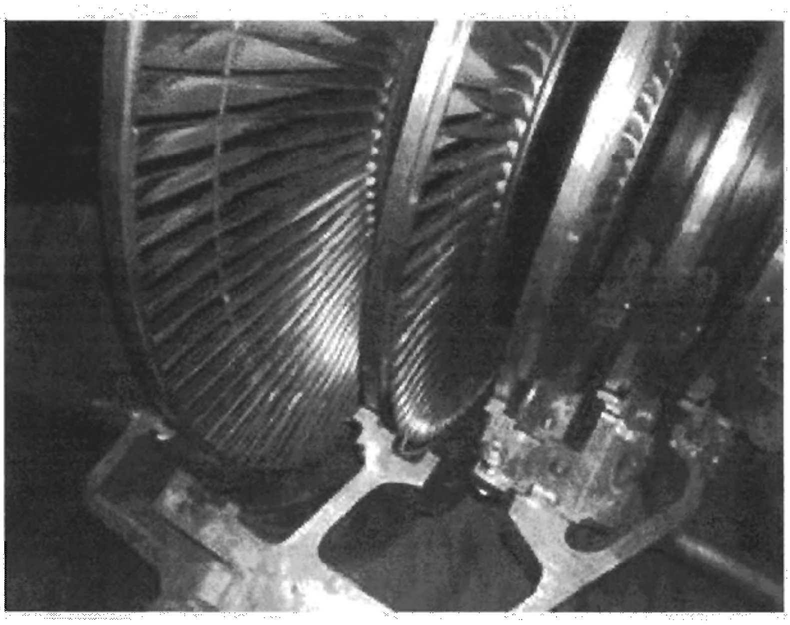


Figure 6.16: Honeycomb turbine shroud ring segment and assembly

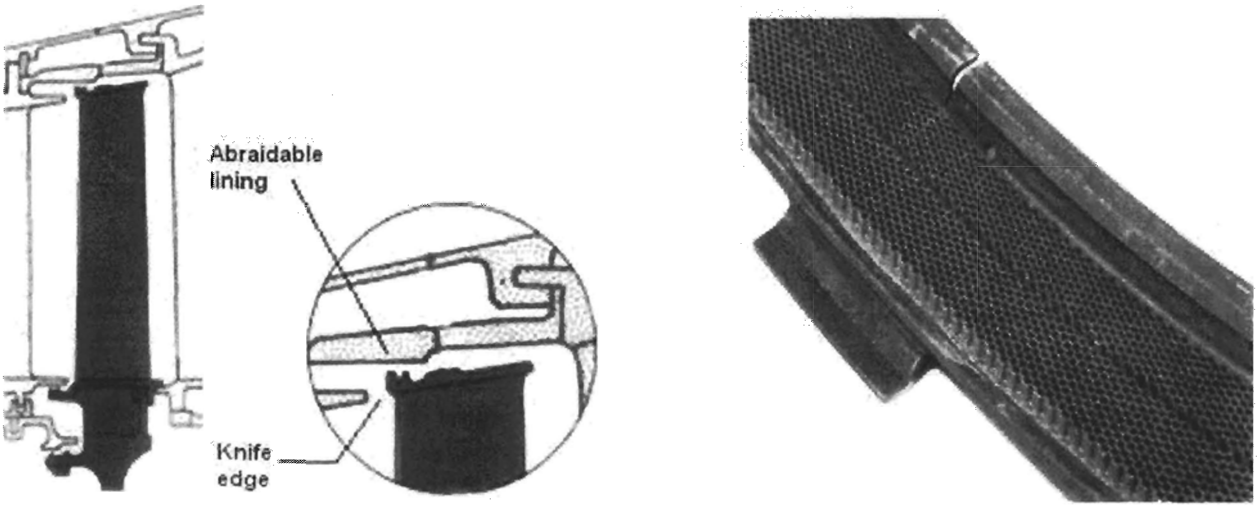


Figure 6.17: Abraidable lining and honeycomb

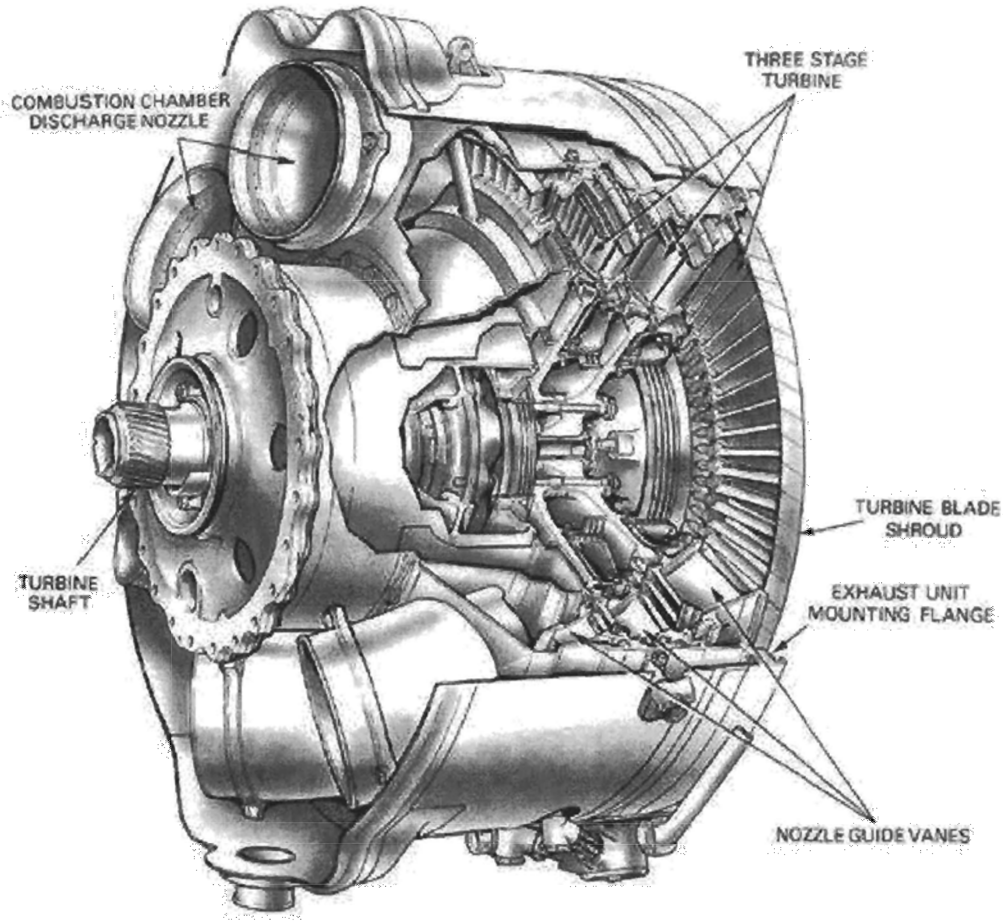


Figure 6.18: A Shrouded turbine disc

Turbine Blade Attachment

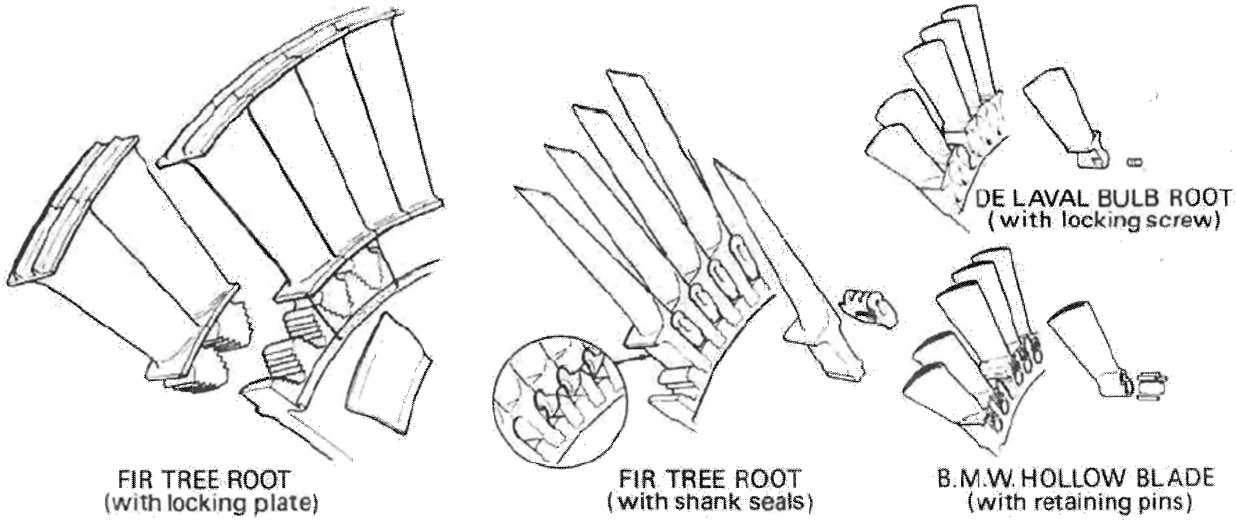


Figure 6.19: Various turbine blade root attachments

Turbine blades are usually attached to the disc by the **fir tree root** method, which allows room for expansion whilst firmly retaining the blade. Also note the other methods shown above.

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Active Clearance Control (ACC)

For maximum turbine efficiency the clearance between the blade-tips and casing should be optimum at all times. Blade length and casing diameter will, however, vary as running conditions change. To maintain efficiency, the casing is air cooled - usually at steady speed and deceleration - **not** during acceleration. This causes the casing to contract and so turbine blade tip clearance can be controlled by varying the air flow. Active Clearance Control is normally only found on engines with FADEC control.

On a very few engines HP compressors have this active clearance control. It is known as Rotor Active Clearance Control (RACC)

The mechanics of the system are quite simple. Cooling air, normally from the fan outlet is passed into a series of manifolds passing around the casing. Holes in the tubes direct the air on to the casing and cool it down. **The system fails safe closed, thus allowing the casing to expand and prevent inadvertent blade tip contact.**

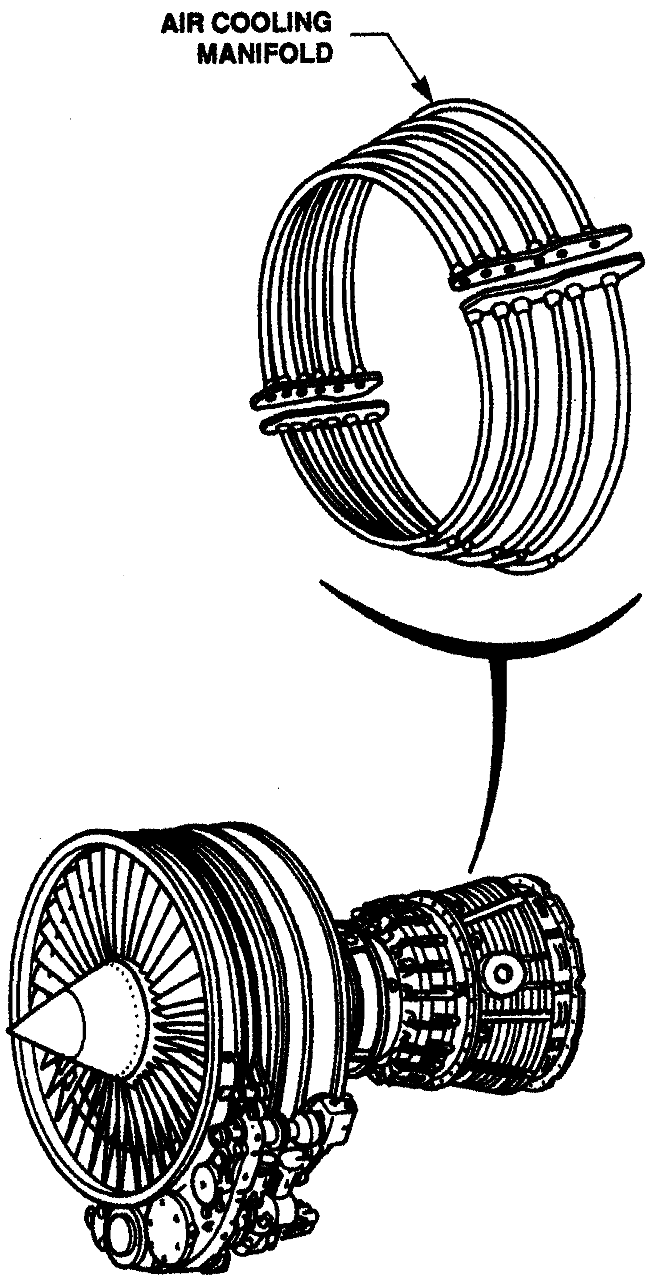

Figure 6.20: Active Clearance Control

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.7 Exhausts

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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.

Table of Contents

Module 15.7 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 Reference	Level
		B1
Exhaust	15.7	2
Constructional features and principles of operation;		
Convergent, divergent and variable area nozzles;		
Engine noise reduction;		
Thrust reversers.		

Module 15.7 - Exhausts

Function

To safely direct the exhaust gases rearwards to atmosphere at a velocity and density necessary to produce the required thrust.

For optimum thrust, from a given mass, the gases must be expanded completely and discharged in a laminar, vortex free and axially orientated flow.

The exhaust system consists of the following components: -

- Exhaust casing, inner cone and its supports
- Exhaust duct (tail pipe or jet pipe and by-pass duct)
- Nozzle

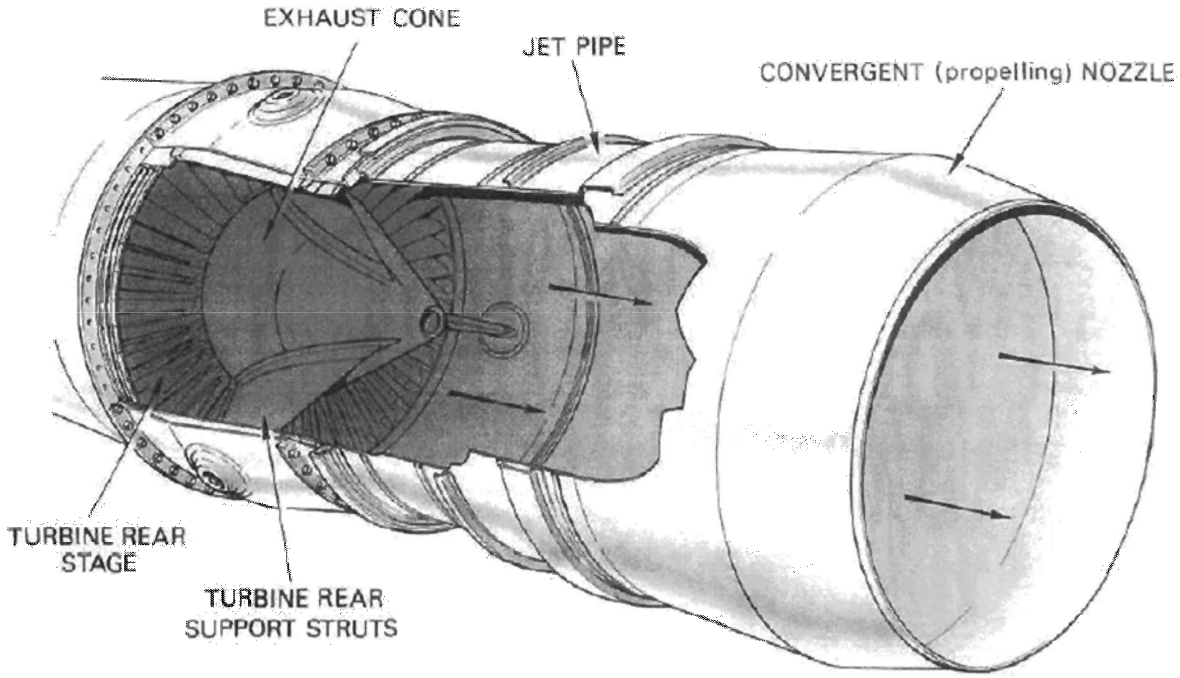


Figure 7.1: A complete exhaust assembly

Construction

Exhaust Casing, Inner Cone and Supports

The exhaust casing fits onto the rear of the turbine casing and houses the cone and its support struts. The casing is usually tapered to the rear, and the exhaust gas thermocouples may be fitted here.

The inner cone shields the rear face of the turbine disc from the exhaust gases and smoothes the gas flow. It increases the exhaust area to the rear, minimising gas velocity and thus frictional losses in the exhaust duct or jet pipe.

The inner cone is supported in place by thin struts of symmetrical aerofoil section. These supply services to the turbine rear bearing and serve as straightener vanes to remove swirl from the gasses.

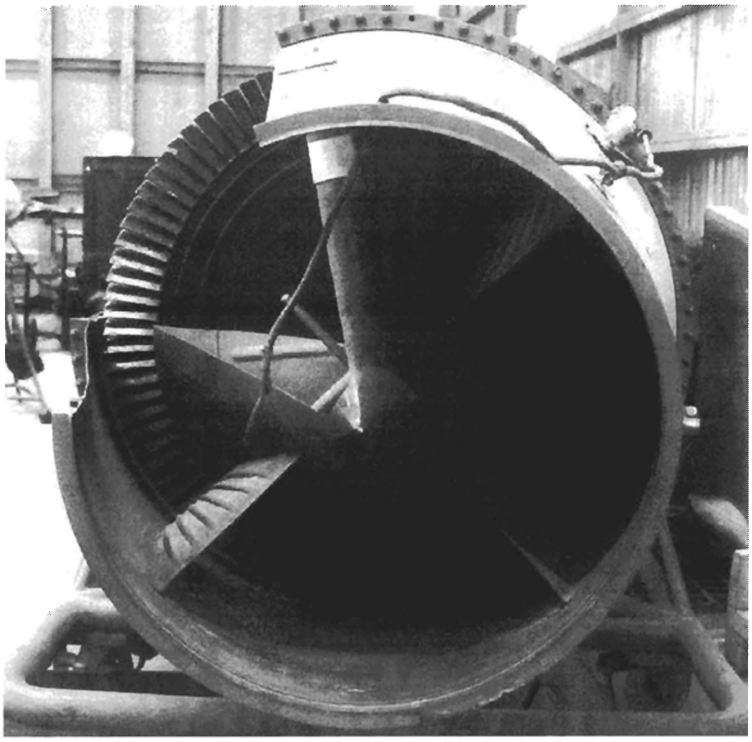


Figure 7.2: A sectioned view of the inner cone and supports

Exhaust Duct (Tail Pipe or Jet Pipe)

This parallel pipe is of variable length depending on the position of the engine in the aircraft. As it is parallel it has no significant effect on the gas flow, but extends the exhaust system clear of the aircraft structure. The length may vary from zero to several metres. The pipe could be used to house the thrust reversers and/or reheat system if fitted, and/or act as a silencer.

Subsonic Nozzles

The nozzle is fitted at the final end of the exhaust duct and for **subsonic aircraft it will be CONVERGENT in shape.**

The velocity of the turbine discharge gases is relatively low but it is increased before they are discharged to atmosphere from the exhaust nozzle. This convergent duct converts much of the heat and pressure energy in the gases into kinetic energy. The gases thus leave the nozzle at high velocity (near sonic).

The area of any exhaust nozzle is important, because this dictates the efficiency with which thrust is produced. The area is dependant on turbine discharge conditions and is fixed by the engine manufacturer, although is sometimes adjustable. In any event the maximum velocity across a convergent nozzle will be Mach 1.0 as a shock wave will form at the throat of the nozzle and thus limit the velocity.

Adjustable Nozzles

Sometimes engines are "trimmed" to their correct operating speed-temperature relationship by slightly changing the nozzle area, either by adjustable tabs or moveable plates known as eyelids.

Low Bypass Exhaust Mixer

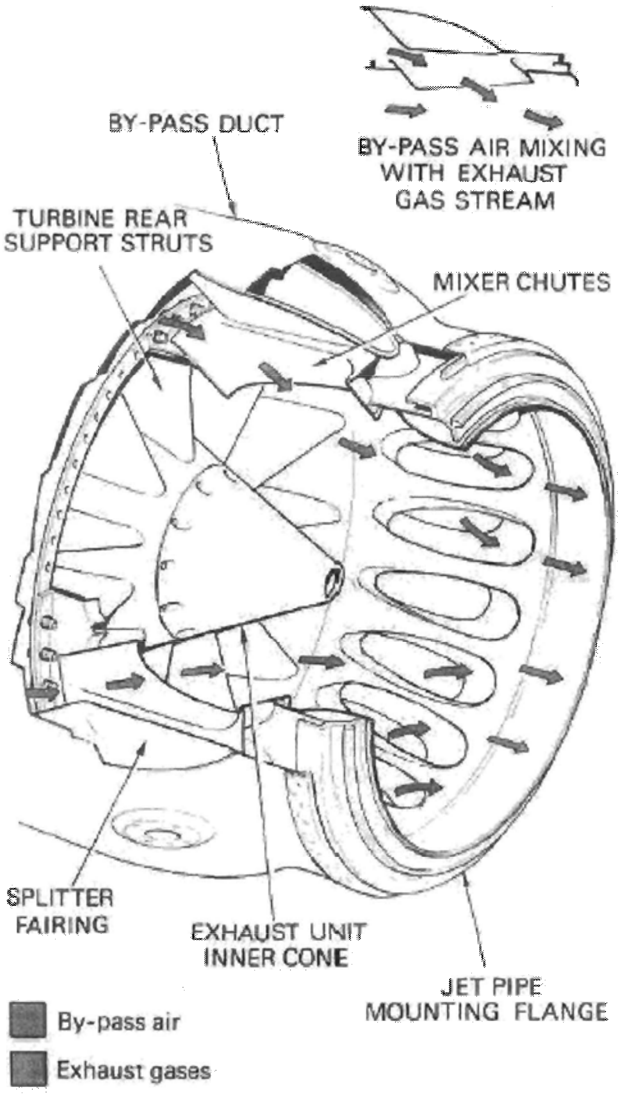


Figure 7.3: Low bypass exhaust mixer

In a low bypass engine the bypass flow is mixed aft of the last stage of turbine. This achieved by ducting the bypass air into the hot stream through a series of mixer chutes. The gas then flows as one down to the exhaust nozzle through the jet pipe. This arrangement is commonly used when a reheat system is fitted in the jet pipe.

High Bypass Engine Exhaust Systems

There are two types of high bypass exhaust system. Internally or externally mixed. The internally mixed system utilises a common exhaust nozzle assembly.

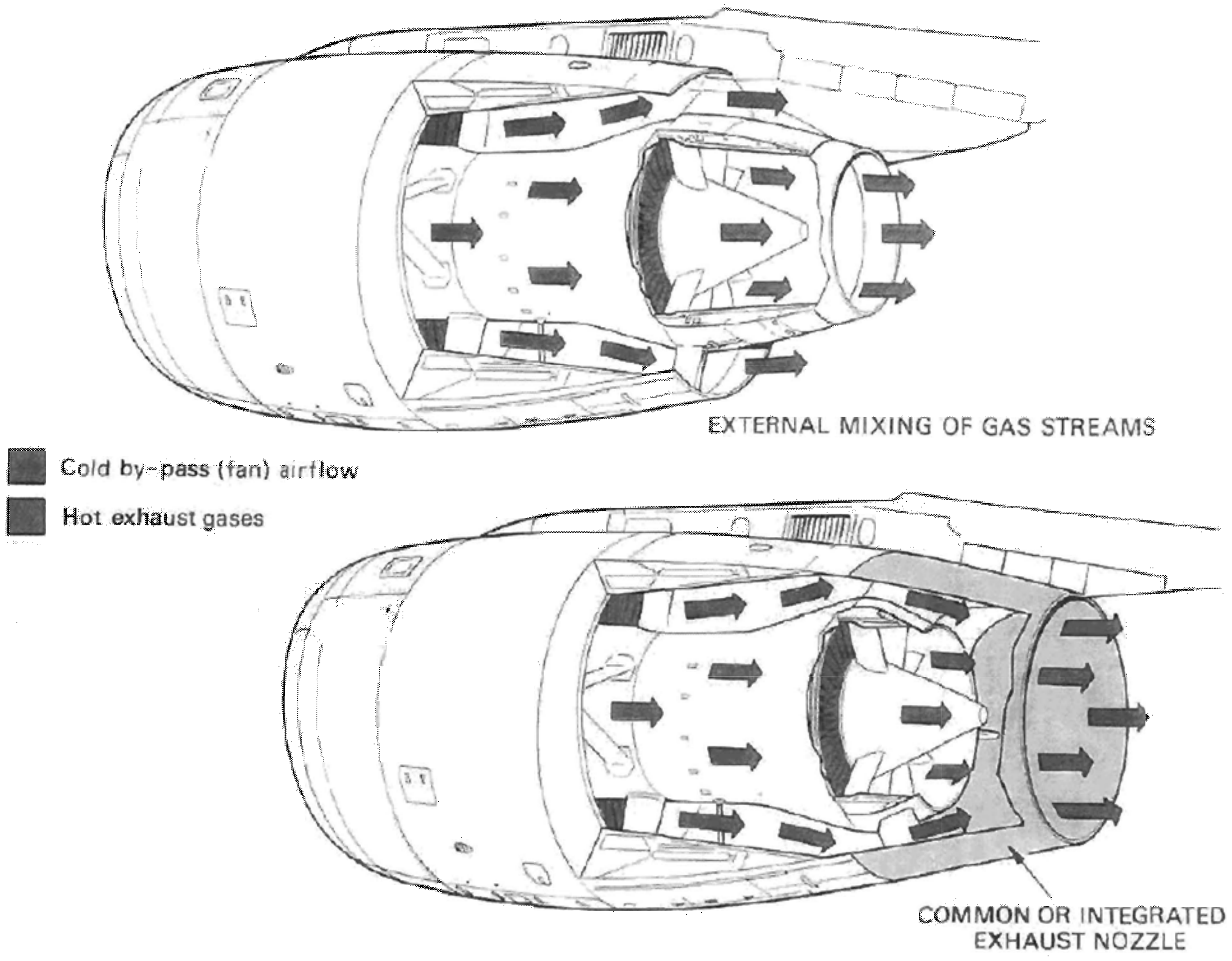


Figure 7.4: External and internal exhaust mixing of a high bypass engine

Supersonic Nozzles

The gas exit velocity in a convergent nozzle is subsonic only at low thrust conditions. At normal thrust levels the gas velocity at the nozzle reaches Mach.1 (in relation to the gas temperature).

When the gas velocity is Mach.1 the nozzle is said to be **choked** and no velocity increase is possible without increasing the gas temperature. When the nozzle is choked, upstream pressures are increased above atmospheric. This pressure differential provides **PRESSURE THRUST** in addition to the normal **KINETIC THRUST** in the way described in section 1.

To maximise the effect of pressure thrust a convergent/ divergent nozzle is utilised. For this to be effective however the pressure ratio of jet pipe to atmospheric must be greater than 1.4: 1 as the extra weight of the convergent /divergent nozzle outweighs the gain of the pressure thrust.

Convergent Divergent nozzles are not normally used on commercial passenger transport aircraft, rather they are seen on rockets, space transport and supersonic gas turbine engine s that utilise reheat.

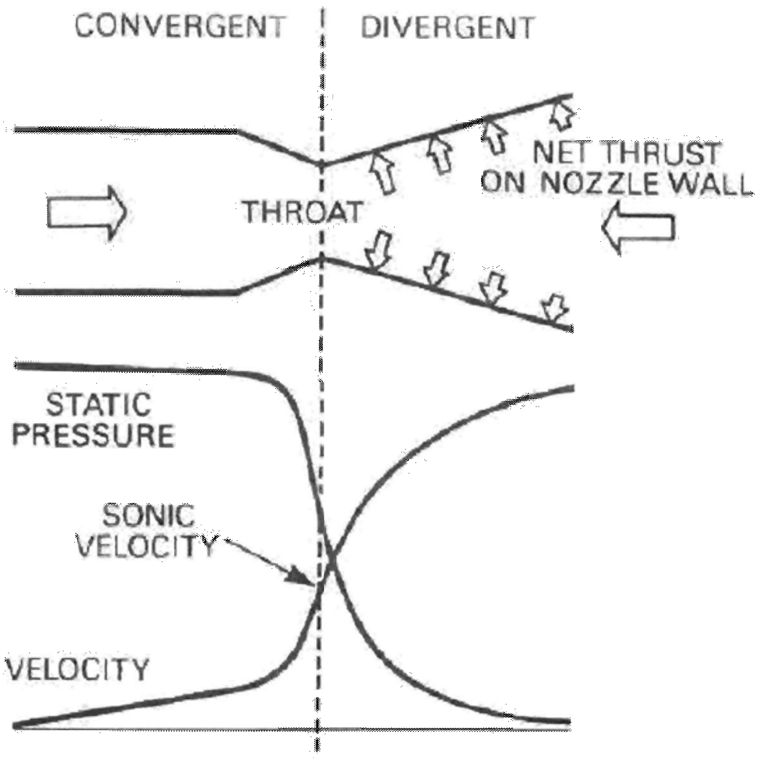


Figure 7.5: Convergent - Divergent nozzle Pressure / Velocity distribution

Materials

The exhaust system is subjected to high gas temperatures therefore it is manufactured from nickel alloys or titanium. In addition further insulation is required usually in the form of a insulating blanket consisting of a corrugated skin of stainless steel filled with a fibrous insulating material.

In the event of extra cooling being required the jet pipe may be double skinned and cooling air is passed between the skins. The hot exhaust gasses induce a flow through this annulus and keep the outer skin cool.

The combined nozzle assembly used in some high bypass engines is made from a bonded honeycomb structure to reduce the weight whilst retaining strength of this large component.

Noise Suppression

Noise in a gas turbine engine primarily emanates from two sources:

- Fans, compressors turbines
- the mixing of jet efflux with the cold ambient air

A turbo prop does not have a large jet efflux, but it does have a large unducted propeller. It is the propeller that makes most of the noise in this case.

This section concentrates on noise suppression in thrust producing engines, as they are by far the biggest culprits!!

Compressor and Turbine Noise

Compressor fan and turbine noise results from the rolling vortexes produced by the rotating blades interacting with the stationary vanes. Noise reduction strategies involve the use of honeycomb noise resistant materials being used in intakes and casings. Invariably they are honeycomb materials; the actual materials used depending on weather it is a hot or cold section of the engine. Lightweight composite materials are used in the lower temperature regions and a fibrous metallic material at the hotter end of the engine.

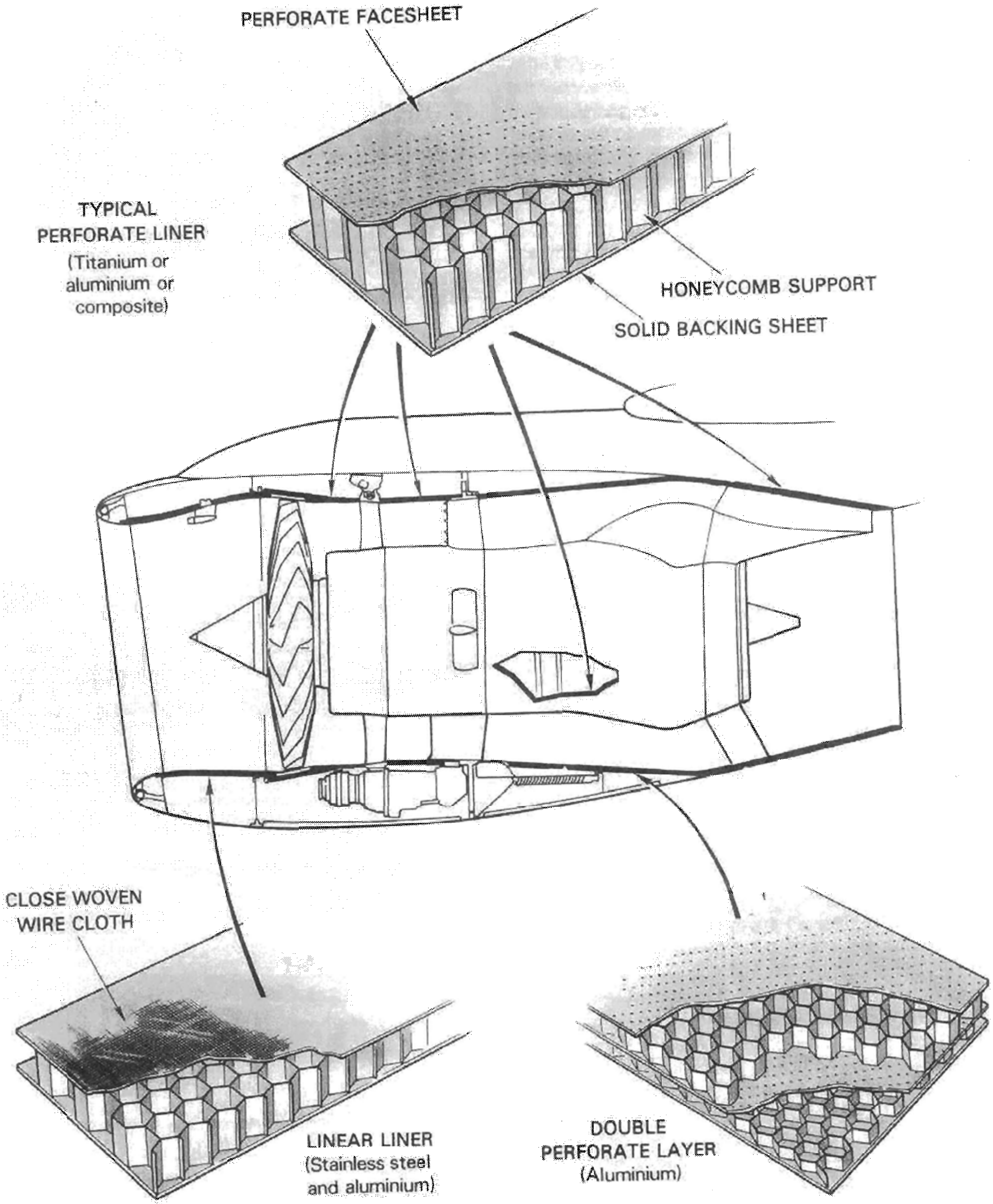
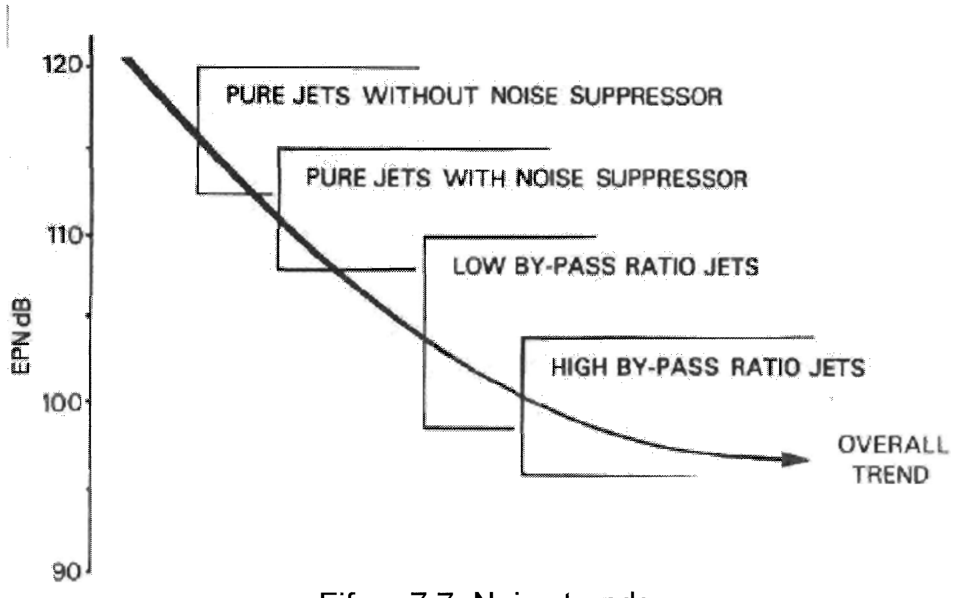


Figure 7.6: Noise absorbing materials and location



Fifure 7.7: Noise trends

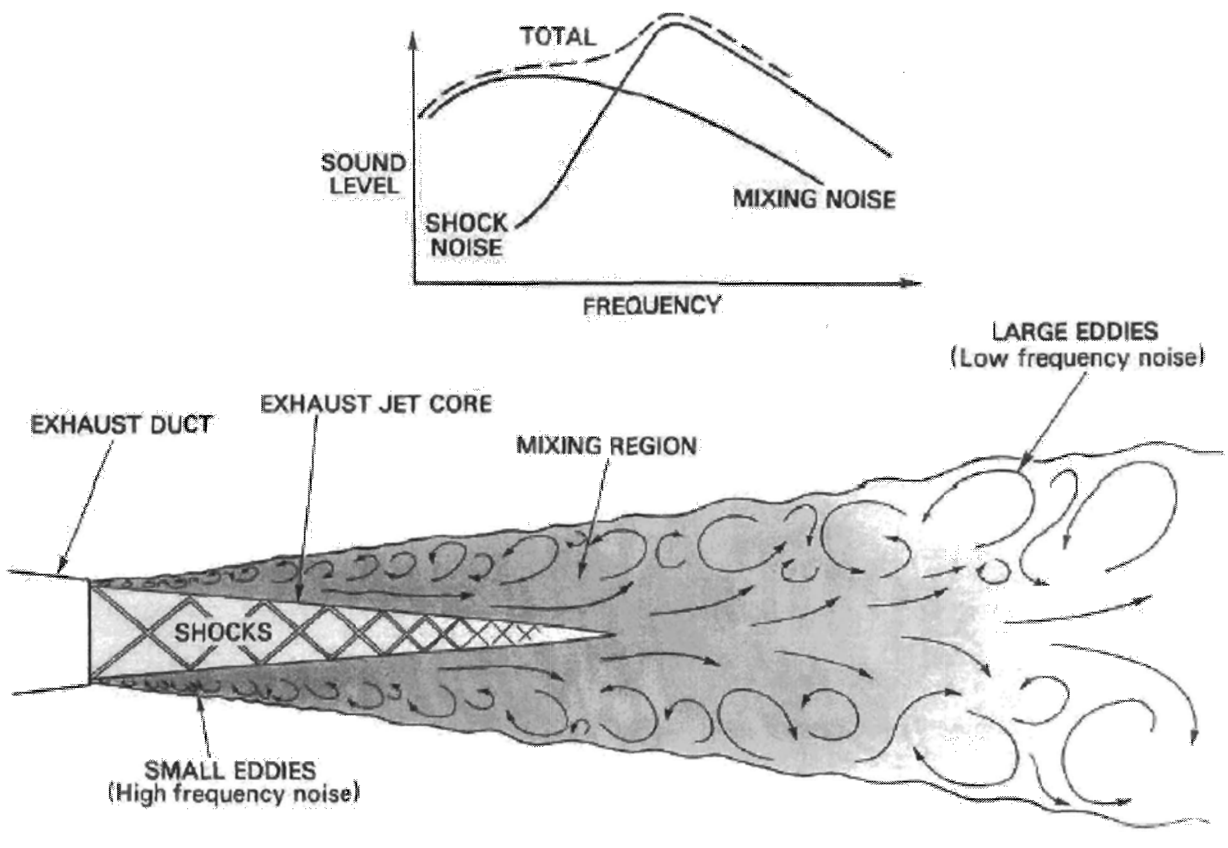


Figure 7.8: Exhaust Mixing

Exhaust Mixing

The hot gasses of the exhaust mixing with the cold ambient air cause jet exhaust noise. The hot gas has a high turbulence and the eddies and vortexes release large amounts of energy as they are cooled and slowed by the cold air. This manifests itself in the form of noise. The noise is worsened if shock waves are being formed in the exhaust. To reduce the noise levels the mixing rate has to be accelerated or the jet velocity must be reduced.

To increase the mixing rate a variety of lobe and mixer nozzles are employed. To reduce the gas flow the nozzle cross sectional area may be increased.

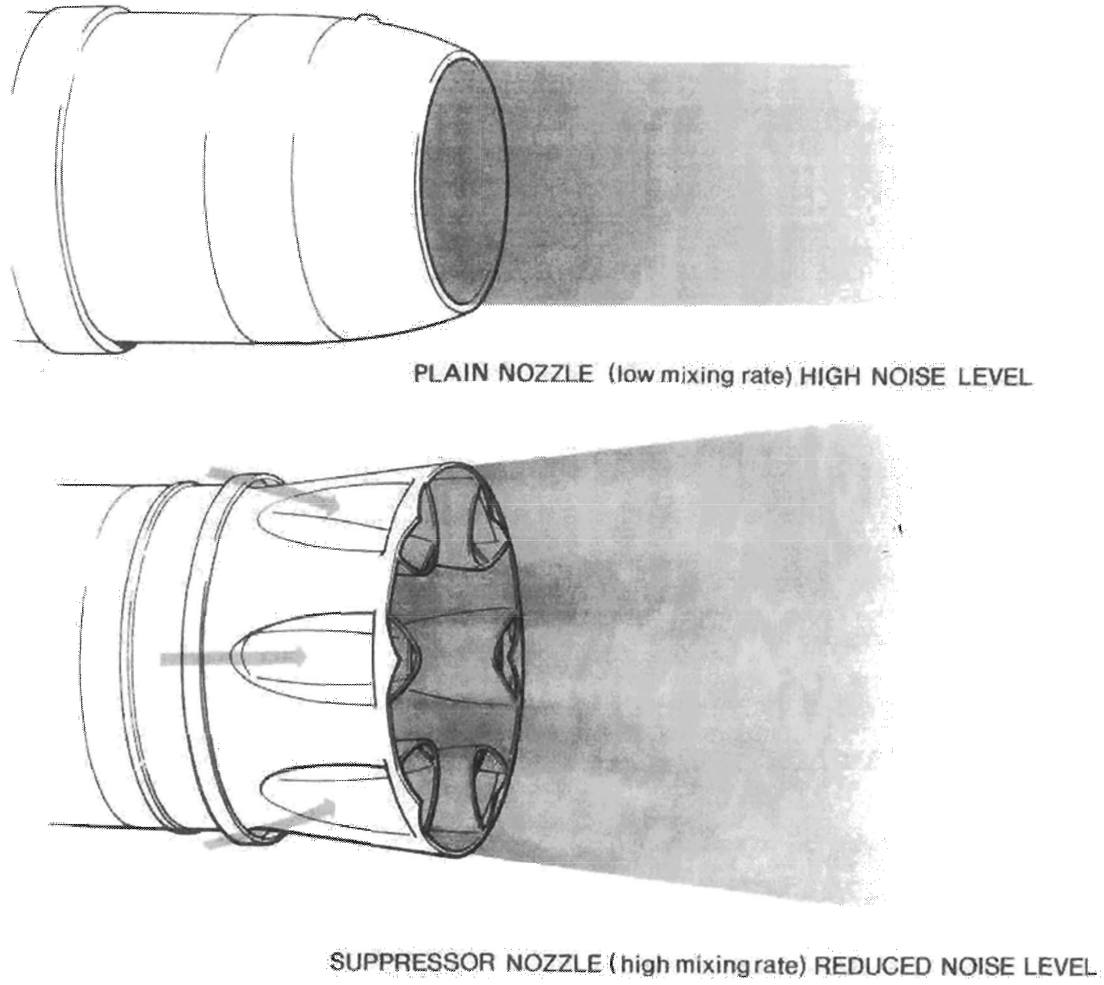


Figure 7.9: A plain nozzle and a noise suppressing nozzle

It will be seen from the chart on page 8 that the high bypass engine is the most quiet compared to the other thrust producing engines. This is because 80% of air is not heated and this cold stream envelops or mixes with the small hot stream.

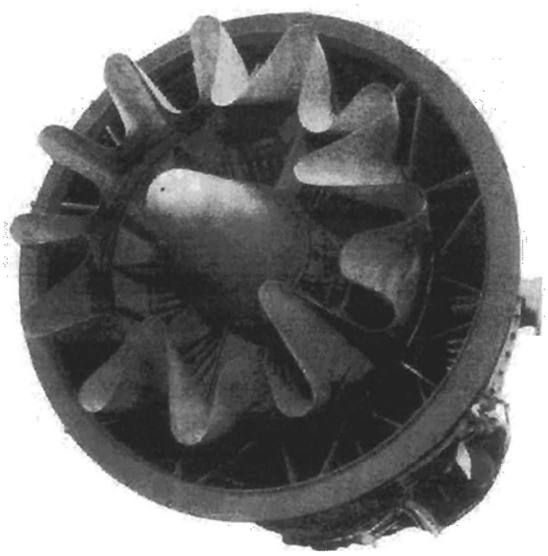
This is so effective that the fan is now the predominant source of noise and acoustic linings are used in the engine intake and around the fan.

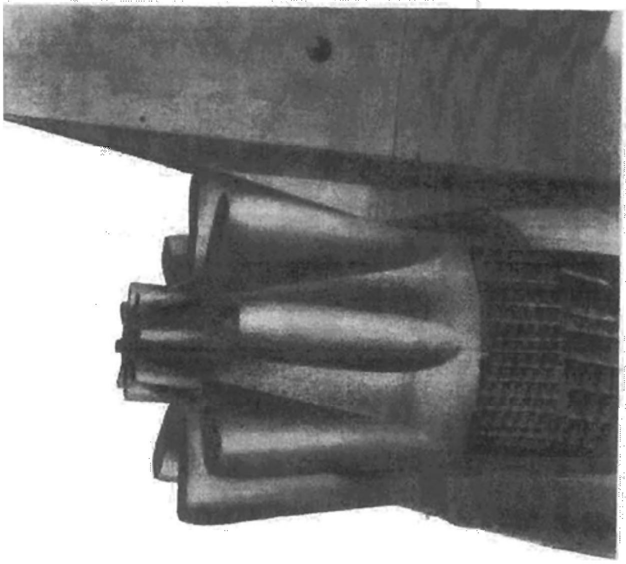
Lobes and Corrugations

Nozzle lobes and corrugations decrease noise output by increasing the shearing area between the exhaust gas and the outside air.

Deep corrugations, lobes, or multi-lobes give the largest reduction in noise level, but performance penalties limit the depth or number of corrugations or lobes.

The same overall area as the basic nozzle must be kept, so when using this method, the final diameter of the suppressor may have to be increased causing excessive drag and weight results.


CORRUGATED INTERNAL MIXER


LOBE-TYPE NOZZLE

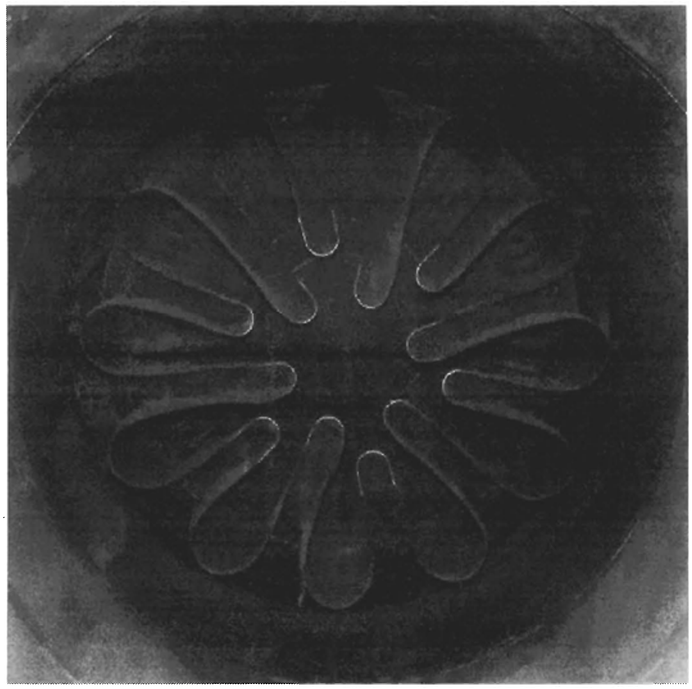


Figure 7.10: Exhaust lobes and corrugations

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Thrust Reversers

Purpose

Thrust reversers are commonly used in commercial aviation to:

1. Aid in braking and directional control during normal landing whilst reducing normal brake wear.
2. Aid in braking during icy or wet runway conditions thus reducing the chance of aqua planning or skidding.
3. Reverse aircraft out of parking stands, however this is dangerous due to the possibility of hot gas and FOD ingestion. This is now rarely seen.

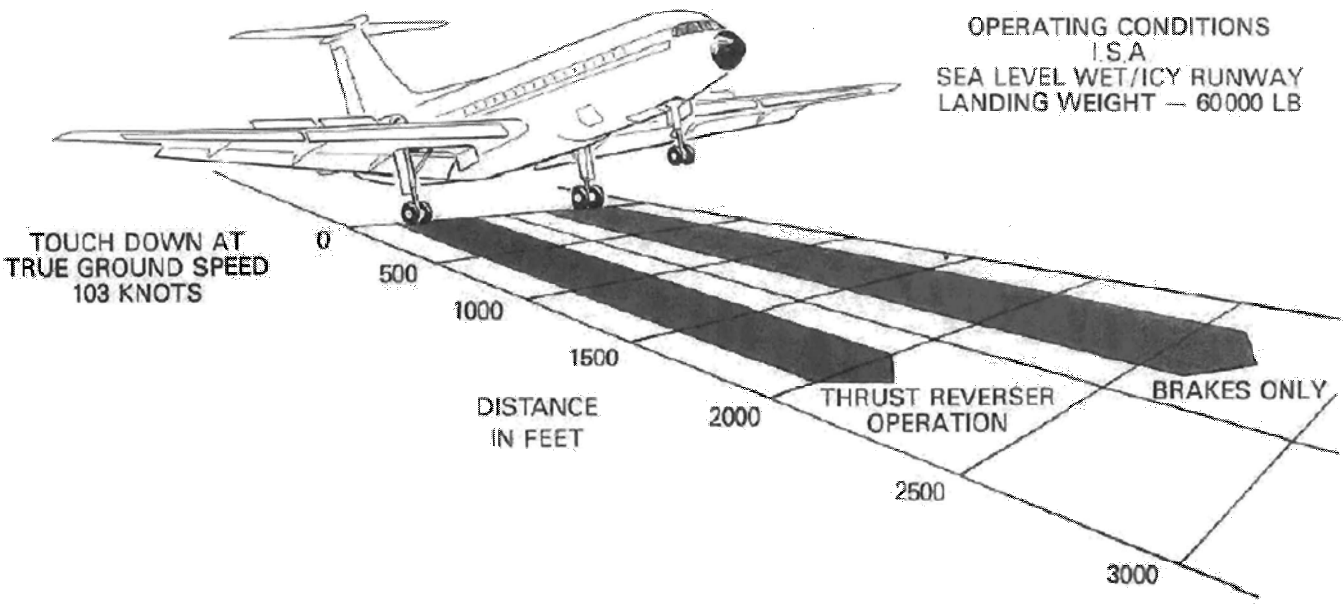


Figure 7.11: Braking benefit of thrust reverse

Thrust reversers generally rotate the airflow through 135°. The air now being directed 45° forward. Reverse thrust in turbo jets is limited to about 80% power, less in some high bypass engines, due to the structural limitation of the reversers.

Thrust Reverser Variations

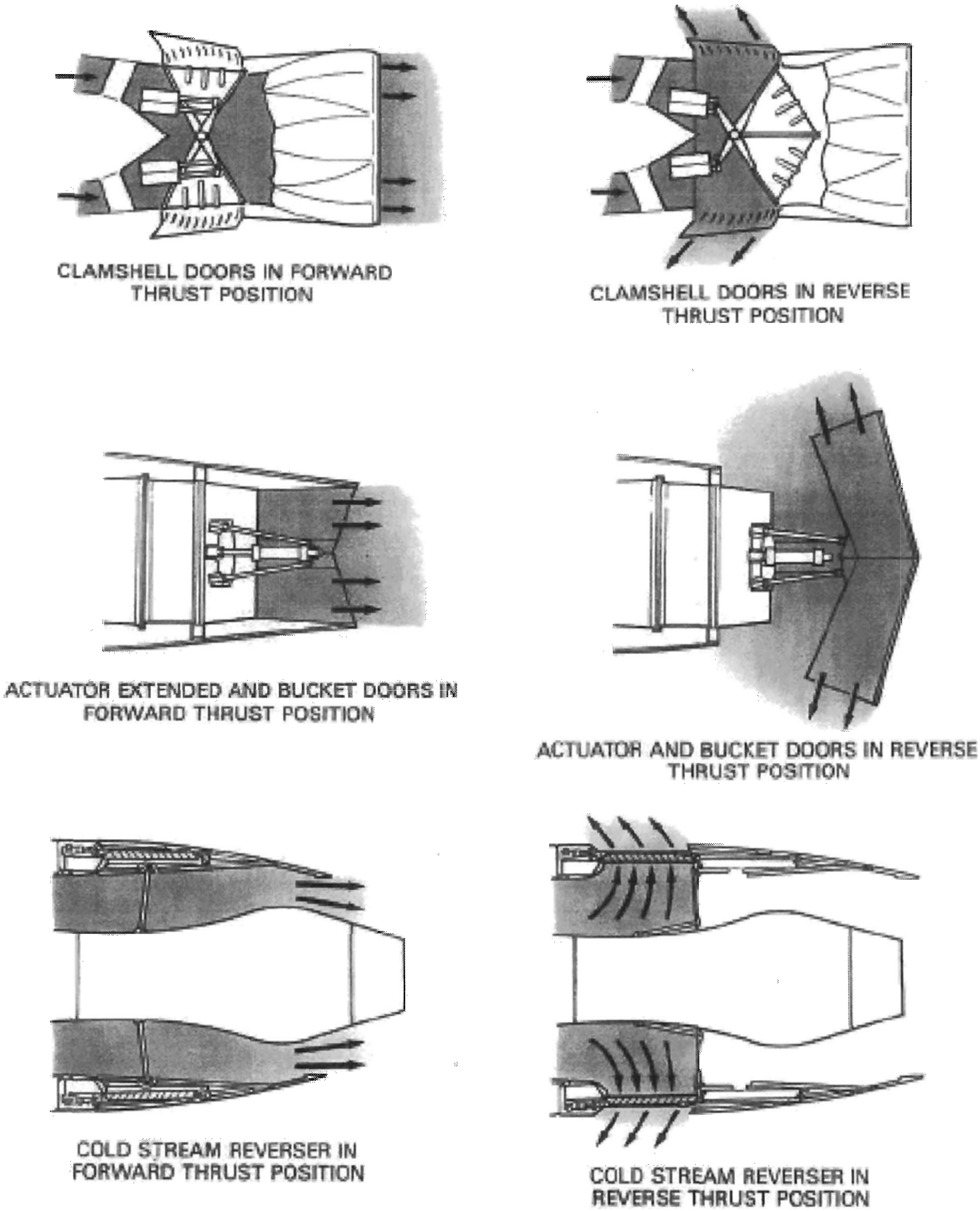


Figure 7.12: Three types of thrust reverser

Clamshell Door Thrust Reverser
Clamshell doors are used on pure jet and low bypass engines, rotating the complete gas flow.

Exceptionally clamshell doors are used to deflect the hot stream of a high bypass engine in addition to the cascade vane and blocker doors in the cold stream. (Boeing 727 JT8D).

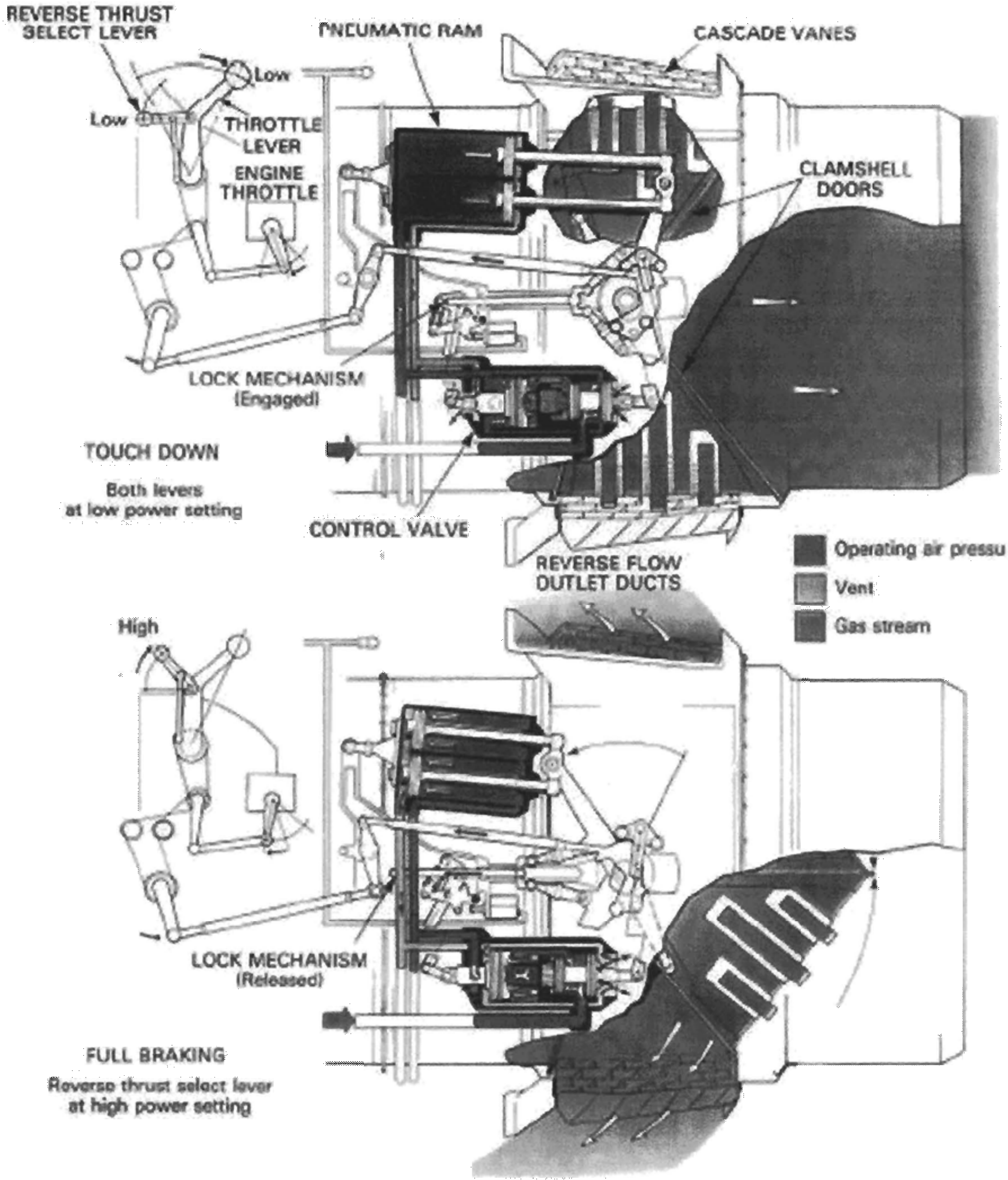


Figure 7.13: Clamshell thrust reverser system

Bucket Doors

Bucket doors are a variation on the clamshell door system, the difference being that the doors are totally external. These are usually seen on smaller gas turbine engines particularly those fitted to executive jet tail mounted engines.

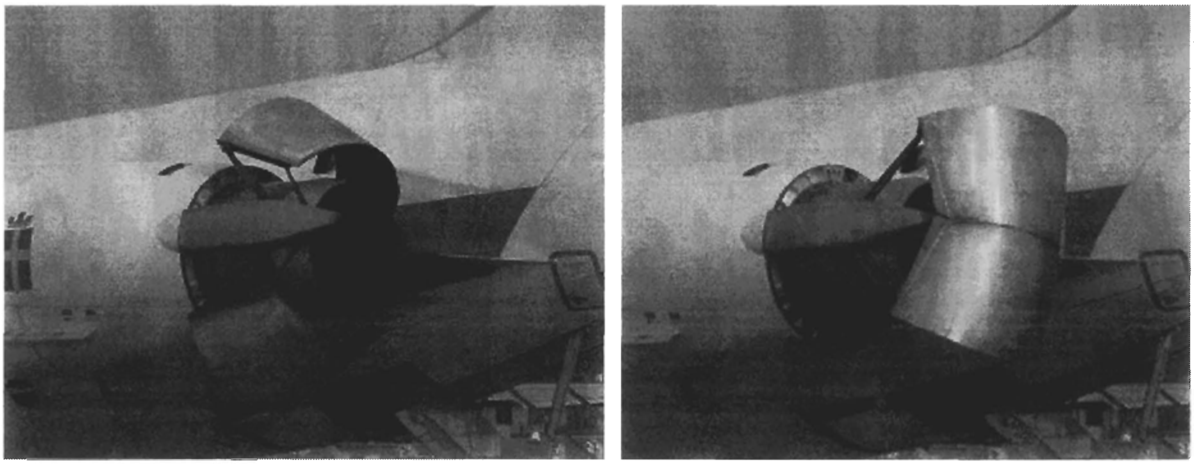


Figure 7.14: Bucket door thrust reversers in operation

Cascade Vanes and Blocker doors

The most common system in use for current high by-pass engines is the cascade vane and blocker door system. Actuated either by hydraulics or aircraft pneumatics. A translating cowl moves aft on either side of the engine C duct revealing a series of cascade vanes. As the translating cowl moves rearward a linkage deploys blocker doors in the cold stream duct. These doors block the aft movement of the air and it is rotated forward through the cascade vanes. Note that the hot stream gas is totally unaffected by this system, but as it only supplies 20% of thrust this is not a problem.

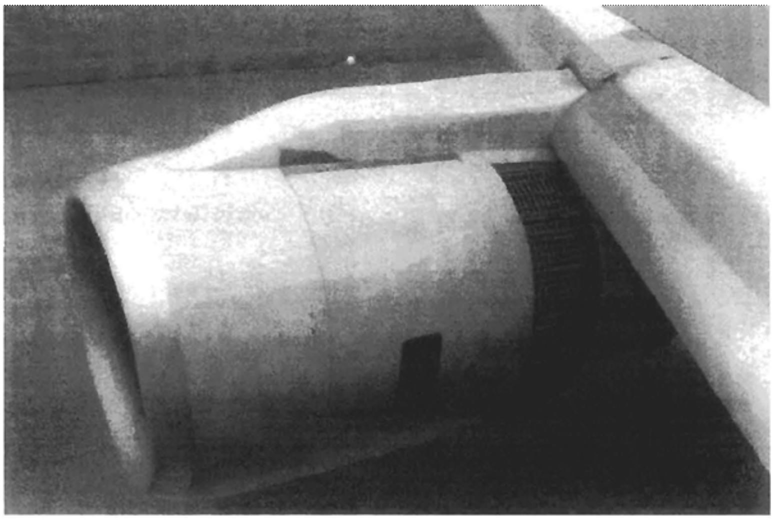


Figure 7.15: Thrust reverser translating cowl pushed back revealing the cascade vanes

In all of the above systems the air is deflected forward about 45°.

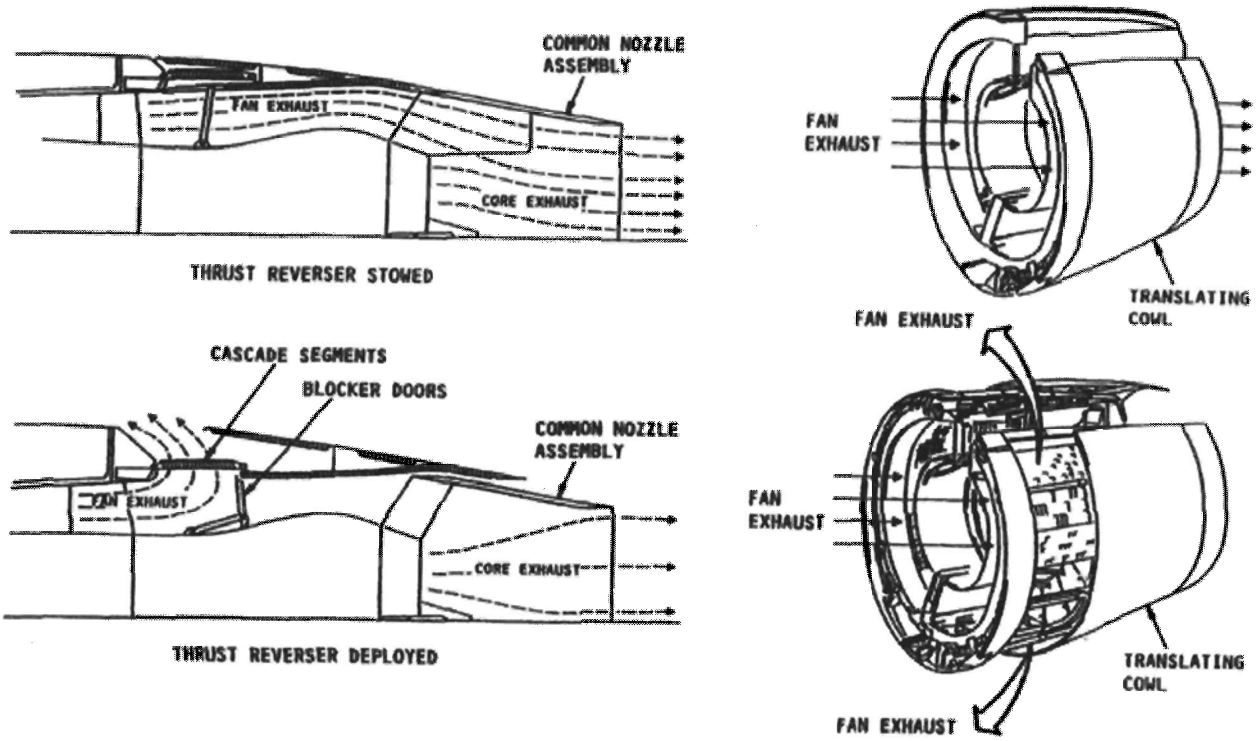


Figure 7.16: Cascade vane reverser system

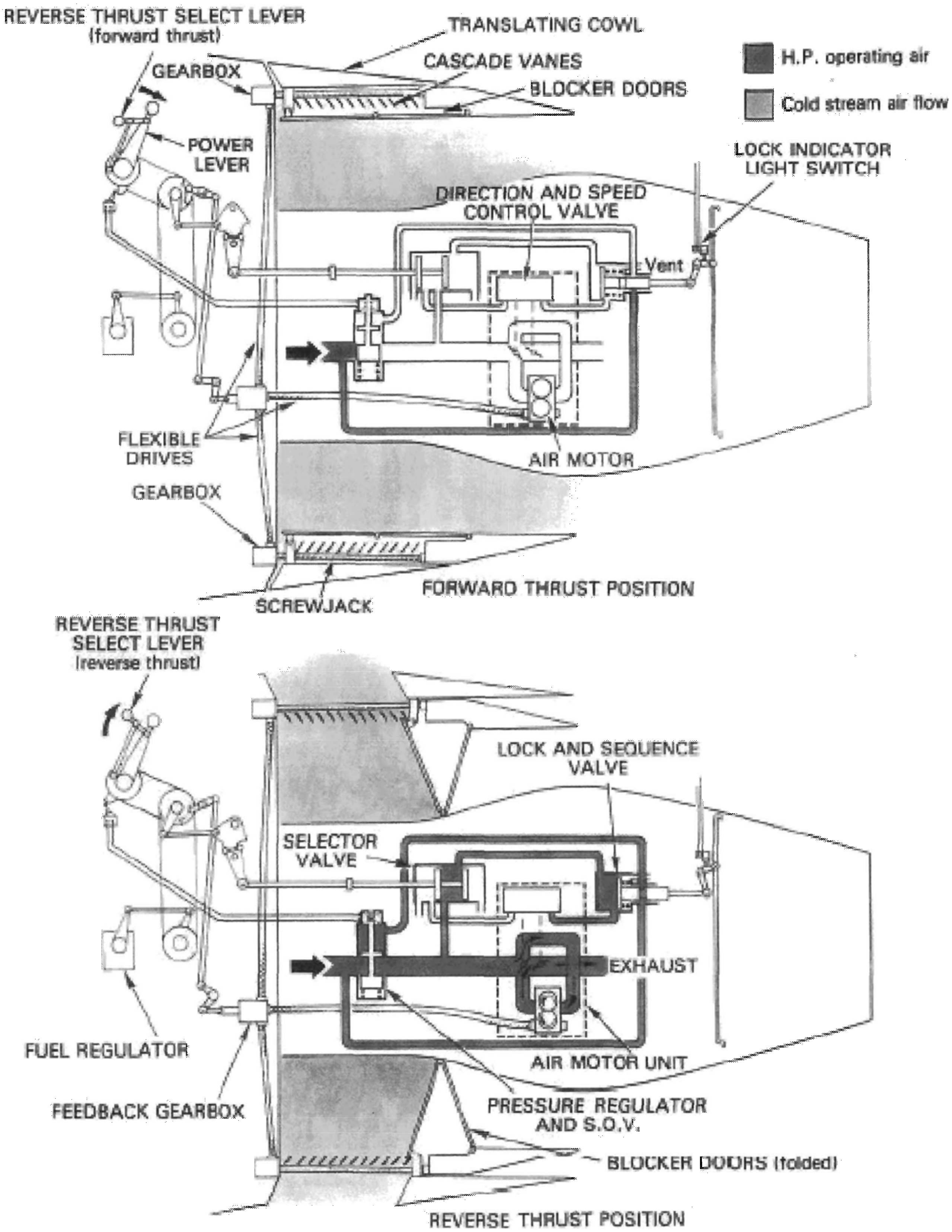
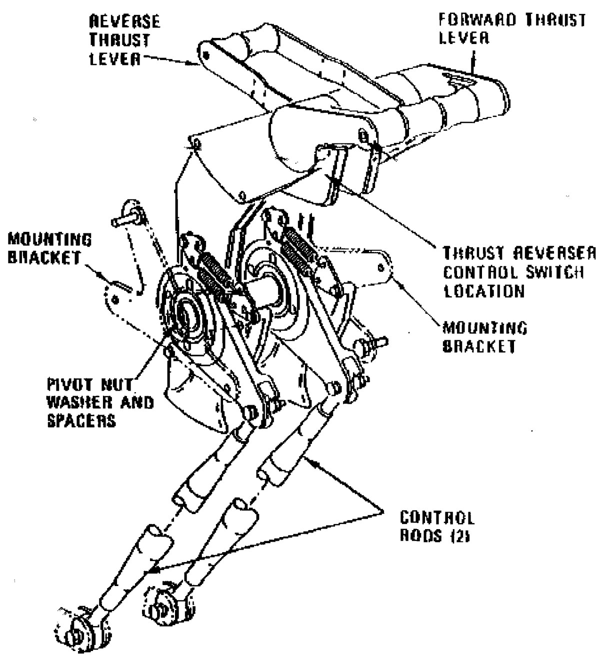


Figure 7.17: Cascade vane reverser system

Reverse Thrust Control

Reverse thrust is selected in the cockpit by a lever mounted forward of the throttles. The initial movement aft of the lever to a fixed detent deploys the reverser, the detent is then removed and continued movement of the lever accelerates the engine to a reverse thrust maximum which is less than max power, due to the structural limitations of the reverser system. An interlock is fitted to prevent forward thrust being applied when reverse is selected and vice-versa.

All commercial passenger transports have at least three levels of safety to prevent inadvertent deployment in flight.



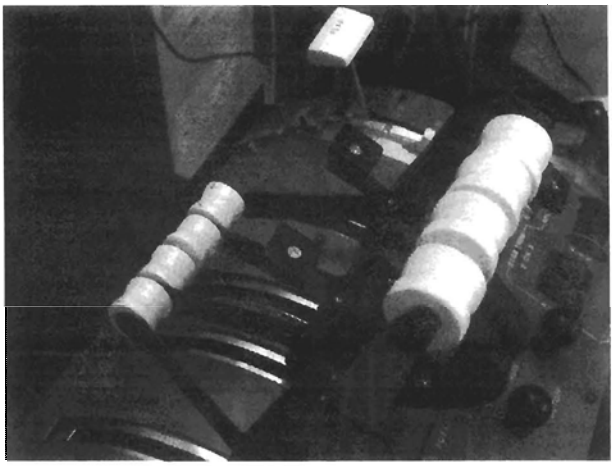


Figure 7.18: Thrust reverse lever mechanism

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.8 Bearings and Seals

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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.

Table of Contents

Module 15.8 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 Reference**	**Level**
		B1
Bearings and Seals	15.8	2
Constructional features and principles of operation.		

Module 15.8 - Bearings and Seals

Bearings

The main bearings of a gas turbine engine are either ball or roller anti-friction types. Ball bearings ride in a grooved inner race and support the main engine rotor for both axial (thrust) and radial (centrifugal) loads. The roller bearings ride on a flat inner race. Because of their greater surface contact area than the ball bearings, they are positioned to absorb the bulk of the radial loading and to allow for axial growth of the engine during operation. For this reason, tapered roller bearings are seldom used

Plain bearings are not used as main bearings in turbine engines, as they are in reciprocating engines, because turbines operate at much higher speeds and friction heat buildup would be prohibitive. Plain bearings (bushings), however, are used in some minor load locations such as in accessories.

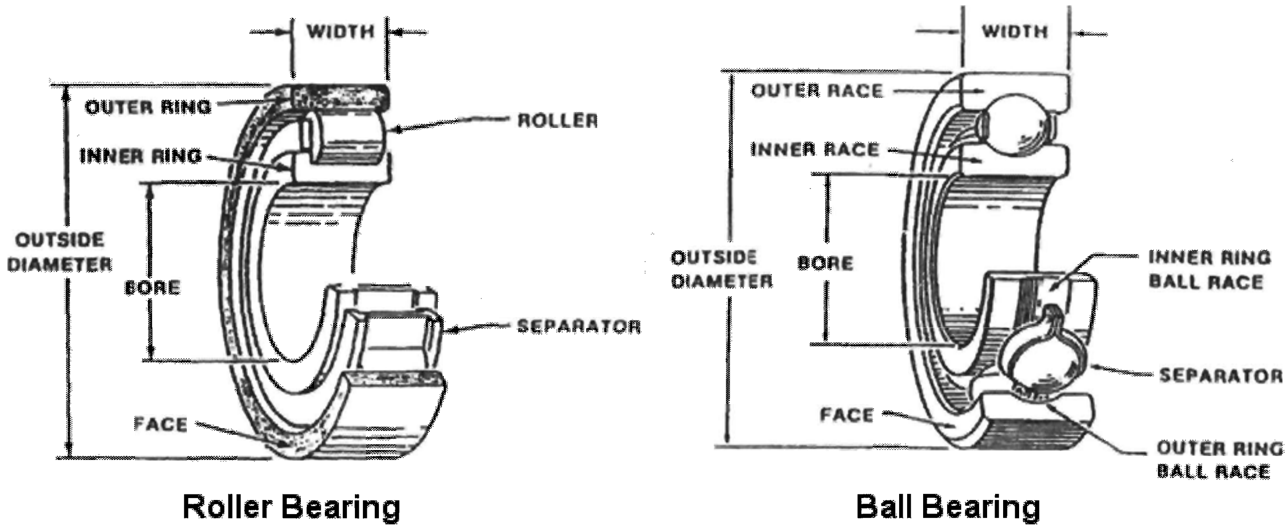


Figure 8.1: Roller and ball bearings

Vibrations induced by the airstream, the aircraft and the engine itself.

The main bearings support the rotor assemblies and then transfer the various loads through the bearing housings and support struts to the outer cases of the engine, and ultimately into the aircraft mountings.

The number of main bearings varies from one engine model to another. One manufacturer might prefer to install three heavy bearings and another five or six lighter bearings to accommodate the same load factors.

Construction features of ball and roller bearings are shown above A design feature to note is that only one of the roller bearing races is grooved, allowing the roller freedom to move axially when the engine expands and contracts during operation. The split inner race is a design feature of the ball bearing which allows for ease of bearing disassembly, maintenance, and inspection, once the bearing is removed from the engine.

The inner races of bearings are normally interference fitted to the rotor shafts to prevent movement on the shaft, and have to be removed with special puller tools. Shown in the below diagram is the oil damped bearing which is provided with an oil film between the outer race and the bearing housing to reduce vibration tendencies in the rotor system and to allow for a slight misalignment of up to five thousandths of an inch.

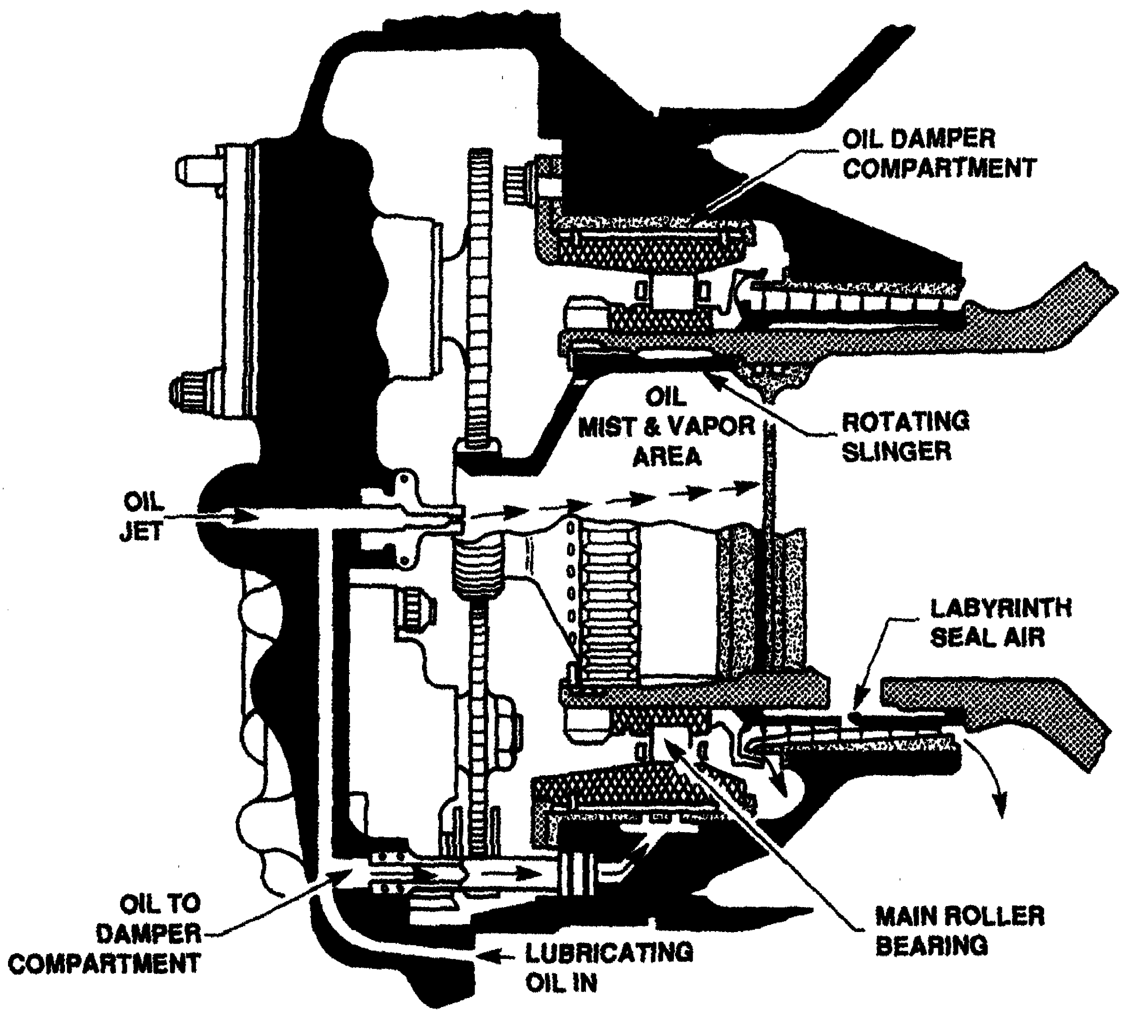


Figure 8.2: Forward compressor roller bearing with oil damped outer race

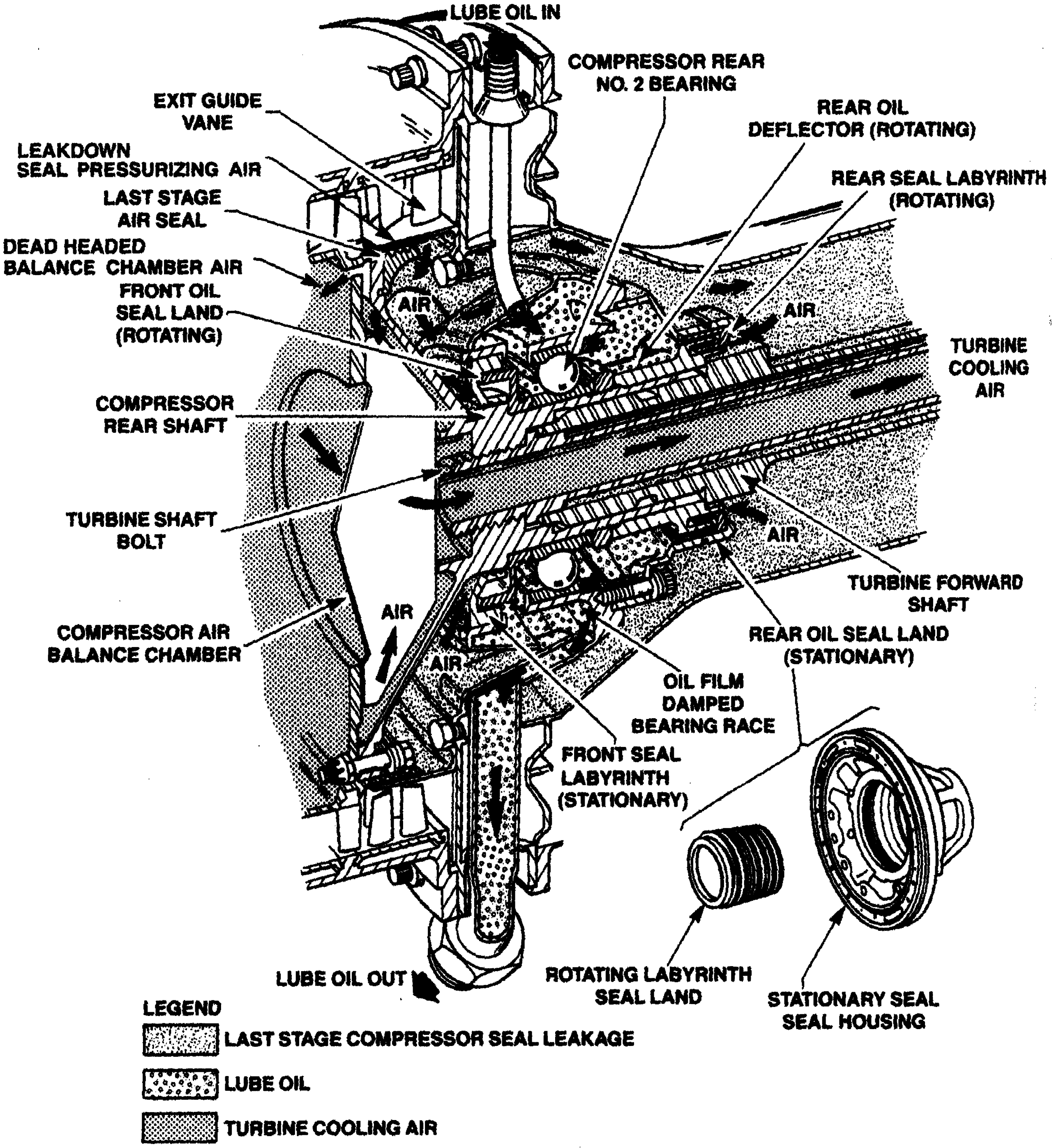


Figure 8.3: Compressor thrust bearing sump assembly

A Bearing Sump (or chamber) consists of:

The Bearing (A Ball or Thrust Bearing in this case)
An Oil Feed
An Oil scavenge
A Labyrinth Seal Arrangement
An Air Supply to pressurize the seal
Static Oil Seals
Pressure Balance Chambers

A Pressure Balance Chamber is used to assist the bearing to oppose the forward thrust on the compressor drum. Some engines do not need an air balance chamber because the opposite (rearward) thrust load, at the turbine, adequately cancels out the forward pushing loads on the compressor.

Seals

Bearing seals are usually of the labyrinth or carbon rubbing type. It is quite usual to see both in the same housing

Labyrinth Seals

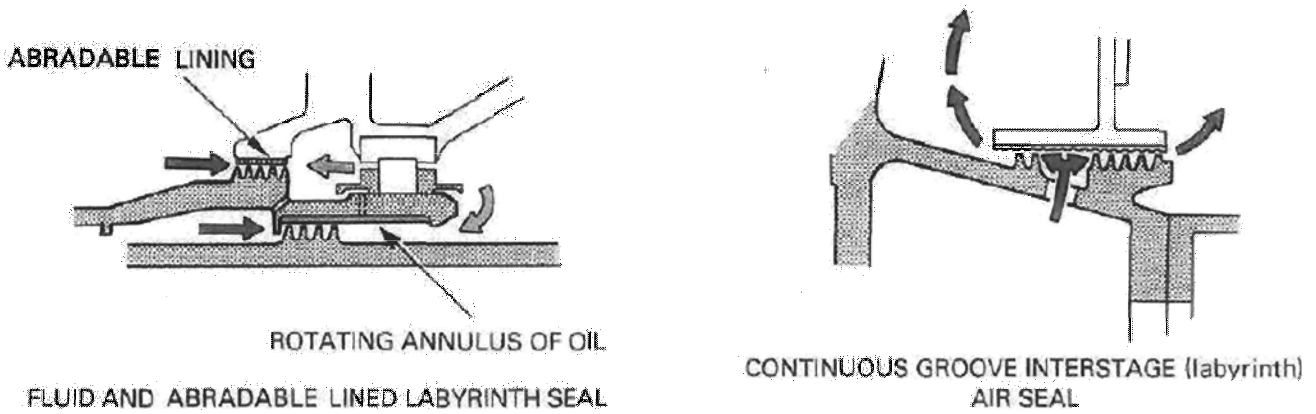


Figure 8.4: Types of labyrinth seal

The two labyrinth seals shown in Figure 8.5 form a compartment in which the bearing is housed. Air from the gas path that is present outside of the bearing compartment bleeds across grooves cut in the labyrinth seal into the bearing housing. These grooves form sealing rings in either a concentric path similar to a screw thread or a non-concentric path with each ring in its own plane. In any case the seal dams formed by the rings allow for a metered amount of air from the engine gas path to flow inward. Pressure within the bearing compartment is in most engines maintained slightly above atmospheric level.

The oil mist created by the oil jet spraying on the rotating bearing is prevented from exiting the bearing compartment by the air entering across the labyrinth seal. The seal pressurizing air then leaves the bearing area by way of the scavenge oil system. The balance chamber uses dead headed air pressure to push against the compressor, and prevent sudden thrust loads from being absorbed totally by the bearing when the engine power changes. Most higher compression engines are designed with a separate vent subsystem as shown in the figure opposite.

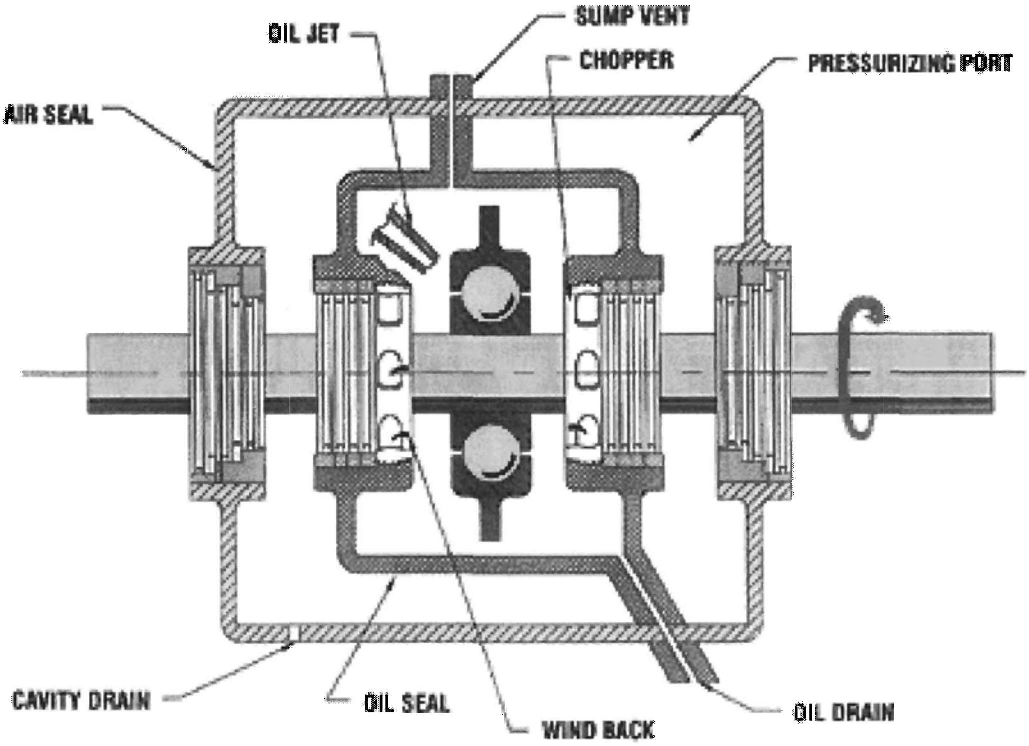
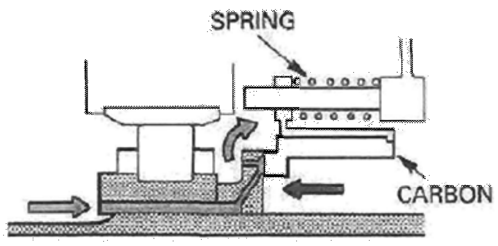


Figure 8.5: Bearing cavity sealed with 2 labyrinth seals

Carbon Seals

Carbon seals are a blend of carbon and graphite. They are similar in function and location to labyrinth seals but not in design. The carbon seal rides on a highly polished chrome carbide surface, while the labyrinth seal maintains an air gap clearance.



The carbon seal is usually spring-loaded and sometimes pressurized with air to create a uniform pressure drop across the seal. The pressurized air also preloads the carbon segment against its mating surface, and provides a more positive oil sealing capability.

Figure 8.6: Carbon seal assembly

The carbon seal shown is classified as a carbon-ring type seal which rides on a seal surface attached to a rotating shaft. Another common design is the carbon-face type seal.
It is similar to those used as drive shaft seals in many fluid carrying accessories. The carbon surfaces are generally stationary with their highly polished mating surface, called a seal plate or seal race, attached to and turning with the main rotor shaft.

The carbon seal will be found where a more positive control over airflow into the bearing sumps is required, or where a full contact type seal is needed to hold back oil which might at times puddle before being scavenged. Conversely, labyrinth sealing will usually be associated with oil system locations designed with higher vent subsystem pressures.

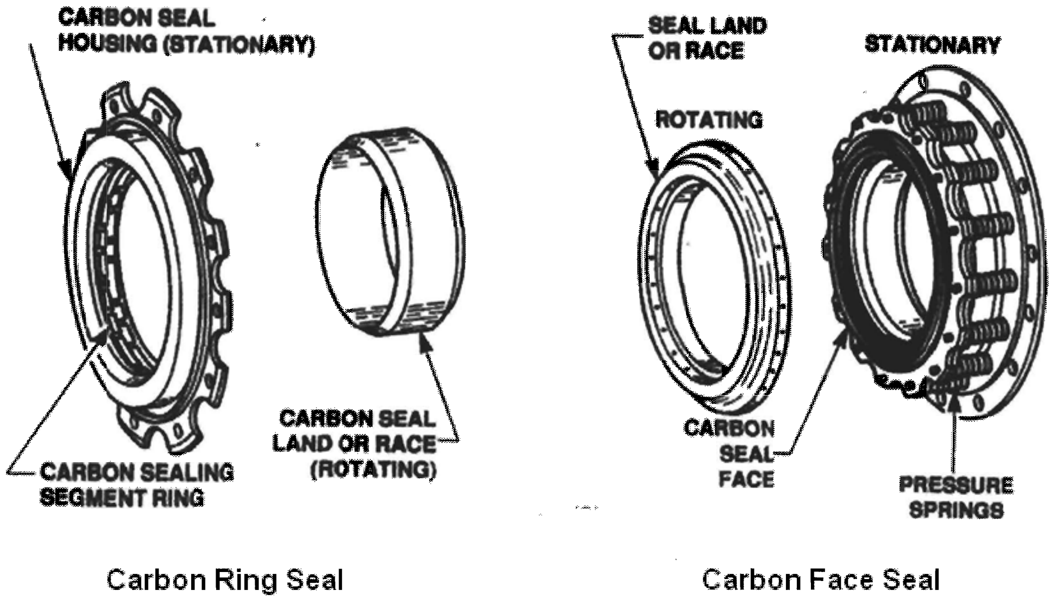


Figure 8.7: Carbon seals

Brush Type Seals

The brush seal shown below is becoming more widely used in gas turbine engines than previously. The seal acts like a labyrinth seal, in that it takes a pressure drop across the interface of the stationary bristle section and its rotating rub ring. Because the seals bristles maintain contact with its runner, its leakage rate is less than a labyrinth seal.

Whereas carbon seals wear due to axial and lateral shaft movement, brush seals do not, as after deflection the brush can reform on the rotating land.

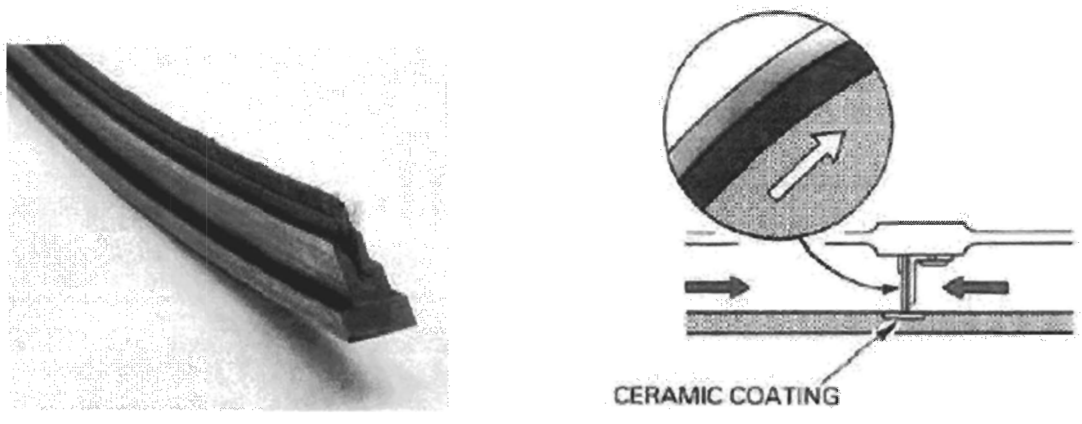
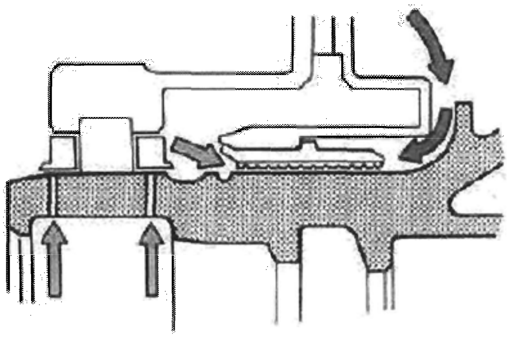
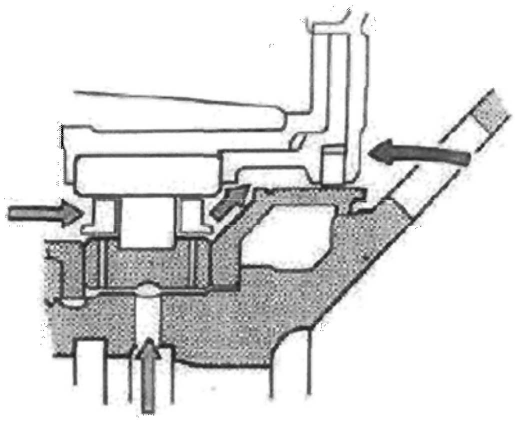


Figure 8.8: Crush type seals

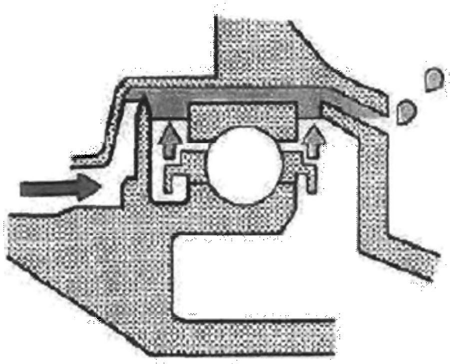
Other Types of Seal



THREAD TYPE (labyrinth) OIL SEAL



RING TYPE OIL SEAL



INTERSHAFT HYDRAULIC SEAL

Figure 8.9: Other types of seals

TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.9 Lubricants and Fuels

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

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Table of Contents

Module 15.9 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 Reference	Level B1
Lubricants and Fuels	15.9	2
Properties and specifications;		
Fuel additives;		
Safety precautions.		

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Module 15.9 – Lubricants and Fuels

Lubricants

Introduction

The correct type of oil must be used for its specific purpose, therefore you must be able to identify a particular lubricating oil. To this end you will need to have a knowledge of the function of particular additives which are used in certain oils. It is important that you are also aware of the general servicing procedures covered in this booklet. The booklet then deals with contamination of lubricating oils and how such contamination is dealt with.

Sources Of Supply

There are three main sources from which lubricating oils can be obtained:-

Mineral,
Vegetable,
Synthetic.

Mineral

The Source for these oils is refined crude oil.

Vegetable

The source of these oils is vegetable in origin, e.g., castor oil, olive oil. Note that vegetable oils are not used on gas turbines.

Synthetic

These oils are obtained from various sources. e.g. fatty acids and esters. Esters are compounds of alcohols and acids.

Synthetic lubricating oils are now used on all modern gas turbine engines.

Lubrication

This is a procedure for reducing friction and wear by keeping close fitting moving surfaces apart, this is achieved by maintaining a film of oil between them. The film of oil may be very thin but providing it has a good viscosity, strength and oiliness such that it can keep a film on the moving surfaces, it will keep them apart. Lubrication is divided into:

Film lubrication,
Boundary lubrication.

Film Lubrication

In this type of lubrication a measurable quantity of oil is maintained on the bearing surfaces. This is considered the ideal form of lubrication which engineers and designers try to maintain.

In this form of lubrication the oil comprises three distinct layers, with the two outer layers clinging to their respective surfaces. The central layers consists of molecules of oil which are continually being torn apart from each other or 'sheared' as a bearing or shaft rotates. The thinner the oil, then generally the greater the ease with which shearing can take place. This is an important factor when starting an engine in cold climatic conditions or at altitude, as apart from the factors of lead and speed of bearing surfaces, the thickness or viscosity of an oil will affect its operating efficiency.

An ideal lubricating oil will be one which is fluid at low temperatures, but which resists the tendency to thin out at high operating temperatures. When an oil thins out excessively the three layers of oil are squeezed out from between the bearing surfaces, and fluid lubrication ceases. An intermediate state is reached before the oil is squeezed out completely, this is known as 'boundary lubrication'.

Boundary Lubrication

In this situation the oil film between bearing surfaces is only a few molecules thick. Under these conditions viscosity is not the important factor, the important factor is 'oiliness" of the oil. This is the ability of the oil molecules to cling together and stick to the bearing surfaces. This factor will be mentioned again when we deal with additives later on.

Property of Oils

The properties required of a gas turbine lubricating oil are that it:

Wets the surfaces needing lubrication , i.e., it has 'oiliness',
Possesses a stable viscosity,
Does not evaporate excessively in use,
Does not injure any material with which it comes into contact,
Must be chemically stable under all working conditions,
Should not be highly flammable,
Should not gum or slude up during its working life,
Should be reasonably safe to handle.

Oiliness

This is the property of the oil to cling to the bearing surfaces.

Viscosity

This is a measure of an oil's internal friction or resistance to flow. An oil which flows freely is said to have a low viscosity. An oil which is sluggish has a high viscosity.

Determining Viscosity

There are various methods for measuring the viscosity of an oil. Viscosity is 'Strokes'. This is a large unit which is divided into 100 parts referred to as centistokes. Under the CGS unit system (centimeter/gramme/second) we refer to an oil's viscosity as being so many centistokes, written (cS).

Example, turbine engine oils are generally in the 2 to 7 cS range.

Note that in the case of SI units the oil's viscosity is given in mm^2/s at a given temperature. ($1\ mm^2/s = 1cS$).

Evaporation

The evaporation of most turbine oils is very low even at fairly high temperatures. The flash point, i.e., the temperature at which a turbine oil gives off sufficient vapours capable of being ignited, is higher than its working temperature.

Example the flash points of most turbine lubricating oils are between 100° C and 260° C.

Damage to Materials

Synthetic turbine oils will attack certain materials. Some of the materials in common use which must not be allowed to come in contact with synthetic turbine oils are:

Natural rubber,
Neoprene,
Pvc,
Perspex,
Certain types of paint finish

Compatible Materials

The following are some of the materials which are compatible with synthetic turbine oils:

Buna N,
Silicone Rubbers,
Thiokol,
Teflon,
Kel F,
Baked Phenolic Finishes,
Thermosetting plastics.

Chemically Stable

Synthetic turbine oils rely on additives to maintain chemical and thermal stability. In use oils should not:

Gum up,
Varnish,
Slude,
Oxidise.

It is the natural tendency of an oil to absorb oxygen and become thick and darken in colour, a property of an oil is that it should resist such oxidation.

Health and Safety when Handling

In general, synthetic turbine oils are only slightly irritant on contact with the skin, however prolonged contact may give rise to dermatitis. Precautionary measures must be taken to avoid personal contact and observe good by hygiene. If the oil contact the eye wash with water and obtain medical advice.

In the unlikely event of ingestion, give water to drink and do not induce vomiting, obtain medical advice immediately.

Oil Additives

The earliest gas turbine engines used straight mineral oils, but progressive development of the gas turbine to provide higher thrust, required a lubricant that was stable over a wide range of conditions and would not break down at high temperatures. So synthetic oils were developed. These first generation synthetic oils are referred to as 'Type 1' oils and are still used on some of the older gas turbine engines. These oils did not meet all the requirements for a lubricant for today's gas turbines, therefore, Type 2 oils were developed. This was done by adding small quantities of various compounds and elements to the basic synthetic lubricant.
Examples of Additives:

Some or all of the following may be added in small quantities to an oil to give that oil some desirable property:-

Extreme pressure additive,
Anti-corrosion additive,
Detergent additive,
Inhibitors.

Extreme Pressure Additives

These additives would be added to an oil which is used in an engine where there are heavily loaded gear trains. Example, a turbo-prop.

Anti-Corrosion Additives

These additives are used to reduce the corrosive effects of various acids within the oil.

Detergent Additives

These additives allow the oil to hold sludge or debris in suspension, this prevents it building up within the engine. It is carried in the system until trapped by the filters.

Inhibitors

These additives are used to slow down the formation of oxidation products.

Oil Types

TYPE 1 and TYPE 2

Table 9.1 shows some of the more common Type 1 and Type 2 gas turbine oils.

TYPE 1	TYPE 2
AEROSHELL 300 BP AERO TURBINE OIL 15 MOBIL JET 1 STAUFFER 1 CASTROL 3C ENCO 15 EXXON 15 EXXON 2389 CALTEX 15	AEROSHELL/ROYCO 500, 555, 560 MOBIL JET IL 254 MOBIL JET IL II STAUFFER II CASTROL 205 ENCO 2380 EXXON 25 EXXON 2380 CALTEX 2380 TURBO/NYCOIL 525 2A

Table 9.1

General Precautions and Procedures

Synthetic oil for commercial turbine engines is usually supplied in one of the following sized containers:

1 US Quart
1 Litre
1 gallon

These convenient size containers minimize the chance of contaminants entering the lubrication system, they also reduce operating costs by reducing wastage.

The following precautions must be observed when servicing a gas turbine lubrication system in order to maintain the integrity of that system:

Absolute cleanliness of all servicing equipment is essential,
Only use servicing equipment for one type of oil, ensure the equipment is marked for the type of oil to be used,
Make sure that the correct type of oil is used to service the system,
Only use oil from clean, clearly marked un-opened cans,
Servicing of a system must be carried out in accordance with the instructions in the Maintenance Manual.

Oil Contamination

The principle contaminants which could be inadvertently introduced into a lubricating system are moisture and other fluids. Water or moisture can cause any or all of the following:

Breakdown of lubrication on heavily loaded surfaces,
Failure of lubrication as a result of water and oil forming an emulsion,
Breakdown of the additives in the oil. This increases the tendency of the oil to sludge up,
Excessive frothing of the oil with subsequent loss o of oil through the vent system.

The introduction of other fluids, such as kerosene, other lubricants, hydraulic fluids, or anti-icing fluids will cause any or all of the of the following:

A change in the viscosity and an increase in the fire risk,
Breakdown of the additives with the possibility of sludge or varnish formation,
Possible breakdown of seals within the lubrication system.

Detention

Water in lubricating oil may be visible as globules or as a separate layer on the bottom of the container or tank. If the water is finely divided, it may be held in suspension, and may cause the oil to look misty instead of bright and clear.

Testing

A quick method of testing for finely divided water can be carried out by heating a small quantity of the oil in a thoroughly dried container to a temperature of 200° C. If the oil crackles while it is being heated, then water is present.

General Procedures

Contamination by other fluids is more difficult to detect in the field. The amount of remedial action would depend upon:

The amount and type of fluid contamination suspected,
The instructions published by the engine manufacturer or listed in appropriate contamination rectification procedures,

In the absence of either of these items of information, a general guideline as to the procedures which might be adopted in part or in full by the operator is as follows:

Take a sample of the oil and send it away for analysis,
Drain the complete system,
Check all pressure and scavenge filters, and magnetic plugs for contamination,
Clean or replace filters,
Flush the system with clean lubricating oil,
Refill the system

Ground-run the engine for a period of time to allow the oil to reach its normal operating temperature. Closely monitor the engine oil temperature, the pressure, the quantity , and all other engine parameters for any abnormal indications,
Shut down the engine, check engine for signs of leakage, drain the system, check or change filters,
Refill the system and replace filters,
Check or monitor the system every 10 hours for the next 100 hrs.

Alternative Lubricating Oils

The engine manufacturer will provide a list in the engine operating instructions or service bulletins of the different brands of lubricating oil which are approved for use within a particular engine. The aircraft operator will pick one of these brands for use within his engines.

The mixing of different brands of approved oil within an engine is not normally permitted by the operator. In an emergency this may be allowed, but the system must be drained at the earliest opportunity and refilled with the correct type and brand of ail. To overcome the problem of topping up a system at an airfield where the operator's brand is unobtainable, most commercial passenger carrying aircraft will carry a few cans of the correct oil in a stowage on the aircraft.

Fuels

International Fuel Specifications

All supplies of aviation fuel used internationally by both civil and military aircraft have to meet minimum quality standards, which are detailed in the specifications issued by one or more of the international controlling authorities. International agreements try as far as possible to see that the specifications are compatible one with another. The purpose of this is to ensure that an aircraft will operate safely and adequately on a particular specified fuel obtained anywhere in the world.

General Requirements

The fuel should ideally meet the following requirements:

Be pumpable and flow easily under all operating conditions.
Permit engine starting at all ground conditions and give satisfactory flight relighting characteristics.
Give efficient combustion at all conditions.
Have as high a calorific value as possible.
Produce minimal harmful effects on the combustion system or the turbine blades.
Produce minimal corrosive effects on the fuel system components.
Provide adequate lubrication for the moving parts of the fuel system.
Reduce fire hazards to a minimum.

Listed Properties

The properties usually listed in a specification include;

Flash Point
Freezing point
Sulphur content
Boiling point
Specific Gravity
Energy Content
Free Water Content
Free particle matter
Chemical composition
Viscosity
Heat of Combustion

Types of Aviation Fuels

Fuels are grouped into two sub-groups - **kerosene** and **wide cut (or wide range).**

The following types of fuels are the most widely used in the industry (civil and military);

Jet-A and Jet A-1

Designed as a low temperature **kerosene** fuel. It is used by most international airlines.

Specification	**Jet-A**	**Jet A-1**
United States	MIL-T-83133	MIL-T-83133
Great Britain	DERD 2494	DERD 2453
Canada	CAN 2-3.23-M80	CAN 2-3.23-M80
France	AIR 3405	AIR 3405
Pratt & Witney	522	522
Allison Div of GM	EMS-64	EMS-64
NATO	AVTUR F-34	AVTUR F-35
Sulphur % total weight	0.05	0.05
Initial Boiling Point °C	163	163
Flash Point °C	42	46
Specific Gravity	0.806	0.816
Freezing Point °C	-40	-47
Heat of Combustion MJ/kg	43.1	43.1
Free water, PPM	30	30
Particle Matter mg/ltr	1.0	1.0

Jet-B, Turbo fuel 5, JP-4 and JP-5

These fuels are a blend of approximately 30% kerosene and 70% gasoline and described as a **wide-cut** fuel. JP-4 and JP-5 are military designations for Jet-B and Turbo fuel 5 respectively.

Specification	Jet-B/JP-4	Turbo Fuel 5/JP-5
United States	MIL-T-5624	MIL-T-5624
Great Britain	DERD 2486/2454	DERD 2498/2452
Canada	CAN 2-3.22-M80	3-GP-24M
France	AIR 3407	AIR 3404
Pratt & Witney	522	522
NATO	F-40	AVCAT F-44
Sulphur % total weight	0.04	0.02
Initial Boiling Point °C	72	170
Flash Point °C	18	64
Specific Gravity	0.764	0.820
Freezing Point °C	-60	-50
Heat of Combustion MJ/kg	43.5	43.1
Free water, PPM	30	30
Particle Matter, mg/ltr	1.0	1.0

Jet-A, Jet-A1 and Jet-B are interchangeable for use in **most** gas turbine engines. Aviation grades 80-145 octane reciprocating engine fuels are often **emergency** alternate fuels for turbine engines.

For the approved fuel and fuel additives used to service a turbine engine, the technician should check the aircraft operators manual or the type certificate data sheet.

Additives

These are normally added by the fuel supply company during production to give the fuel some improved property or to prevent specific problems within the airframe and engine fuel systems (for use in adverse weather conditions, for example). Sometimes however, the additive is mixed with the fuel at the point of engine servicing. The following additives are the most common used.

Anti-Oxidants - Prevent the formation of gum deposits on fuel system components caused by oxidation of the fuel in storage and also inhibit the formation of peroxide compounds in certain fuels.

Static Dissipators - Eliminate the hazardous effects of static electricity generated by the movement of fuel through modern high flow rate transfer systems. **It does not reduce the requirement for the normal bonding of components.**

Corrosion Inhibitors - Protects the metals in the fuel system, and may improve the fuels lubricating properties.

Fuel System Icing Inhibitors - Reduce the freezing point of water precipitated by the fuel as it cools, thereby reducing the risk of ice restricting fuel flow to the engine.

Metal De-activators - Suppresses the catalytic effect which some metals, particularly copper, have on fuel oxidation.

Biocide additives - Reduces the risk of microbiological growths in the fuel systems. **Biopor** is a well known antifungal additive

Note: Additives may be mandatory or optional, it often depends on whether the fuel is used for military or civil aircraft or the country concerned. Maximum and minimum concentrations are specified and must not be exceeded. A product called Prist is a well known point of refuelling additive that protects against fungicide and freezing of entrained water.

Refueling/defueling and Fuel Tank Work Safety Precautions

When the personnel are working inside fuel tanks or the aircraft is to be refuelled or defuelled, the following precautions should be taken to ensure the safety of the aircraft and personnel.

- Avoid all unnecessary contact and use protective equipment to avoid contact.
- Remove promptly any fuel product that gets on the skin.
- Do not use fuel or similar solvents to remove oil or grease from the skin.
- Never wear fuel soaked clothing. Remove immediately and clean before re-use.
- Avoid breathing fuel vapours. Maintain well ventilated work areas.
- Clean up spilled products immediately. Keep spills out of sewers, streams and waterways.
- Be familiar with proper first-aid techniques for handling unexpected/gross contacts and seek proper medical attention immediately for assistance.
- Have suitable fire fighting equipment available and adequately manned.
- Use only specially sealed lighting equipment and "spark free" power tools.
- Use an air fed vapour mask at all times inside the tank.
- Ensure that both the aircraft and refuelling vehicle are earthed.
- Ensure that there is an escape route for the refuelling vehicle and that they are kept clear.
- When the aircraft is to be pressure refuelled, the earthing wire on the refuelling pipe should be connected to the earth point on the aircraft **before** connecting the refuelling pipe, and when the aircraft is to be refuelled through the overwing filler point, the earthing wire on the refuelling pipe should be connected to the earth point on the aircraft **before** removing the filler cap and inserting the nozzle. The earthing wire should remain in position until **after** the refuelling pipe is disconnected or the filler cap replaced as appropriate.
- No radio or radar equipment should be operated while refuelling or defuelling is taking place, and only those electrical circuits concerned with the operation should be switched on.

Fuel Contamination

Water Detection

All aviation fuels contain some **dissolved water** and **free water**. Dissolved water is like humidity in air in that it cannot be seen. It is not a problem as long as it remains dissolved. Free water, also called **entrained water**, is present in tiny droplets and is visible. It is water in excess of water that dissolves. Large quantities of free water (over 30 parts per million) can cause engine performance loss or even flame out.

A **HYDROKIT** (Exxon trade name) is a quick, go/no-go test for detecting the presence of minute quantities of undissolved water in turbine fuel. The HYDROKIT indicator powder, packaged in a ten millilitre evacuated test tube, gives a distinct pink/red colour change in the presence of 30 parts per million or more of undissolved water. Boeing also recommend the use of water soluble food colouring to identify free water. In any case water settles at the bottom of the sample jar as it is heavier than fuel.

Figure 9.1: Shell Water Detector

Microbiological Contamination

The problem - This problem can cause inaccurate fuel tank contents indication, blockage of filters and corrosion of aluminium alloy fuel tanks. This type of contamination is normally more of a problem with kerosene type fuels. The contamination is of the form of a fungus called **Cladosporium Resinae**, the spores of which are present in most kerosene type fuels and are too small to be filtered out.

In order to grow, these spores need a temperature of 25°C to 35°C and the presence of free water in the fuel. The fungus requires both warmth and water to grow. The growth starts at the boundary of a water droplet, eventually fills the droplet which bursts and releases more spores into the fuel. Any imperfections in the tank coating will be penetrated by the fungus and corrosion pitting over a larger area may result. Fungal attack can also be a cause of stress corrosion cracking.

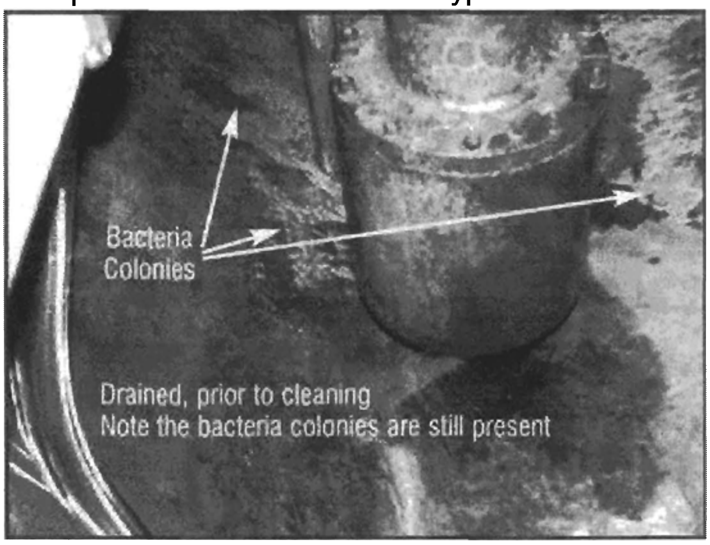

Figure 9.2: Microbiological contamination in a fuel tank

Often water droplets will remain attached to a surface due to surface tension. Upward facing surfaces are most likely to be effected, and the worst contamination is usually at the lower inboard end. Because of this, modern integral tanks are designed to provide a fuel flow across the bottom thus minimising the risk of water collecting in stagnant areas.

The prevention - The use of fungicidal additives to the fuel is often recommended by the aircraft manufacturers, particularly when the aircraft is operating in areas of high contamination risk. The following additives may be used on a continuous or intermittent basis;

> **Ethylene Glycol Monomethyl Ether (E.G.M.E.)** is widely used as an anti-icing additive and is also a biocide. It must be thoroughly mixed with the fuel **before** refuelling and special injection equipment is necessary. Used in a concentration of 0.15% by volume.
>
> **Biopor** may be used as a biocide on a continuous basis at a max. concentration of 135 ppm or, on an intermittent basis (e.g. once every two moths) at a max. concentration of 270 ppm. Biopor mixes easily with fuel and may be mixed prior to refuelling or poured directly into the aircraft tanks. For non-continuous use, the treated fuel (approx one third tank capacity) should be left as long as possible (three to four days) for maximum effect, but this fuel must be diluted before being burned.

Inspection for contamination - Contamination is more easily identified when the tank is partially full. After removal of one of the overwing inspection hatches, inspection can be made using a flame-proof torch, for signs of **brown slimy deposits**. Corrosion resulting from fungal attack, although not often visible, may appear as white spots through the fungus.

If fungus is found - Its position should be noted and it should be removed as soon as possible. The decontamination process may vary between different aircraft manufacturers, but the following is typical;

- Drain out and isolate all fuel, ventilate the tank to permit entry. It may be required to remove all the tank components.
- Wash the tank with detergent and water, using a bristle brush to aid in the removal of fungus.
- Rinse the tank with clean water spray to remove the detergent.
- Apply a biocidal rinse to kill any remaining spores. The rinse is usually **5% chromic acid** or **50% methanol in water**, and is left in the tank for a short period.
- Thoroughly rinse the tank with clean water, dry with warm air.

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.10 Lubrication Systems

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.

Table of Contents

Module 15.10 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 Reference**	**Level**
		B1
Lubrication Systems	15.10	2
System operation/lay-out and components.		

Module 15.10 - Lubrication Systems

System Basic Requirements

The system should meet the following basic requirements:-

Each bearing should receive a predetermined flow of oil.
The oil must be supplied at a predetermined pressure.
The oil temperature must be within system limitations.
The oil must be clean - free from any contamination.

Functions of the lubricating oil:

To reduce friction
To reduce temperature
To clean the system

Lubricating Oil Characteristics

Many of the bearings in a gas turbine engines are located in a region of the engine where they will pick up considerable amounts of heat. To help in controlling the temperature of the bearing housings a flow of low pressure air is passed over the outside surfaces, this will both cool and pressurise the housing helping to reduce leakage. The oil itself will need to have the following characteristics:-

Low viscosity.
Manufactured from synthetic sources.
A high heat capacity.
Chemically stable over a wide range of operating temperatures.

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Pressure Relief Valve System

The complete oil system can be divided into the following parts:-

Suction Sub-System
Pressure Sub-System
Scavenge Sub-system

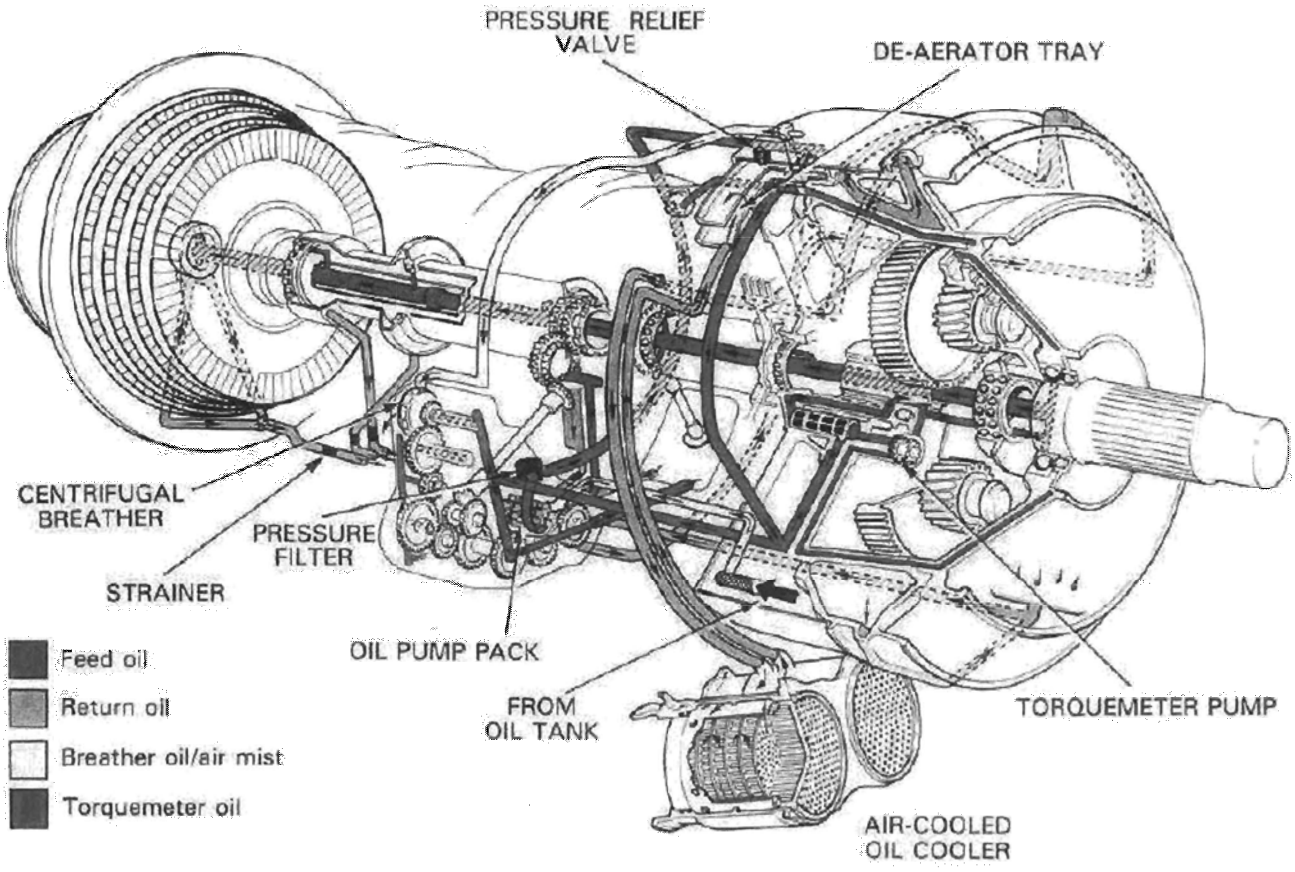

Figure 10.1: A Pressure Relief Valve Oil System

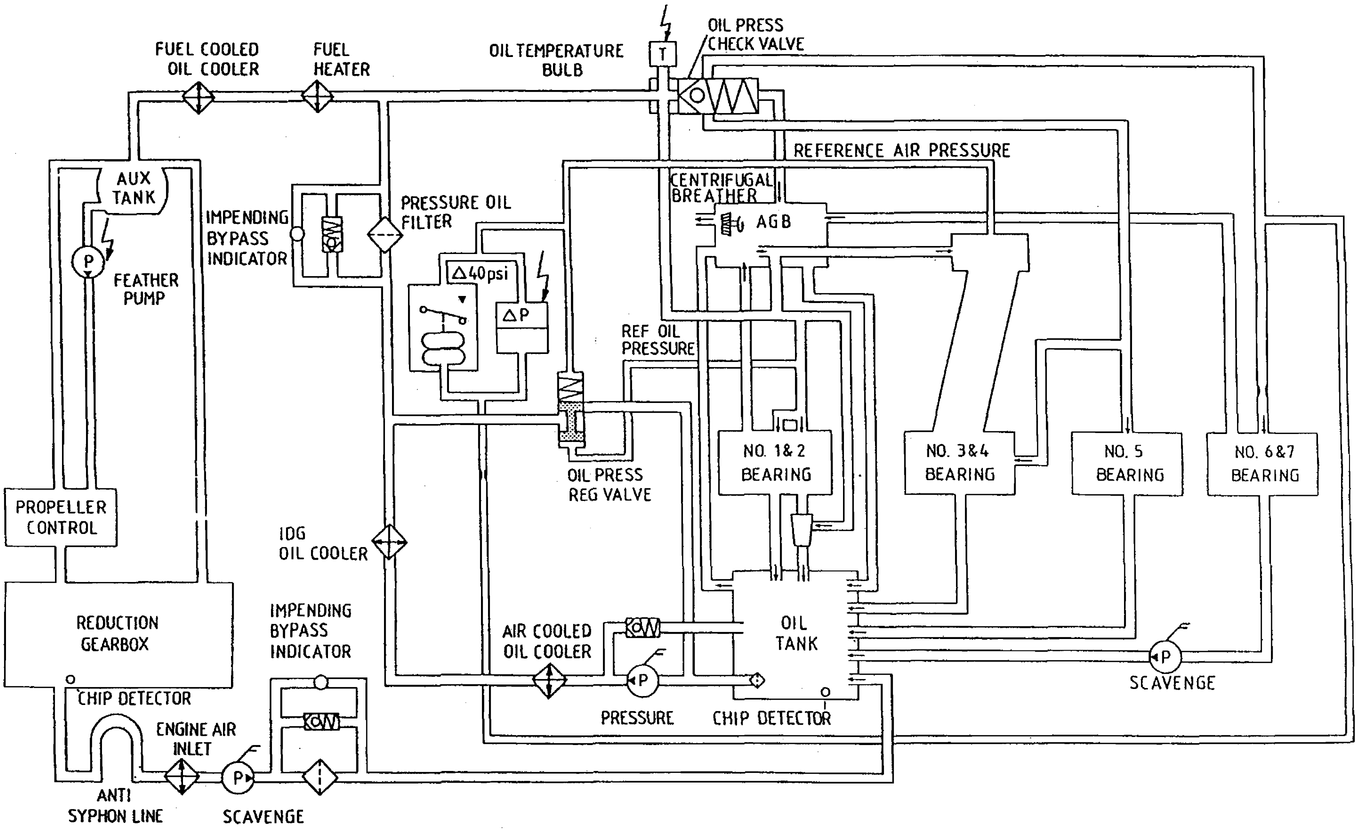

Figure 10.2: Pressure Relief Valve System Example – PW 125 Engine

Suction Sub-System

The **reservoir** of oil will be contained either in a separate oil tank (known as a dry sump), or the base of an accessory gearbox casing (known as a wet sump system). A sight glass will be used to give an indication of the oil level. The reservoir will be replenished by a either a pressure re-oiling system or a open line filling cap, and vented to atmosphere. A **suction filter** protects the oil feed to the **pressure pump**. The scavenge return line will include a **de-aeration tray** inside the reservoir. A rotating **centrifugal breather** may be used on the vent system to separate oil from the air. Oil capacity will depend on the role of the aircraft.

Pressure Sub-System

The **engine driven pressure pump** which is normally a gear type pump draws oil from the reservoir through the suction filter and delivers it to the pressure system. **A pressure relief valve is connected from the pump output to the inlet side and opens to relieve excess oil pressure.** A characteristic of the pressure relief type of system is that indicated oil pressure is independent of engine RPM. The oil is then fed to a **pressure filter** which removes any small particles of dirt/debris, hence only clean oil is fed to the system.

Transmitters provide the essential signals of pressure and temperature for display on the flight deck instruments.

The system then delivers oil to each of the main rotating bearing assemblies and auxiliary gearbox bearings by a series of internal pipes. At each bearing location a calibrated spray jet or metering device provides each bearing with the designed quantity of oil. The oil jets are positioned to ensure that the oil is accurately sprayed onto the bearing surfaces to penetrate around the rolling surfaces.

The oil then drains to the bottom of the bearing housing where it flows into the collector trays.

Scavenge Sub-System

From each of the bearing housings the oil is drawn by a series of **gear type scavenge pumps** through individual **scavenge filters.** This oil will contain considerable quantities of air from that used to seal and cool the various bearing housings.

The scavenge pumps will normally be of a greater capacity than that of the pressure pumps (1.5 times at least), to accommodate the increased volume of oil due to aeration, temperature rise and to maintain the bearing housings dry.

The output from the scavenge pumps is fed back to the oil reservoir passing through/over chip detectors and through an oil cooler(s) which may be fuel and/or air cooled.

Individual scavenge pumps are used to ensure that each bearing is correctly emptied. Individual scavenge filters are used to identify and localise any wear debris produced from failed bearings.

The example shown above is a sophisticated version of a pressure relief valve system. In older systems the PRV shown returning oil from the pump outlet to the oil tank is the pressure regulating valve. In this system this valve is a surge protection valve and not normally open. Pressure regulation is carried out by the oil pressure regulating valve. Above 75% N_2 this valve maintains oil pressure to 60 PSI above the No.1 bearing air cavity. Thus ensuring that constant pressure is maintained across the bearing labyrinth seals.

This engine is a turbo prop and as it has a reduction gear system, like all turbo props, will utilize an oil of greater viscosity than usually used by a turbo jet. Also note that the propeller pitch/feather control system utilizes normal engine oil.

Full Flow System

The Pressure Relief Valve System described previously has the disadvantage that it over-oils at low RPM and slightly under oiled at Max RPM after the relief valve has cut in.

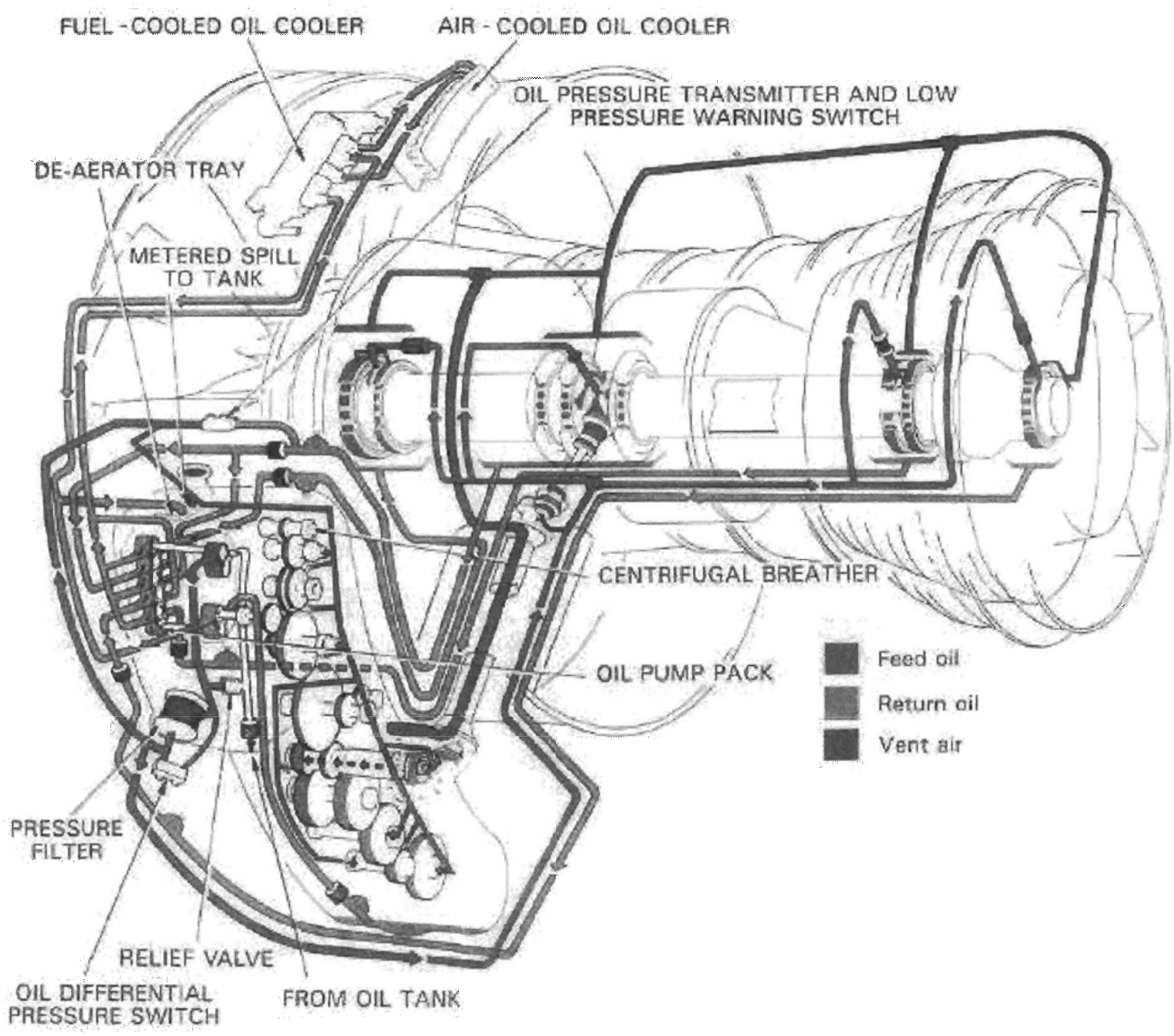

Figure 10.3: A Full Flow Oil System

The full flow system is identical to the Pressure Relief Valve System in that it has all the same sub-systems and components, but is different in the following ways :-

1 The pressure pump is not as large, hence the build up of pressure with increased RPM is not as great.

2 A pressure relief valve is fitted as a safety device only and **would not open during normal operation.**

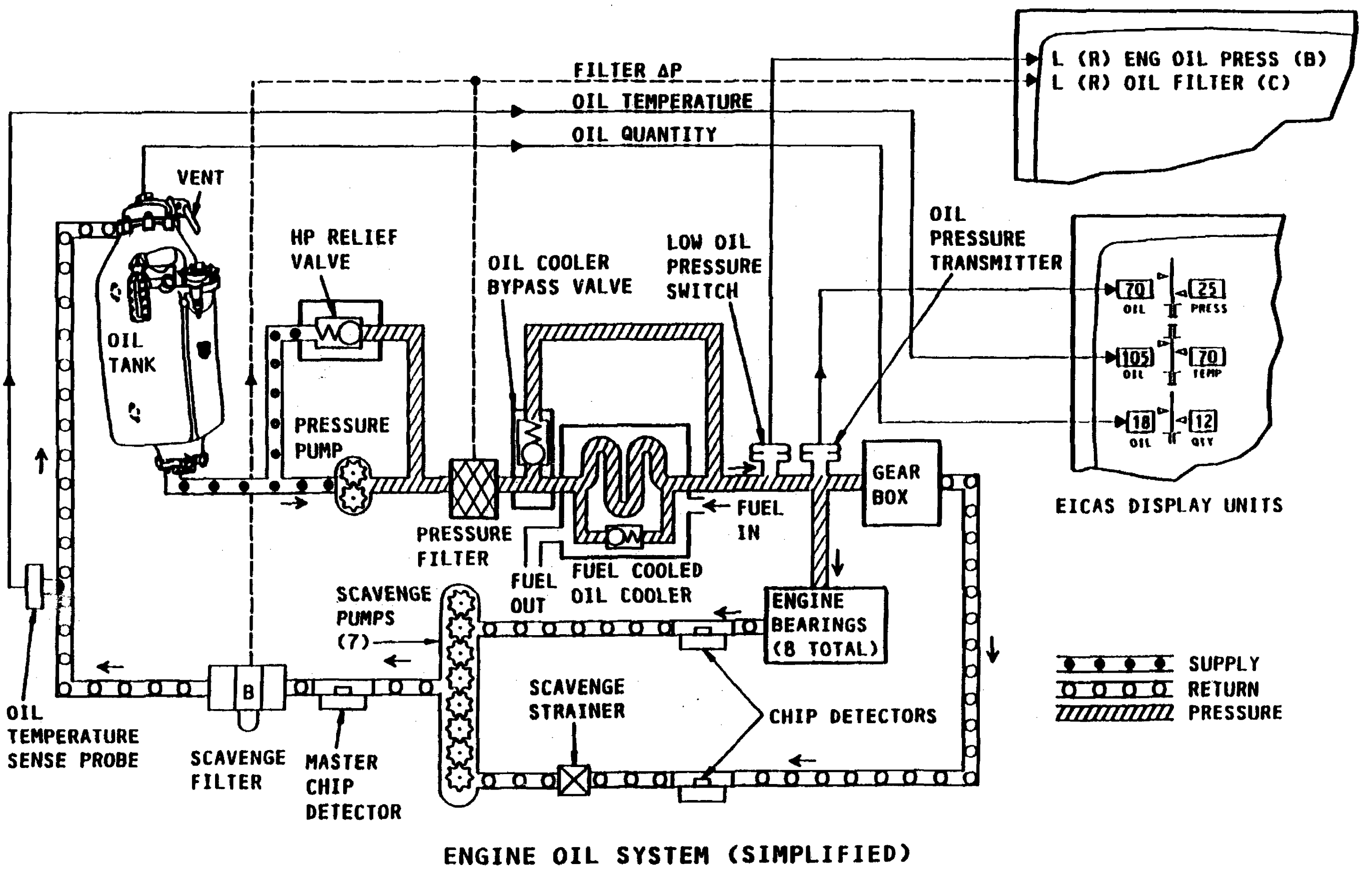

Figure 10.4: Full Flow Oil System Example - RB211- 535

Total Loss System

The total loss system is generally used only on engines that run for periods of short duration only. The system is used on booster engines, which are only required to operate for take-off. Such an engine need not use a recirculatory system, which incur high weight penalties. The system requires none of the scavenge system components. The used oil is dumped into the engine exhaust or to the atmosphere, hence the name "total loss".

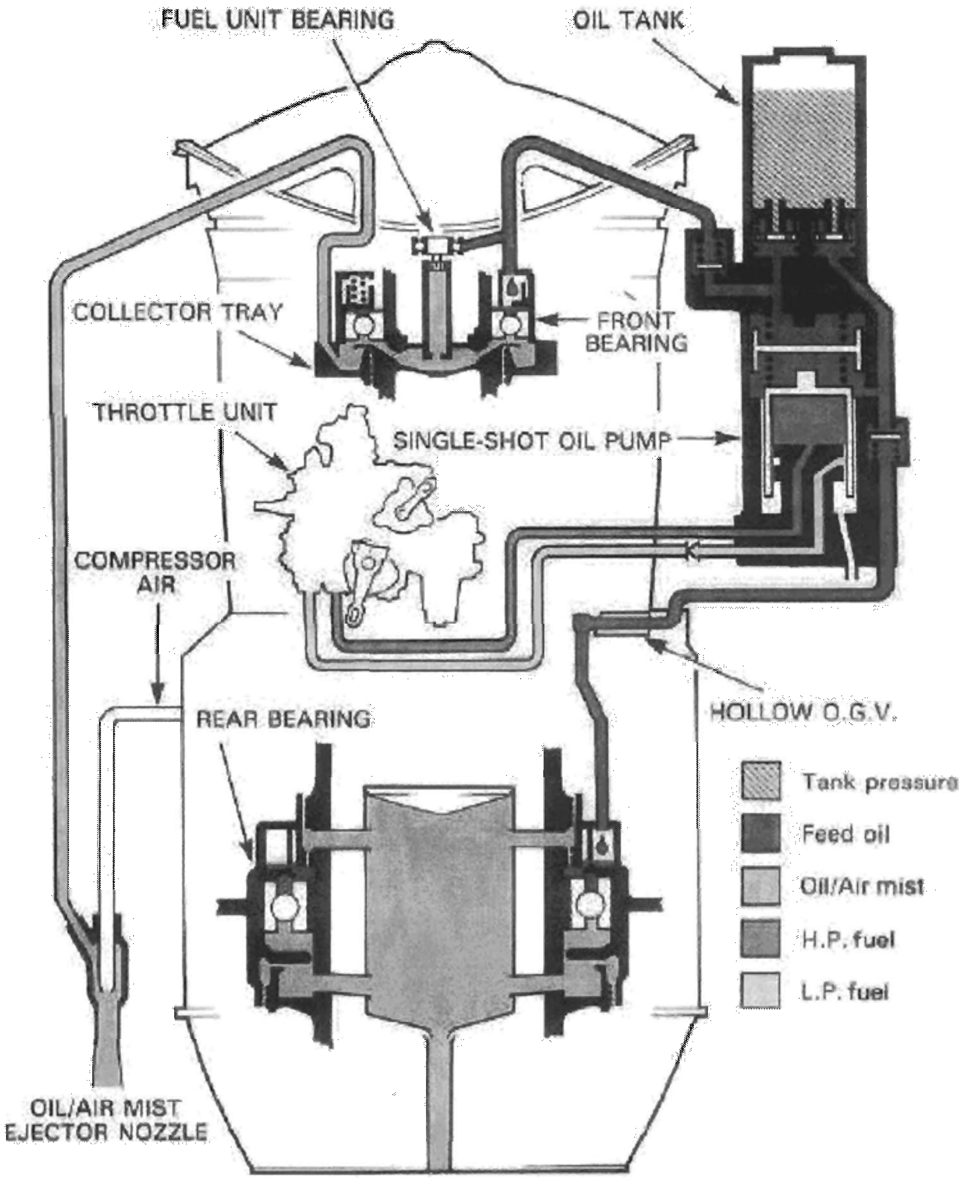

Figure 10.5: Total Loss Oil System

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Types of Bearing Lubrication

The bearings in a gas turbine engines are lubricated in one of the following ways:-

Spray jet/pressure fed
Splash oil
Metered oil
Film Lubrication

Spray Jet/Pressure Fed

The majority of the bearing housings in the engine have a small spray jet which directs oil directly onto the rolling elements of the bearing. The spray jet is fed with pressure oil. Heavily loaded gears may also be lubricated this way (reduction gears in a turbo-prop engine).

Splash Oil

Only very lightly loaded bearings are splash lubricated. Common examples are the gears inside the gearbox.

Metered Oil

Some engines may have bearings supplied by a metering system which is fed from the main engine pressure oil galleries. The metered oil feed is to supply the bearing with just the right quantity of oil in relation to engine speed e.g. compressor front bearings (SPEY engines).

Film

This is when the surfaces concerned are separated by a substantial quantity of oil. Film lubrication is the most common phase of lubrication. The oil separates the two surfaces so that friction is reduced to that existing between the molecules of the lubricant. The oil in direct contact with the surfaces moves with the surfaces, friction occurs only by reason of the intermediate layers sliding over one another. With perfect lubrication, no wear of the bearing surfaces should occur, except possibly on starting. With film lubrication, the viscosity of the oil is important because it controls the ability of the oil to keep the surfaces apart.

Squeeze Film

An application of the film lubrication principle is the squeeze film bearing shown below. To minimise the effect of the dynamic loads transmitted from the rotating assemblies to the bearing housings, a squeeze film type of bearing is used. The outer race of the bearing and the bearing housing has a small clearance between them, with the clearance being filled with oil. the oil film dampens the radial motion of the rotating assembly and the loads transmitted to the housing thus reducing vibration and possible damage by fatigue to the engine.

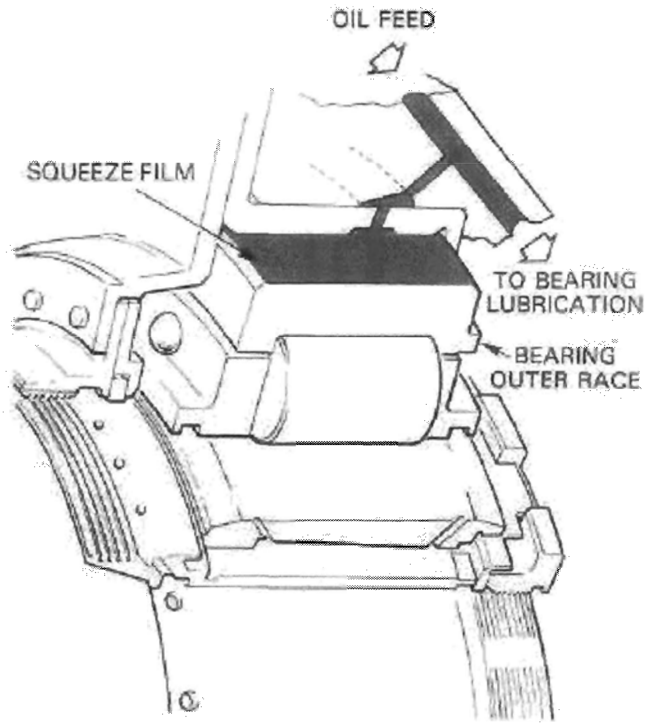

Figure 10.6: Squeeze Film Bearing

Components

Oil Tank

The oil supply reservoir in a dry sump system is normally classified as a hot tank or cold tank system. This depends upon whether the fuel cooled oil cooler is before the oil tank in the scavenge system or after the lube pump in the pressure line. Modern systems tend to use the hot tank system.

The oil tank is usually located at a point above the pump assembly to enable gravity to assist the flow of oil to the pumps. Some tanks are vented to atmosphere whilst others are lightly pressurised to enable positive flow of oil to the pump assembly.

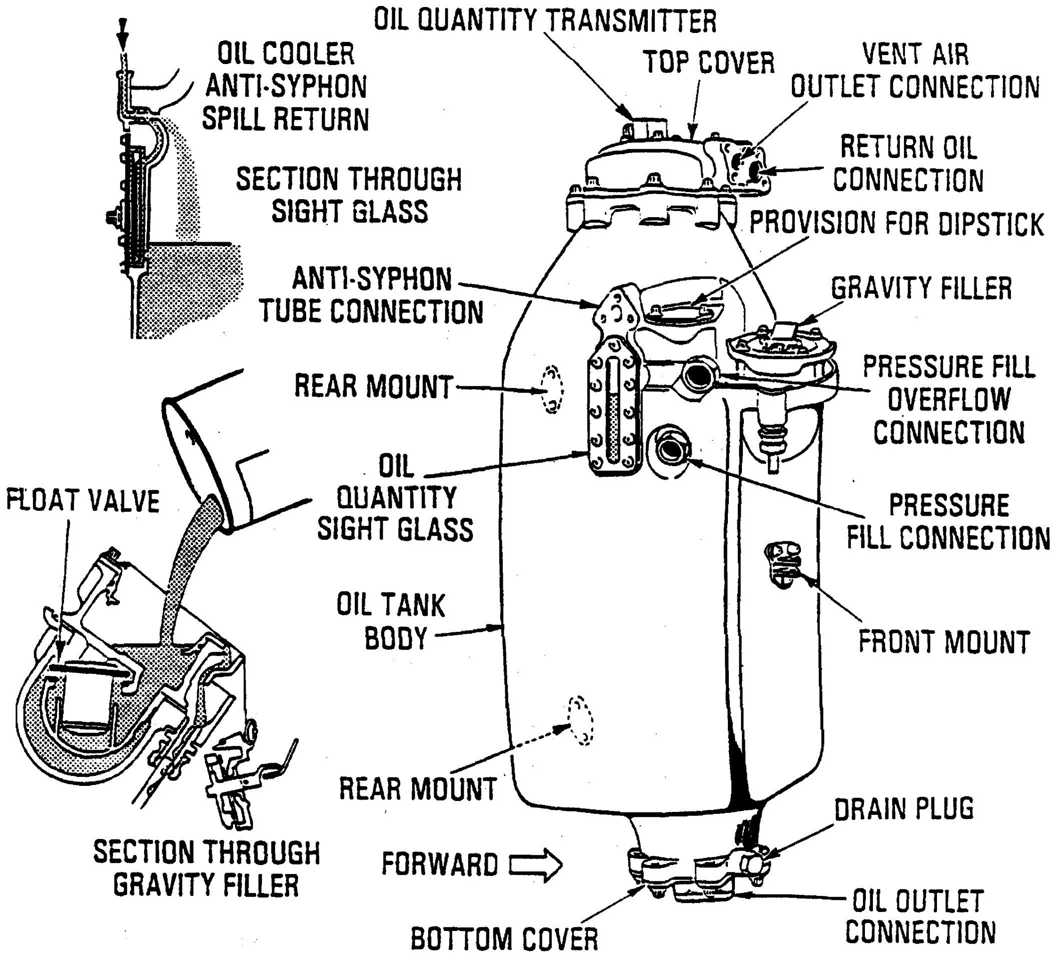

Figure 10.7: RB211-535 Oil Tank

Anti siphon tube
Required to break a siphon action on engine shut down that would cause the oil to siphon back to the accessory gearbox via the return oil tube

Gravity Filler
Has a float valve in the neck to prevent major oil loss if the cap is not fitted properly. In addition a scupper drain collects any spilt oil during replenishment.

Oil Quantity Transmitter
A ladder of resistors that transmit oil quantity to EICAS. A full indication on the sight glass corresponds to the filling until oil flows into the scupper drain. The EICAS indicates 21 quarts of useable oil for this engine in this condition.

Pressure fill and overflow ports.
These ports provide the option of filling the tank using a pressurised cart, until the oil flows from the overflow port.

Servicing of the oil System
Never replenish the oil system immediately after shut down or when the engine is cold. The AMM will prescribe time limits, typically not before 10-minutes after shut down and not longer than 1 hour.

After maintenance it is normal to run the engine at idle rpm with only a limited amount of oil showing on the tank quantity to establish a warm datum and then a complete top up is carried out after the minimum time shown in the AMM after shutdown.

Internally within the reservoir is normally a deairation tray that separates return oil from the air and at the outlet it is normal to have a strainer to pre filter the oil prior to entry to the pump.

Oil Pumps

The function of the oil pressure pump or lube pump is to supply oil under pressure to the parts of the engine that require lubrication. Many pump assemblies consist of not only the pressure or lube element but scavenge elements as well, all-in-one housing usually driven from the accessory or high speed gearbox. By its nature an oil pump is designed to provide a volume of flow to the engine. How much pressure it creates is a function of how much resistance to flow there is. The more the flow is restricted, the higher the oil pressure will tend to be. For example, as an oil filter starts to clog, the resistance to flow increases in front of the filter and the pressure increases.

The three most common oil pumps are: the vane, gerotor, and gear types. All are classed as positive displacement pumps because they deposit a fixed quantity of oil in the pump outlet per revolution. All three types of pumps are also self-lubricating. These category pumps are also referred to as constant displacement types because they displace a constant volume per revolution.

Vane Pump

The vane pump illustrated could be a single element type or one element of a multiple pump. Multiple pumps of this type generally contain one pressure element and one or more scavenge elements, all of which are mounted on a common shaft. The drive shaft mounts to an accessory gearbox drive pad and all pumping elements rotate together.

Pumping action takes place as Rotor Drive Shaft and Eccentric Rotor, which act as one rotating piece, drive the sliding vanes around. The space between each vane pair floods with oil as it passes the oil inlet opening and carries this oil to the oil outlet. As the spaces diminish to a zero clearance, the oil is forced to leave the pump. The downstream resistance to flow will determine the pump output pressure unless a relief valve is present to regulate pressure.

Vane pumps are considered to be more tolerant of debris in the scavenge oil. They are also lighter in weight than the gerotor or gear pumps and offer a slimmer profile. They may not, however, have the mechanical strength of other type pumps.

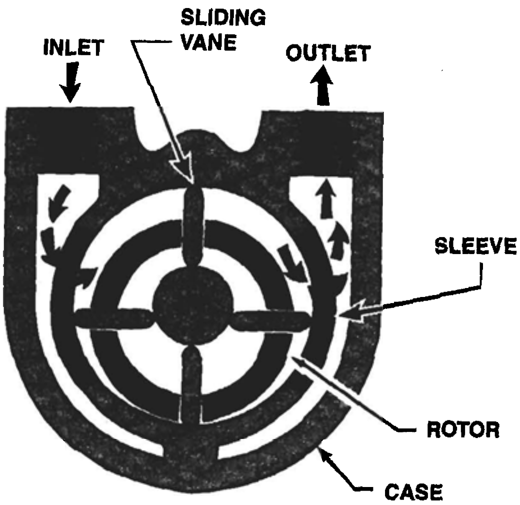

Figure 10.8: Vane Type Pump

Gerotor Pump

The diagram shows one pumping element mounted on a multiple-element pump main shaft. The gerotor pump, sometimes referred to as gear-rotor, utilizes a principle similar to the vane pump. The gerotor uses a lobe-shaped drive gear within an elliptically-shaped idler gear to displace oil from an inlet to an outlet port

Notice that the inner driving gear has six lobes (teeth) and that the outer idling gear has seven openings. This arrangement allows oil to fill the one open pocket and move inlet oil through the pump as it rotates until a zero clearance forces the oil from the discharge port. The principle of operation is that the volume of the missing tooth multiplied by the number of lobes in the outer gear determines the volume of oil pumped per revolution of the outer gear. A complete pumping element is shown, one of several which could be mounted on a single shaft within the same pump housing. The diagram depicts the principle of operation of the gerotor pump.

The operation would be as follows:

a) From 0° to 180°, inter-lobe space increases from a minimum to a maximum volume. Most of the 180° it is open to the intake port allowing it to fill with oil.
b) As the space reaches maximum volume, it is closed to the intake port and is in a position to open to the discharge port.
c) At 270°, the space decreases in volume, forcing its oil out the discharge port.
d) As the space reaches minimum volume at 360° it is closed to the discharge port and begins to open to the intake port, repeating the cycle. This action takes place in each of the seven inter-lobal spaces between the inner six-lobe gerotor and the outer seven-lobe gerotor, giving an essentially continuous oil flow.

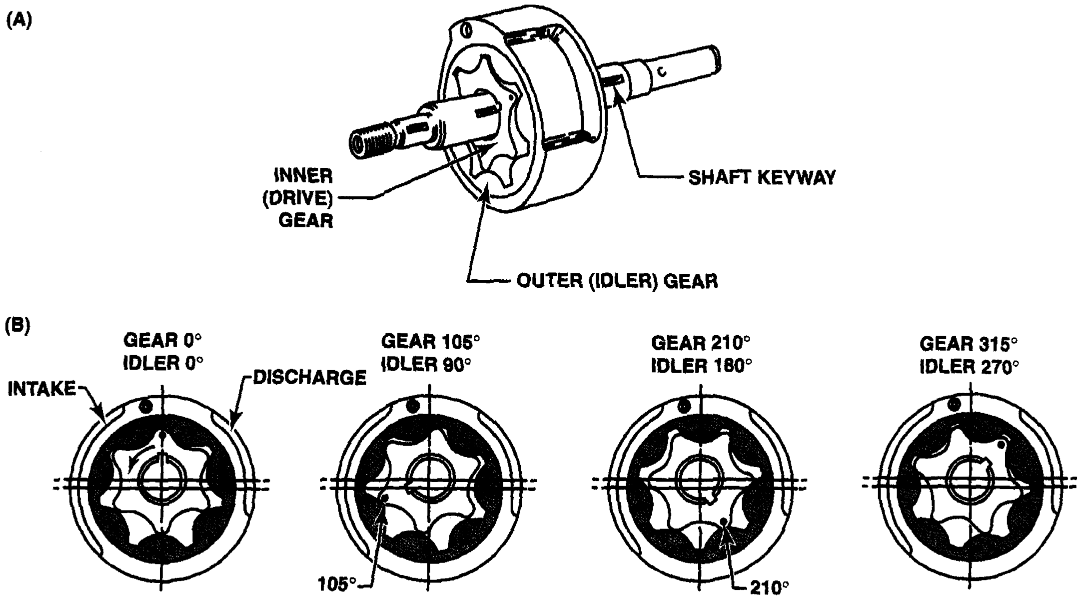

Figure 10.9: Gerotor Type Oil Pump

Gear Pump

The single element gear type pump takes in inlet oil and rotates in a direction which allows oil to move between the gear teeth and the pump inner case until the oil is deposited in the outlet. The idler gear seals the inlet from the outlet preventing fluid backup and also doubles the capacity per revolution. This pump also incorporates a system relief valve in its housing which returns unwanted oil to the pump inlet. The second figure below shows a dual pump with both a pressure and a scavenge element. This is the most common pump assembly seen on gas turbine engines and for large engines it is normal to have up to 7 scavenge pumps.

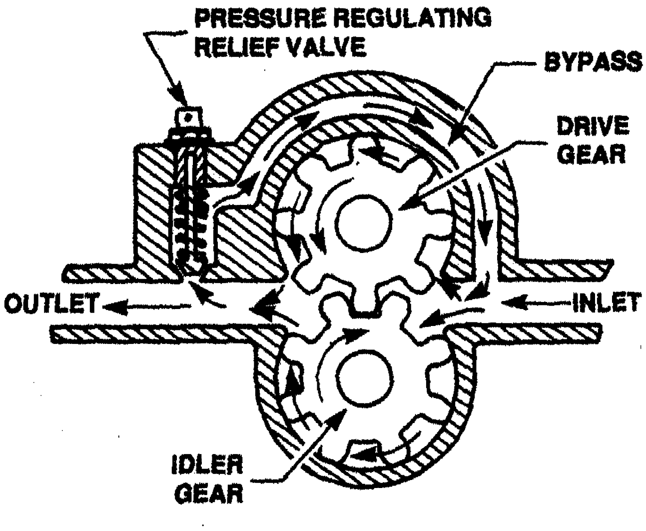

Figure 10.10: Sectioned Gear Type Pump

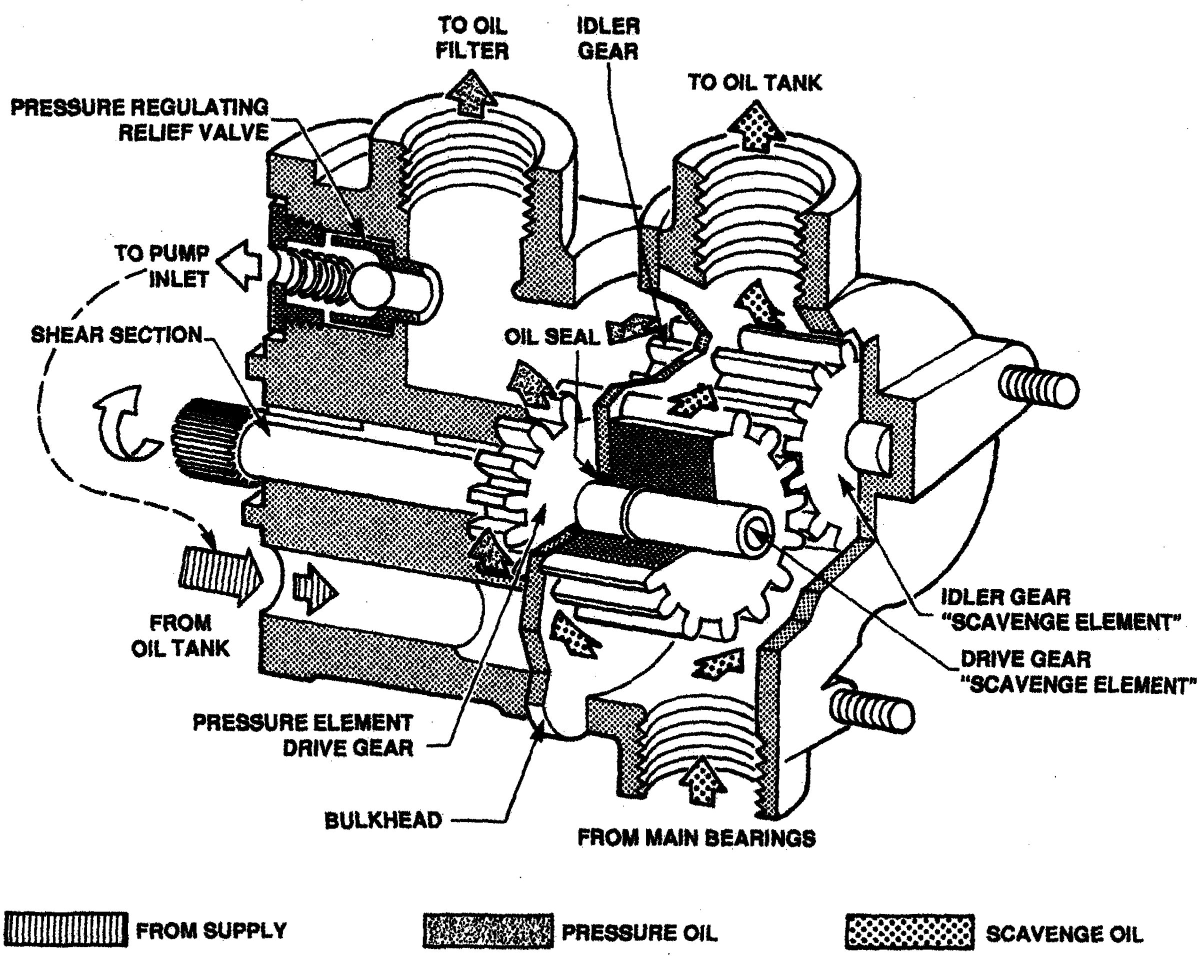

Figure 10.11: Gear Type Pump with Single Scavenge Element

Filters

Oil filters are generally of the following types:

Cleanable Screen Filters
Fibre Filters
Thread Filters
Scavenge Screen Filters

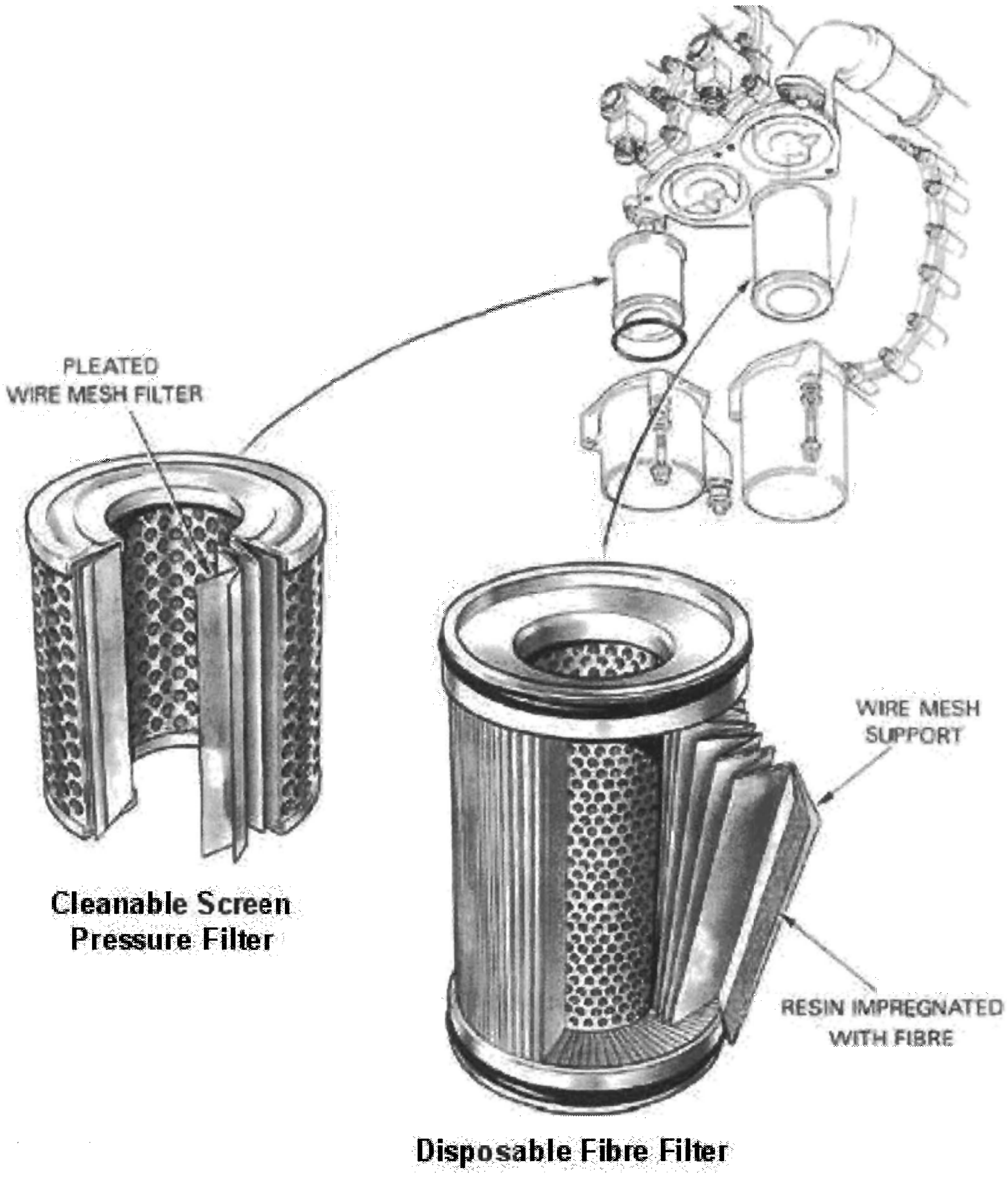

Figure 10.12: Cleanable and Fibre filters

Cleanable Screen Filters
Also known as a pleated screen, wafer screen and screen and spacer type. All these filters are made from woven wire and can be reused after cleaning in an ultrasonic bath. Woven wire filters cannot generally filter below 40-microns and are generally found in the pressure supply sub system as they can resist the force created due to the flow of oil under pressure

Fibre Filters
Fibre filters can screen down to 15-micron and are disposable. They are generally used in scavenge return lines.

Thread Filters
Thread filters are also known as last chance filters. They are fitted just before a bearing chamber as a last chance to catch debris into the bearing.

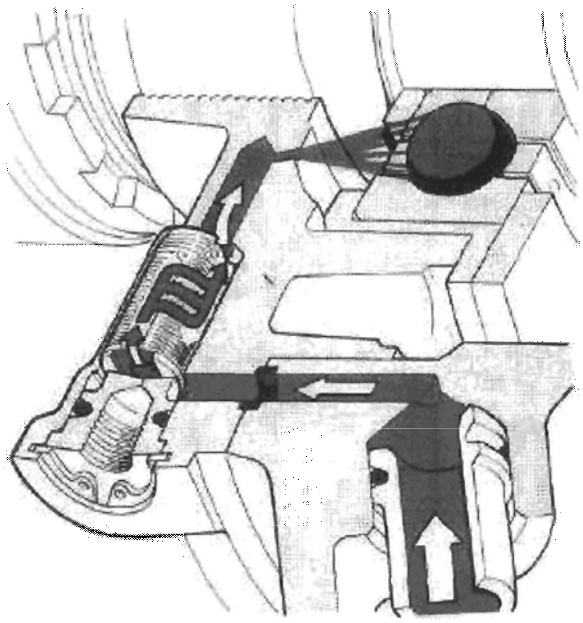

Figure 10.13: Last Chance Thread Filter

Scavenge Screen Filters
Scavenge screen filters are coarse mesh filters fitted in individual scavenge lines to catch large debris that may have come from the bearings, labyrinth seal damage is a good example. The base of these screens is often used to accommodate Magnetic Chip Detectors.

Delta-P Indication

Pressure and scavenge filters often have mechanical bypass in the event of blockage or cold starting to prevent flow limiting within the filter. Prior to this happening it is normal to have an indicator showing that the filter is imminently going to bypass. The indication, known as a 'Delta P' (also written "ΔP ") indication can either be a mechanical pop out indicator or an electrical signal connected to a warning system in the cockpit.

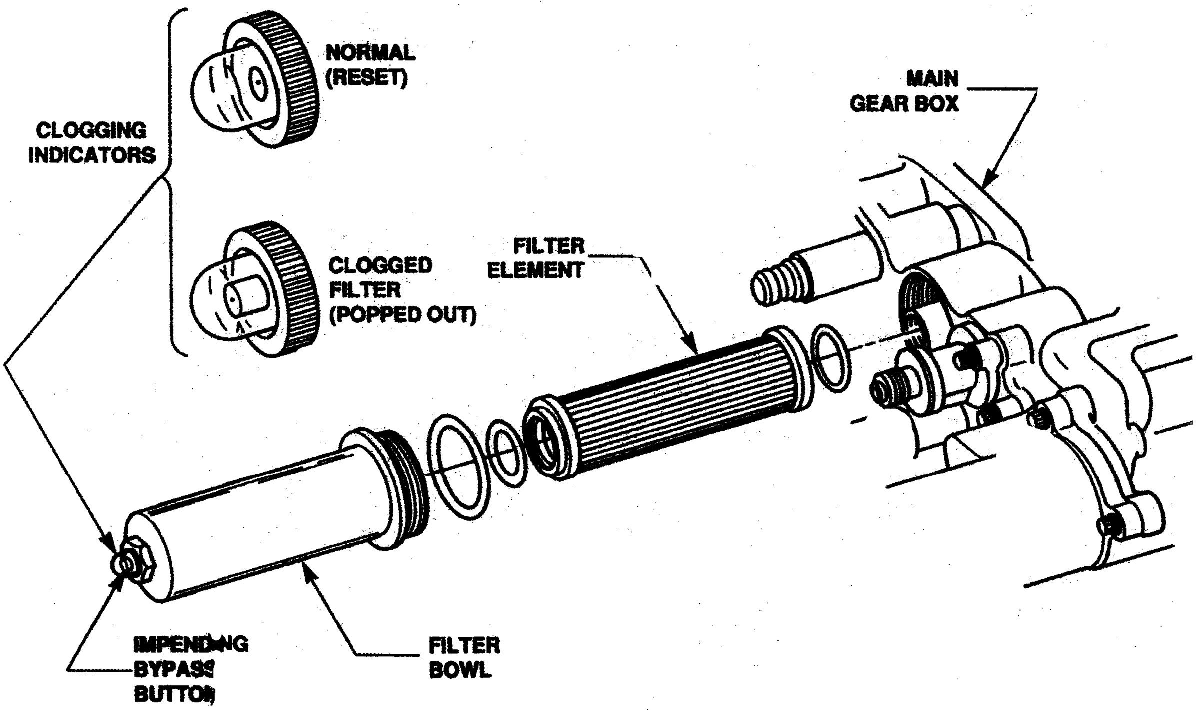

Figure 10.14: Filter with Delta-P pop-out indicator

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Fuel Cooled Oil Coolers

A Fuel Cooled Oil Cooler (FCOC) serves two purposes, firstly it cools the oil and secondly they warm the fuel. Fuel contains water and as it is passed though the elements of the LP Fuel Filter it has a tendency to freeze. The cooling matrix can be by passed firstly if the oil is sensed as too cold or secondly if there is a blockage. Not all FCOC have thermostatic valves, some simply have a delta P bypass in the event of cold oil causing a pressure differential. FCOC are always located in the fuel system immediately before the LP Fuel filter.

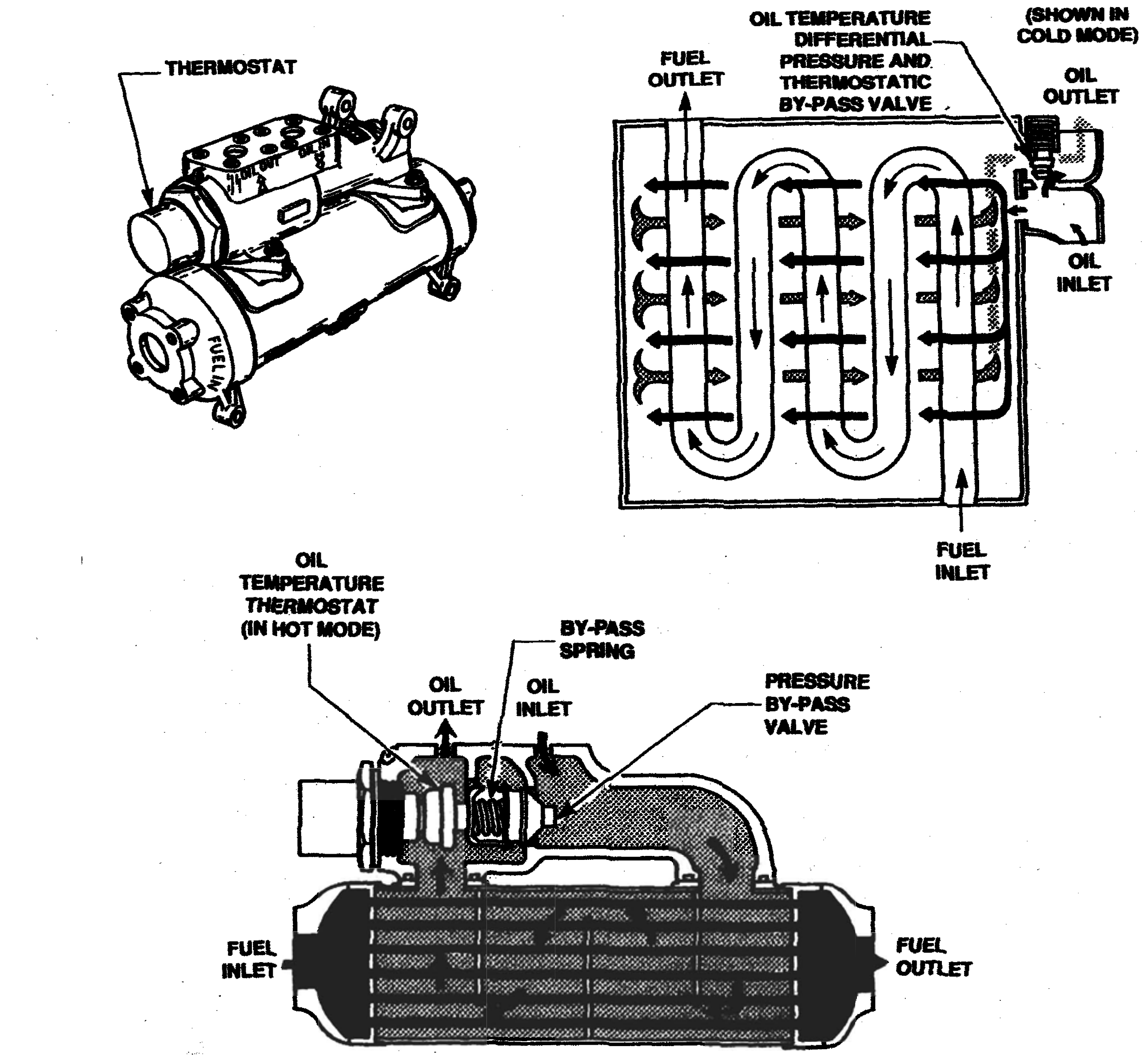

Figure 10.15: Thermo Valve Closed When Oil is Hot

FCOC are located in the oil system either in the pressure sub system, and the oil tank is known as a hot tank or in the scavenge line to the oil tank and as a result the oil tank is a cold tank system.

In the event of oil quantity increasing a failed FCOC matrix would be suspected

Some larger engines have a secondary air-oil cooler that is activated under high power conditions.

Air-Oil Separation

Oil after pressurisation and expansion expands and gains air. This air must be removed prior to recirculation. A deareator tray is normally fixed in the top of the oil tank and the return oil splashed across this tray and air is extracted. This air is either vented or regulated to maintain a small positive pressurisation.

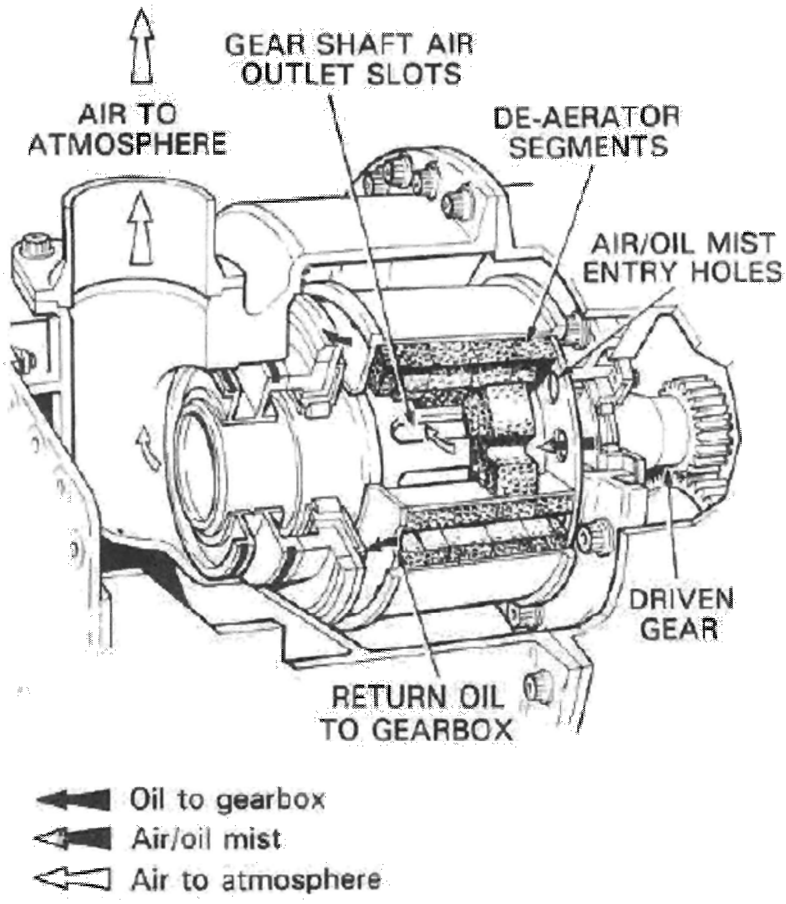

Figure 10.16: A centrifugal air-oil separator

The gearbox usually contains an air/oil centrifugal breather. The purpose of this component is to separate oil from the air mist in the gearbox. The air is vented overboard and the oil is returned to the tank.

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Anti Static Leak Check Valve

gas turbine engines are prone, when shut down, to oil draining back from the bearings and oil tank into the gearbox. Anti siphon tubes are usually fitted to prevent this, but as a back up leak check valves are fitted. An example is shown in the circuit below. During engine operation, oil pressure from the rear sump supply line holds the anti leakage valve open. When the engine is shut down, spring tension closes the valve.

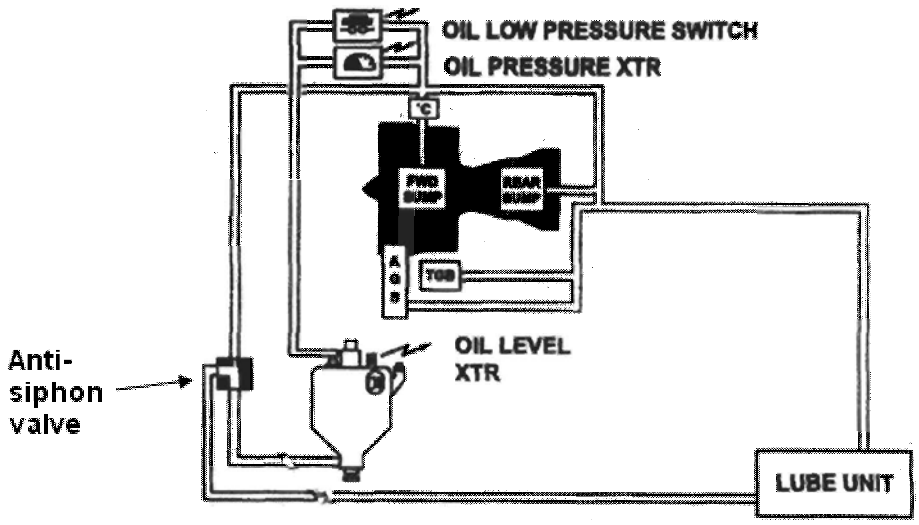

Figure 10.17: CFM 56 Oil Supply Circuit

Vent Sub-System

The presence of pressurised air in bearing cavities is as a result of gas path air leaking across carbon or labyrinth type oil seals. On some engines a separate sub system is installed to vent this seal leakage air overboard. Figure 10.18 illustrates RB 211-535 oil system which has a comprehensive vent sub system. Note however that the LP turbine bearing does not have an air vent line as the bearing is small enough to transmit the air with the oil back to the oil tank, where it is separated on the deareator tray.

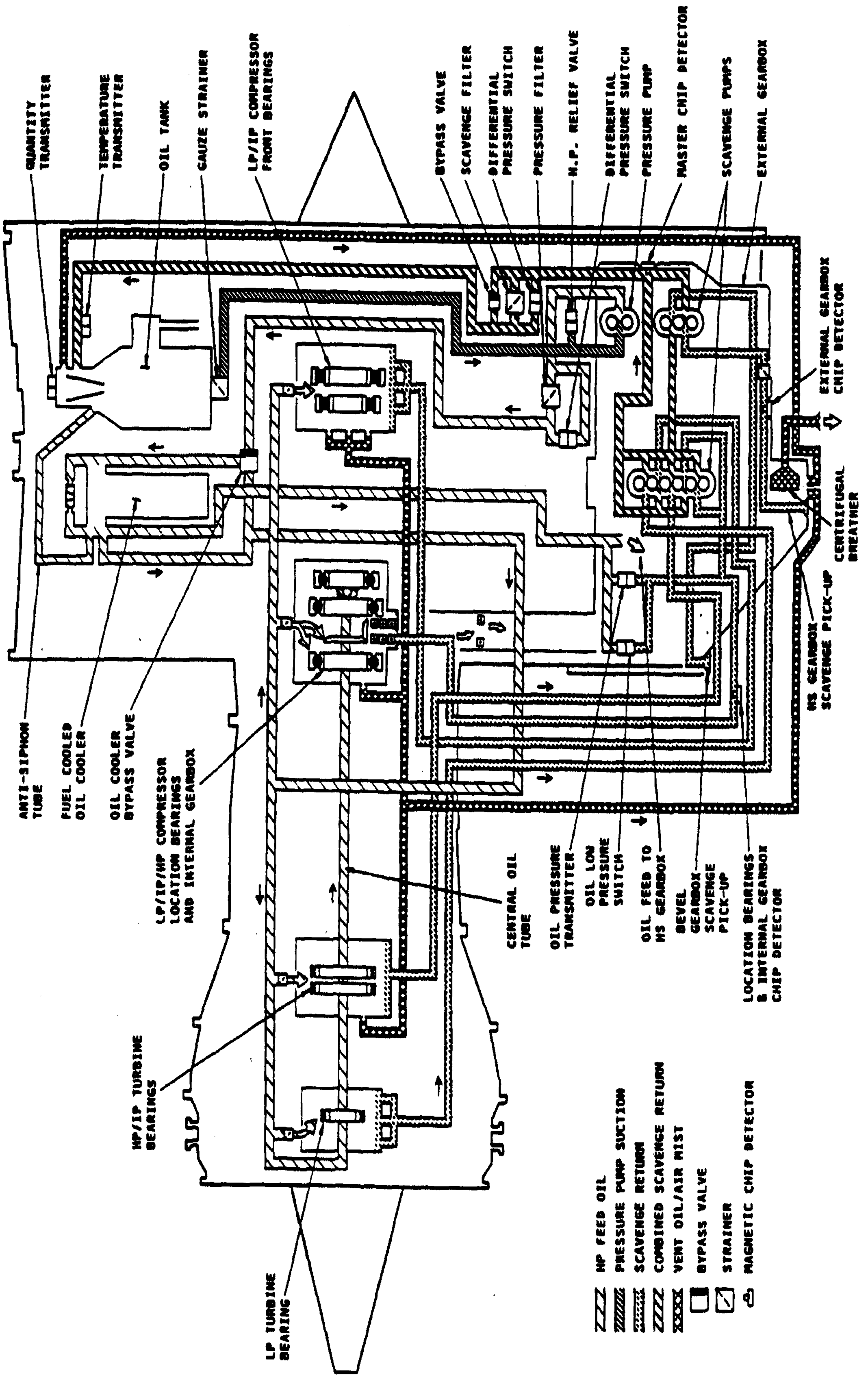

Figure 10.18: RB 211-535 Oil System

Chip Detectors

There are three types of chip detectors in common use:

Magnetic Chip Detectors
Indicating Magnetic Chip Detectors
Pulsed Chip Detectors

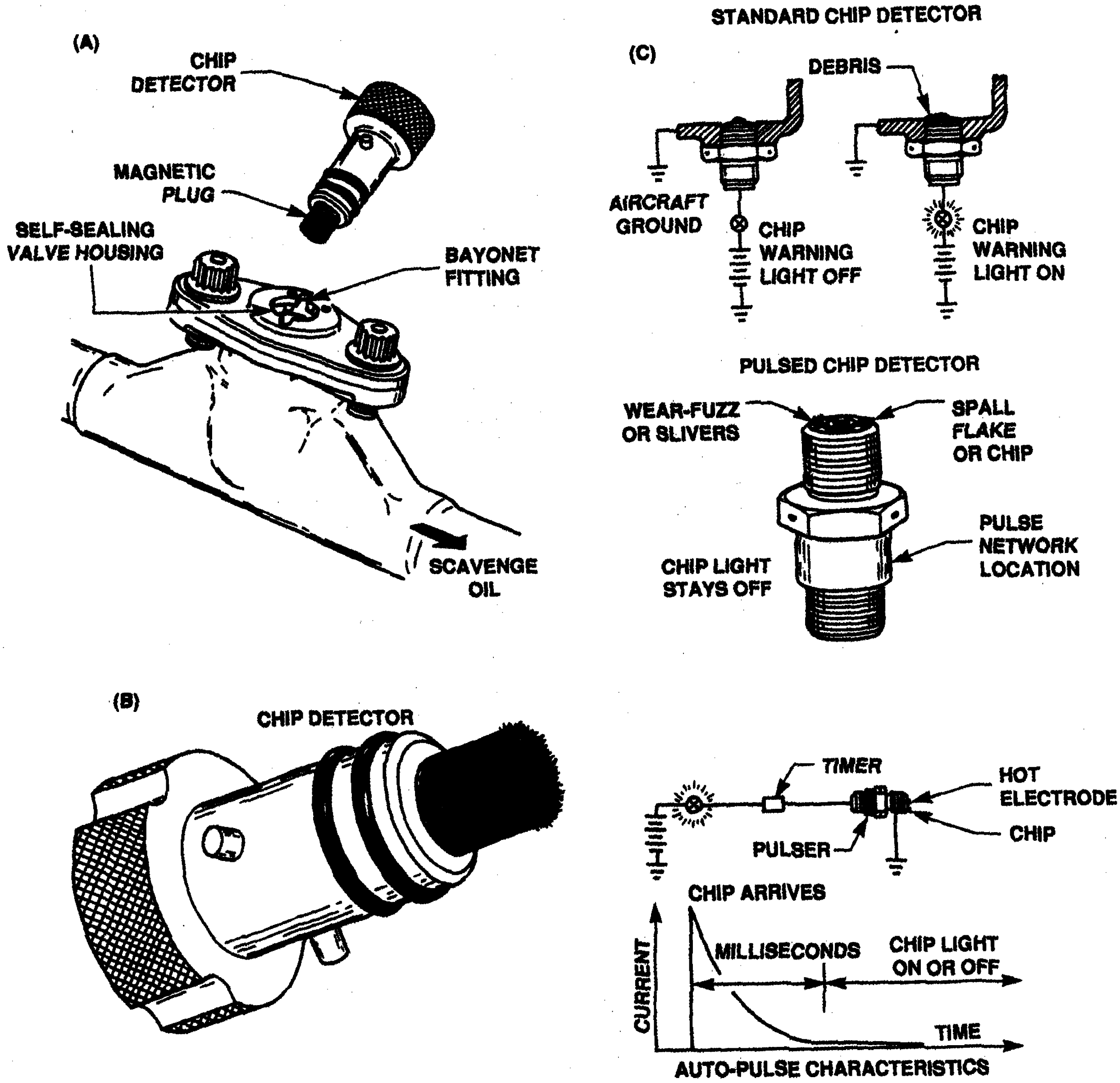

Figure 10.19: Magnetic, Indicating and Pulsed MCDs

Magnetic Chip Detectors (MCDs)

Many scavenge systems contain permanent magnet chip detectors which attract and hold ferrous metal particles which would otherwise circulate back to the oil tank and the engine pressure subsystem, possibly causing wear or damage. Chip detectors are a point of frequent inspection to detect early signs of main bearing failure.

As a general rule, the presence of small fuzzy particles or grey metallic paste is considered satisfactory and the result of normal wear. Metallic chips or flakes are an indication of serious internal wear or malfunction

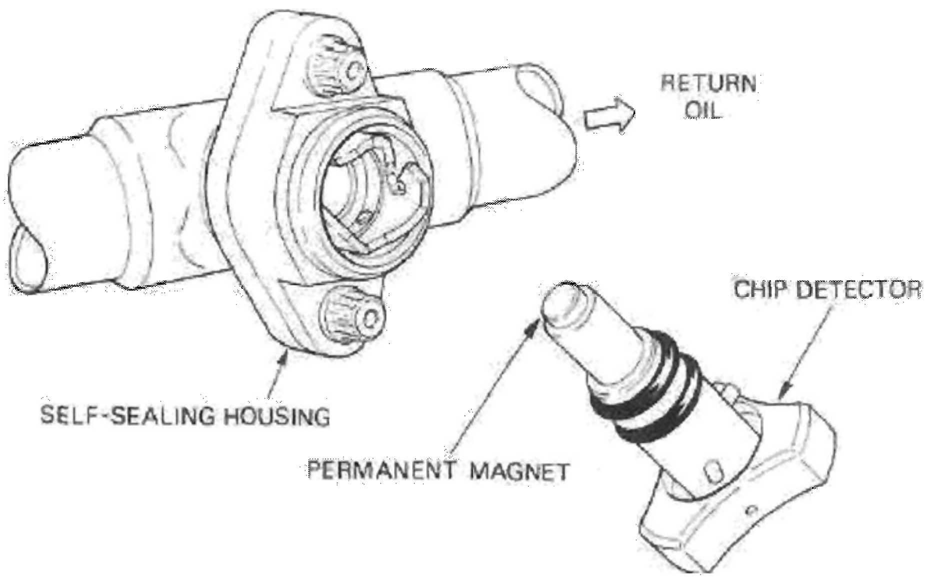

Figure 10.20: Magnetic Chip Detectors

NB The following safety precautions are required when fitting bayonet type MCDS

Ensure that serviceable seals are fitted
Ensure that the bayonet prongs are in place and secure
Ground run for leak check after fitment.

Indicating Magnetic Chip Detector

The diagram below shows an indicating-type magnetic chip detector. It has a warning circuit feature. When debris bridges the gap between the magnetic positive electrode in the centre and the ground electrode (shell), a warning light is activated in the cockpit. When the light illuminates, the flight crew will take whatever action is warranted, such as in-flight shutdown, continued operation at flight idle, or continued operation at normal cruise, depending on the other engine instruments readings.

Pulsed Chip Detector System

A newer type of chip detector is the Electric Pulsed Chip Detector, which can discriminate between small wear-metal particles, both ferrous and non-ferrous, considered non-failure related, and larger particles, which can be an indication of bearing failure, gearbox failure, or other potentially serious engine malfunction

The Pulsed Chip Detector looks like the Indicating Chip Detector at the gap-end, but its electrical circuit contains a pulsing mechanism which is powered by the aircraft 28 VDC bus.

The pulsed detector is designed with either one or two operating modes: Manual only or manual and automatic.

In the manual mode, each time the gap is sufficiently bridged, regardless of the particle size, the warning light will illuminate in the cockpit. The operator will then initiate the pulse; electrical energy will discharge across the gap-end in an attempt to separate the debris from the hot centre electrode. This procedure is called bum-off. If the light goes out and stays out, the operator will consider the bridging a result of a non-failure related cause. If the light does not go out, or repeatedly comes on after being cleared, the operator will take appropriate action, such as reducing engine power or shutting down the engine.

In the automatic mode, if the gap is bridged by small debris, a pulse of electrical energy discharges across the gap. The resulting burn-off prevents a cockpit warning light from illuminating by opening the circuit before a time-delay relay in the circuit activates to complete the current path to ground. If the debris is a large particle, it will remain in place after the burn-off cycle is completed and a warning light will illuminate in the cockpit when the time delay relay closes.

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.11 Fuel 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.

Table of Contents

Module 15.11 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 Reference	Level B1
Fuel Systems	15.11	2
Operation of engine control and fuel metering systems including electronic engine control (FADEC);		
Systems lay-out and components.		

Module 15.11 - Fuel Systems

Principles of Fuel Metering

The Fuel Metering Valve

The flow of a fluid through an orifice (jet) depends on the area of the orifice and the square root of the pressure drop across it, i.e.

Fuel Flow = Orifice Area x Pressure Drop

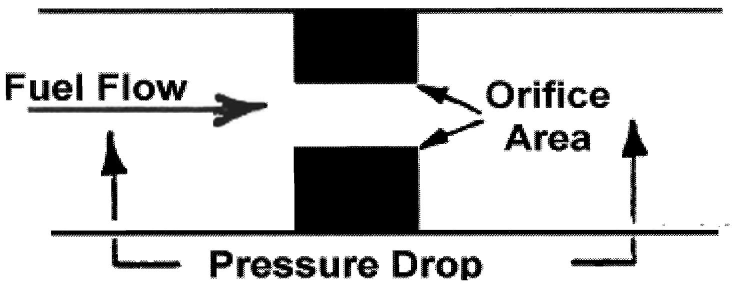


Figure 11.1: Principle of the fuel metering valve

Thus it is possible to vary fuel flow by changing orifice area or the pressure drop across the orifice. In a fuel system the orifice is variable and is in fact the throttle valve.

Application to the Flow Control System

In the flow control system the fuel flow required to give a selected RPM is selected by throttle area under the control of the pilot (manual control). Compensation for air density variation is superimposed on this selection by the altitude sensing control unit (pressure drop control unit) varying the pressure difference across the throttle valve.

Control Principle

The controlling principle of a flow control system is that a constant throttle pressure drop is maintained irrespective of throttle area (position) for a given height and speed.

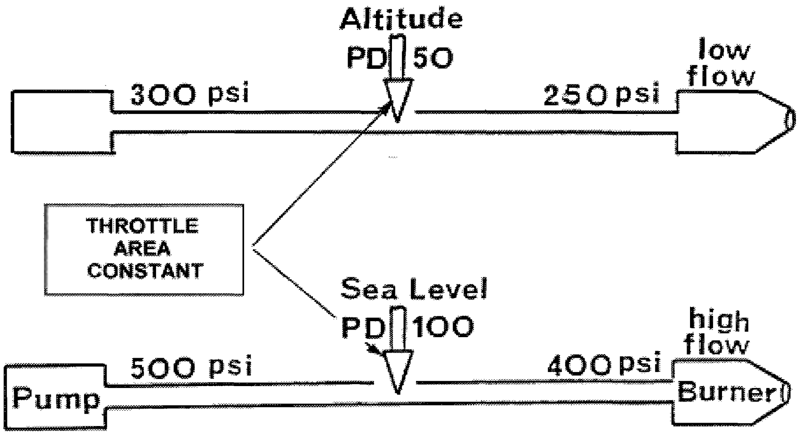


Figure 11.2: Principle of barometric flow control

If however, height and speed change, then the altitude sensing unit will vary the pump output and fuel flow (thus throttle pressure drop) by changing the pump output at constant throttle setting.

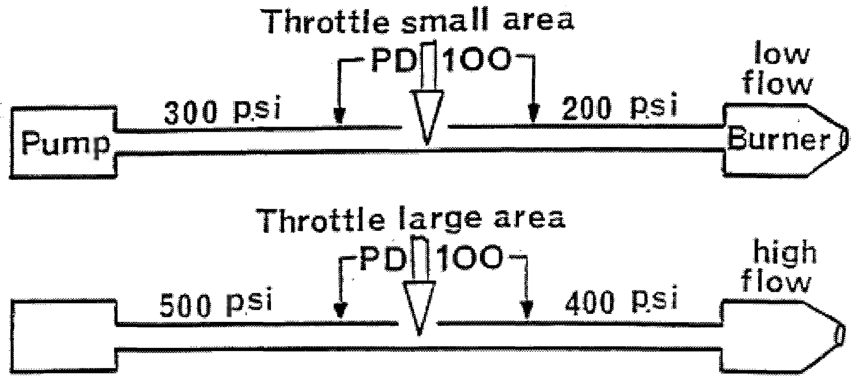


Figure 11.3: Constant pressure drop

Hydro-Mechanical Control Units

In hydro-mechanically operated flow control units (FCUs), the method of control is to use servo fuel as a hydraulic fluid to vary fuel flow (e.g. by varying pump swash-plate angle). The pressure of the servo fuel is varied by controlling the rate of flow out of an orifice at the end of the servo line; the higher the outflow, the lower will be servo pressure and vice versa. There are two types of variable orifice: the half-ball valve and the kinetic valve.

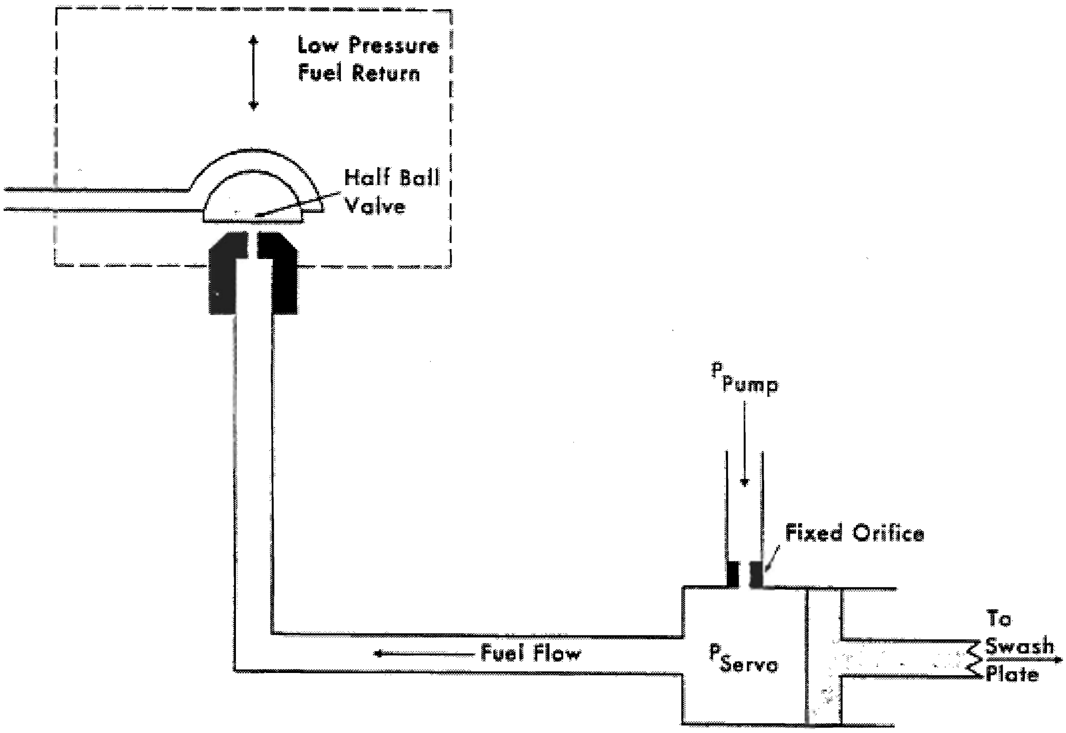


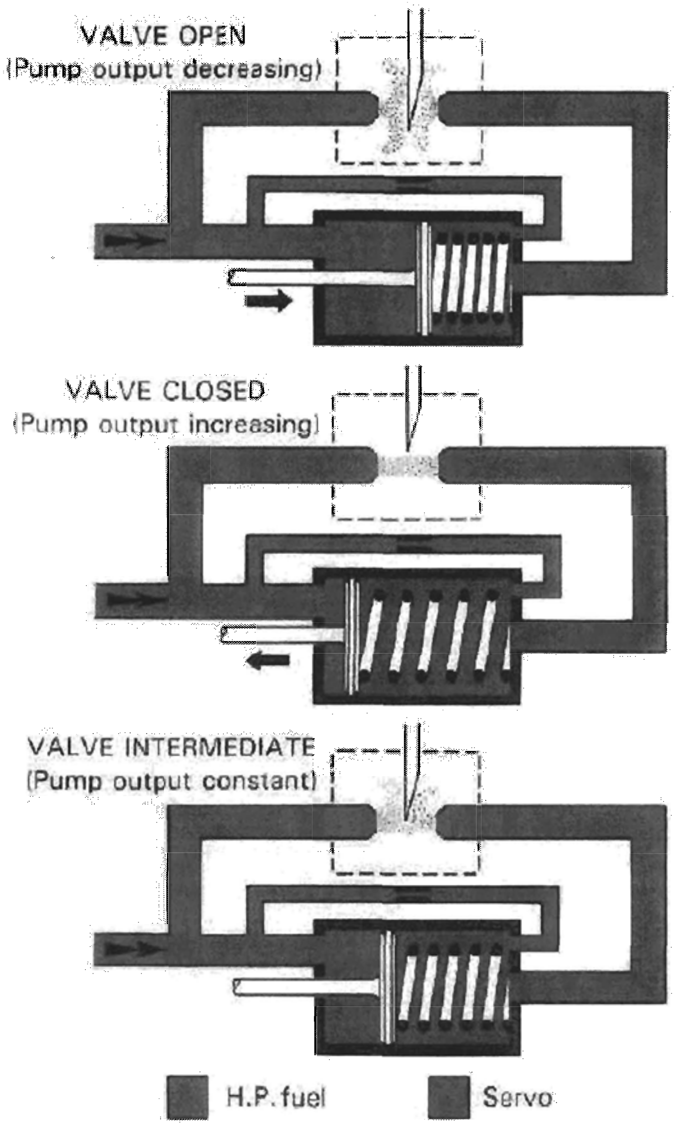
Figure 11.4: Half ball valve system

The Half-Ball Valve

In this arrangement, a half-ball on the end of a pivot arm is suspended above the fixed outlet orifice (see figure). Up and down movement of the valve varies servo fuel outflow and thus servo pressure and pump output.

The Kinetic Valve

A line containing pump output fuel is so placed as to discharge on to the face of the servo outflow orifice and the kinetic energy so produced restricts servo fuel bleed. A blade can be moved downwards to interrupt the high-pressure flow; this reduces the impact onto the servo orifice, thus causing a greater outflow and a reduction in servo pressure (see figure). The kinetic valve is less prone to dirt blockage than the half-ball type, although it is more complex.



Condition 1: With the kinetic valve in the open position, the blade separates the opposing flows from pump delivery and the servo cylinder. As there is no opposition to the servo flow, the volume of servo fluid reduces and the piston moves against the spring under the influence of pump delivery pressure. The movement of the piston reduces the pump stroke and therefore it's output.

Condition 2: With the valve fully closed, the kinetic energy of the pump delivery fuel prevents leakage from the servo chamber. Servo fuel pressure therefore increases and, with the assistance of the spring, overcomes the pump delivery pressure, thus moving the piston to increase the pump stroke and output.

Condition 3: Under steady running conditions, the valve assumes an intermediate position such that the servo fuel and spring pressure exactly balances the pump delivery pressure.

Figure 11.5: Operation of Kinetic Valves

Barometric Controls

The function of the barometric control is to alter fuel flow to the burners with changes in intake total pressure (P1) and pilot's throttle movement. Several different types of hydro-mechanical barometric control are available. Three of the most common types are described. For simplicity, the description and operation of each type of flow control is related to the half-ball valve method of controlling servo fuel pressure.

Simple Flow Control

The Simple Flow Control Unit (see figure 11.6) comprises a half-ball valve acting on servo fuel bleed, whose position is determined by the action of an evacuated capsule (immersed in P1 air) and a piston subjected to the same pressure drop as the throttle valve. Fuel from the pump passes at pressure P pump through the throttle, where it experiences a pressure drop to burner pressure P burner. The response to P1 and throttle variations can now be examined.

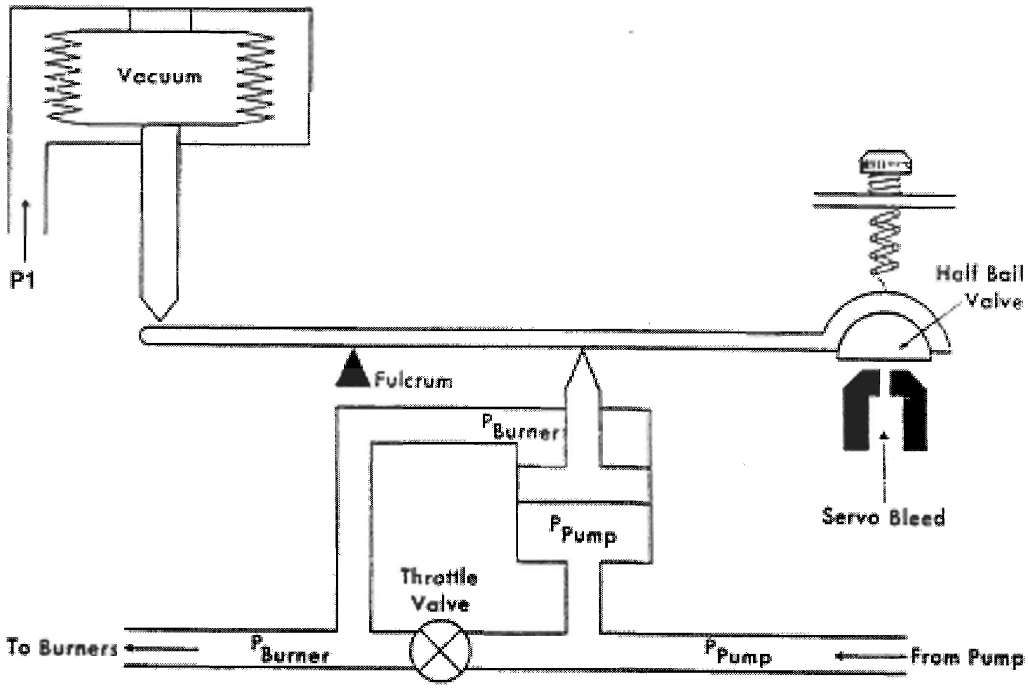


Figure 11.6: Simple flow control

Throttle Variations

If the pilot opens the throttle, the throttle orifice area increases, throttle pressure drop reduces and therefore PPUMP falls, PBURNER rises and the piston moves down, allowing the spring to lower the half-ball valve against the capsule force, increasing servo pressure and pump output. The increased fuel flow increases the throttle pressure drop to its original value, returning the half-ball valve to its sensitive position.

P1 Variations

If the aircraft climbs, P1 will fall, causing the capsule to expand and raise the half-ball valve against the spring force. Servo pressure will fall, swashplate angle will reduce and fuel pump output will reduce. The reduced flow will cause a reduced throttle pressure drop.

Thus Simple Flow Control keeps the throttle pressure drop constant, regardless of throttle position. At very high altitude the system becomes insensitive and it is not used on large turbo-jets. Nevertheless, it is fitted on the Adour and Dart and has proved to be a reliable and fairly accurate control unit.

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Proportional Flow Control

The Proportional Flow Control Unit (see figure 11.7) was designed for use on large engines with a wide range of fuel flow. The problem of accurate control over this wide range was overcome by operating the controlling elements on a proportion of the main flow.

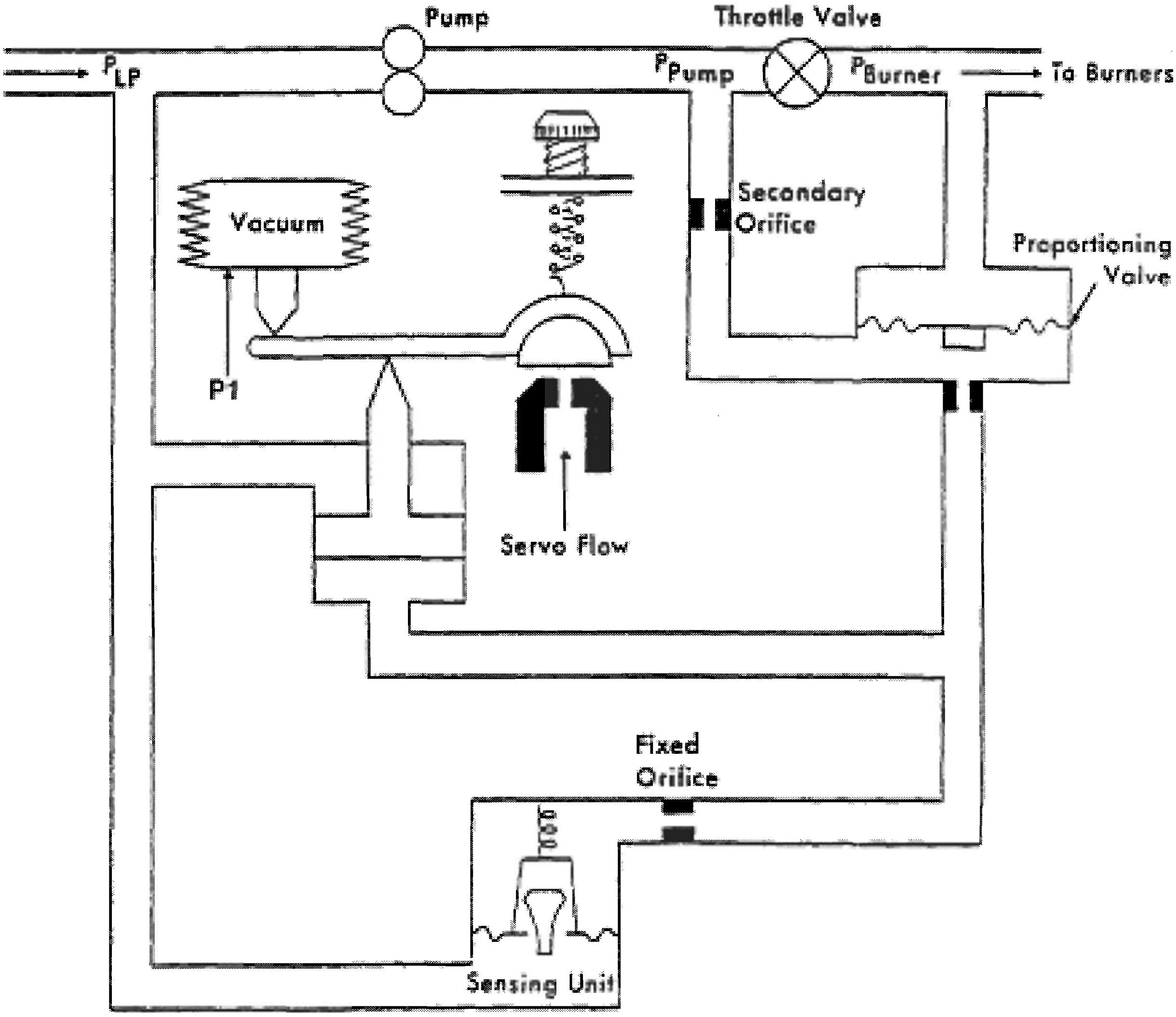

Figure 11.7: Proportional flow control

The proportion varies over the flow range, so that at low flows a high proportion is used for control and at high flows, a smaller proportion. Fuel passes into the controlling (or secondary) line through a fixed secondary orifice and flows out through another orifice to the LP side of the pump. Secondary flow is controlled via the proportioning valve and sensing valve, which maintains an equal pressure drop across the throttle valve and secondary orifice. Servo pressure is controlled by a half-ball valve operated by P1 and by secondary pressure.

Throttle Variations

If the throttle is opened, its pressure drop is reduced and the proportioning valve closes until the pressures across the diaphragm are equalised. Thus secondary flow and pressure are reduced, the piston drops, the half-ball valve closes and pump stroke increases. The increased fuel flow increases secondary pressure until the half-ball valve resumes its sensitive position, but the proportioning valve remains more closed than previously, taking a small proportion of the increased flow.

P1 Variations

Variations in P1 will cause the capsule to expand or contract, thus altering the position of the half-ball valve and altering fuel flow. This tends to cause rapid changes in secondary pressure with resultant instability; damping is provided by the sensing valve, which adjusts to control the outflow to LP, thus damping secondary pressure fluctuations. The valve is contoured to operate only over a small range of pressure drops so that during throttle movements it acts as a fixed orifice.

Acceleration Control Units

The function of the Acceleration Control Unit (ACU) is to provide surge-free acceleration during rapid throttle openings. There are two main types of hydro-mechanical ACU in service.

The Flow Type ACU

With the flow type ACU (see figure 11.8) all the fuel from the pump passes through the unit, which compares fuel flow with compressor outlet pressure (P3), which is proportional to engine speed.

The fuel from the pump passes through an orifice containing a contoured plunger; the pressure drop across the orifice is also sensed across a diaphragm.

When the throttle is opened, the pump moves towards maximum stroke and fuel flow increases. The increased flow through the ACU orifice increases the pressure drop across it and the diaphragm moves to the right, raising the half ball valve and restricting pump stroke. The engine now speeds up in response to the limited over-fuelling and P3 rises, compressing the capsule. The plunger servo pressure drops and the plunger falls until arrested by the increased spring force. The orifice size increases, pressure drop reduces and the diaphragm moves to the left, closing the half-ball valve and increasing fuel flow. Fuel flow will increase in direct proportion to the increase in P3.

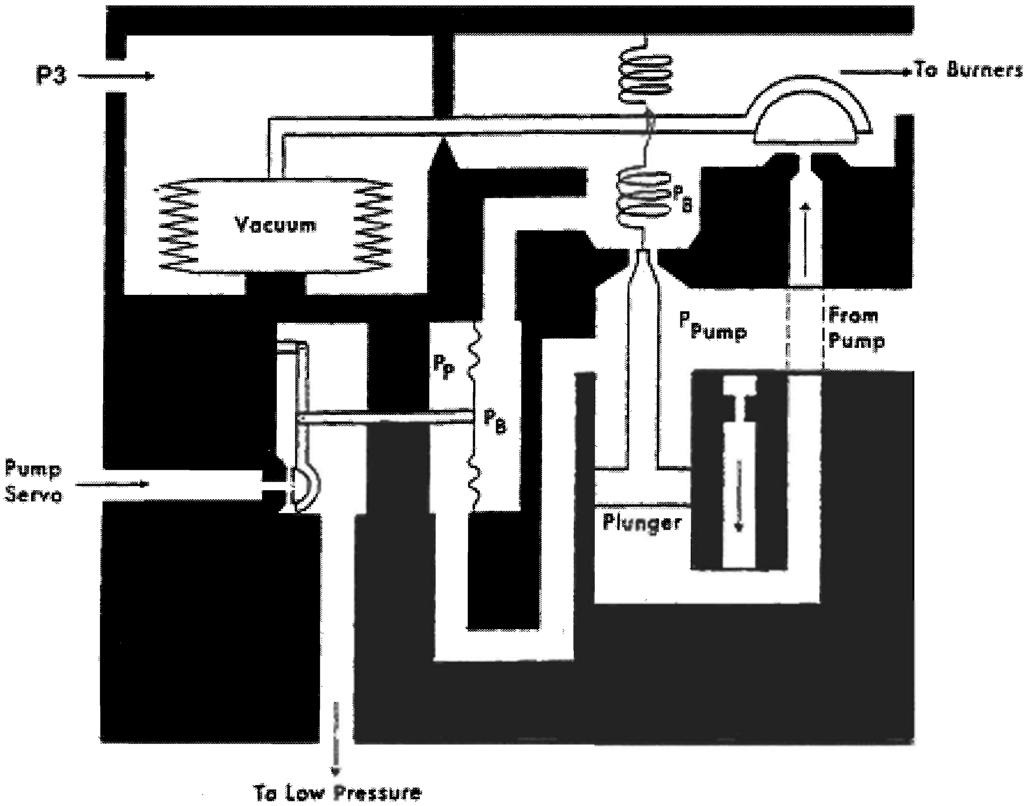

Figure 11.8: Acceleration Control Using Compressor Discharge Pressure

The Air Switch

In order to keep the acceleration line close to the surge line, it is necessary to control on "Split P3 air" (a mix of P3/P1) initially and then on full P3 at higher engine speeds. This is achieved by the air switch (or P1/P3 switch) shown in the figure 11.9. At low speeds, P3 passes through a plate valve to P1 and the control capsule is operated by reduced, or split P3 until P3 becomes large enough to close the plate valve and control is then on full P3.

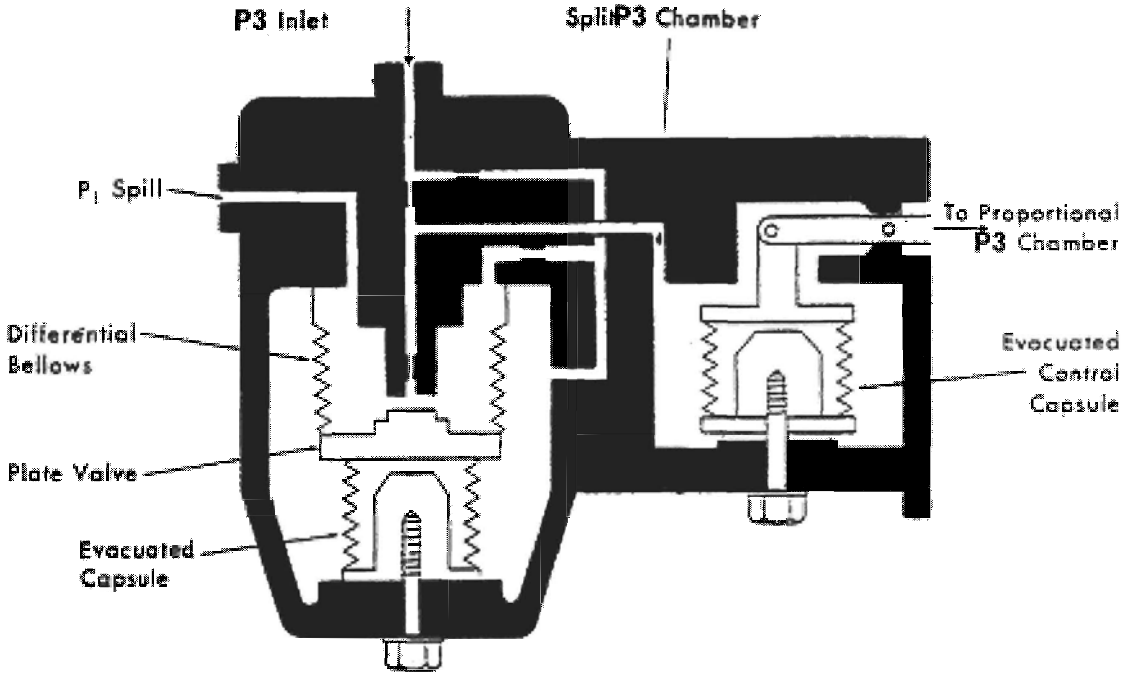

Figure 11.9: Air switch

The dashpot Type ACU

The dashpot ACU uses two co-axially mounted throttle valves, The inner one is moved by the pilot, the outer (main) throttle valve will move but is controlled by a dashpot which slows the valve movement down to limit the acceleration fuel flow. When closing the throttle the pilot pushes both sleeves in together.

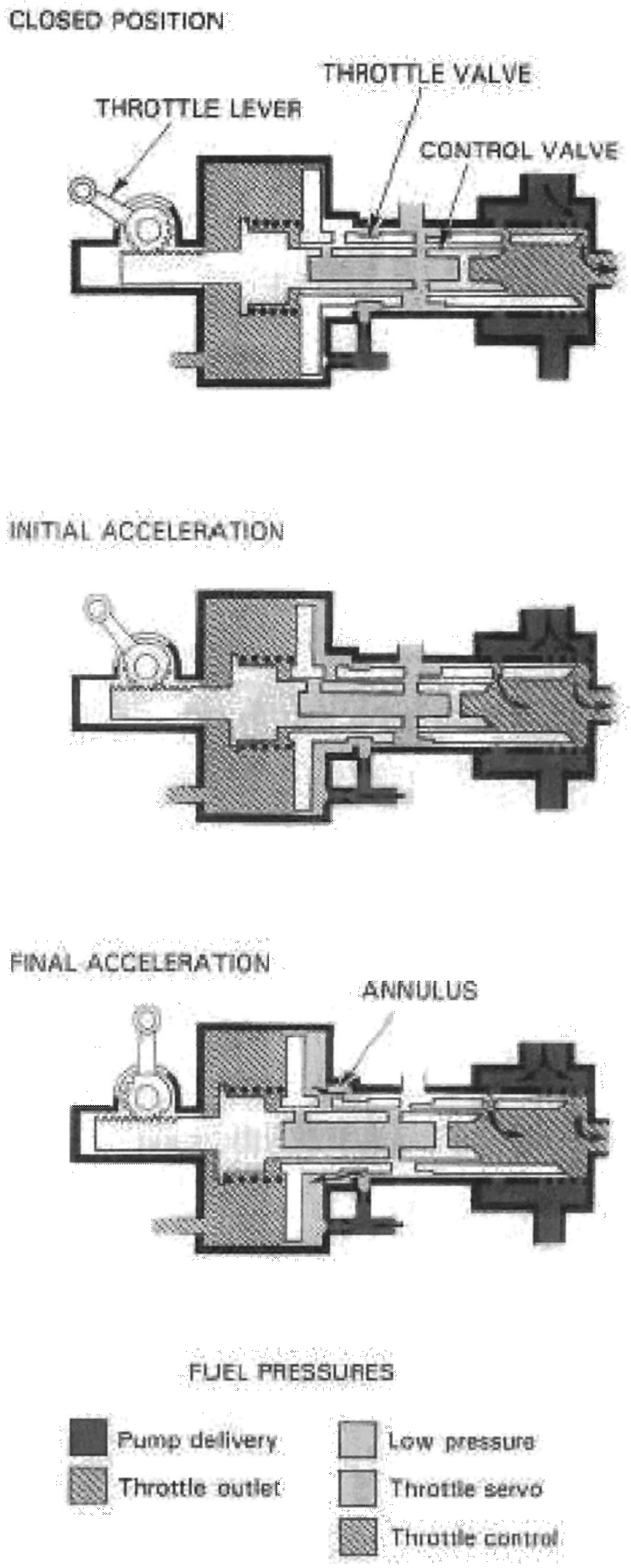

Figure 11.10: Dashpot throttle

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Engine Protection Devices

Described below are typical protection devices that will override any excessive demands made on the engine by the pilot or by the control units.

Top Temperature Limiter

Turbine gas temperature is measured by thermocouples in the jet pipe. When maximum temperature is reached, these pass a signal to an amplifier, which limits pump stroke by reducing pump servo pressure or moves the throttle valve in series with the pilot.

Power Limiter

A power limiter is fitted to some engines to prevent over-stressing due to excessive compressor outlet pressure during high-speed, low altitude running. The limiter (see figure 11.11) takes the form of a half-ball valve which is opened against a spring force when compressor outlet press (P3) reaches its maximum value. The half-ball valve bleeds off air pressure to the ACU control capsule, thus causing the ACU to reduce pump stroke.

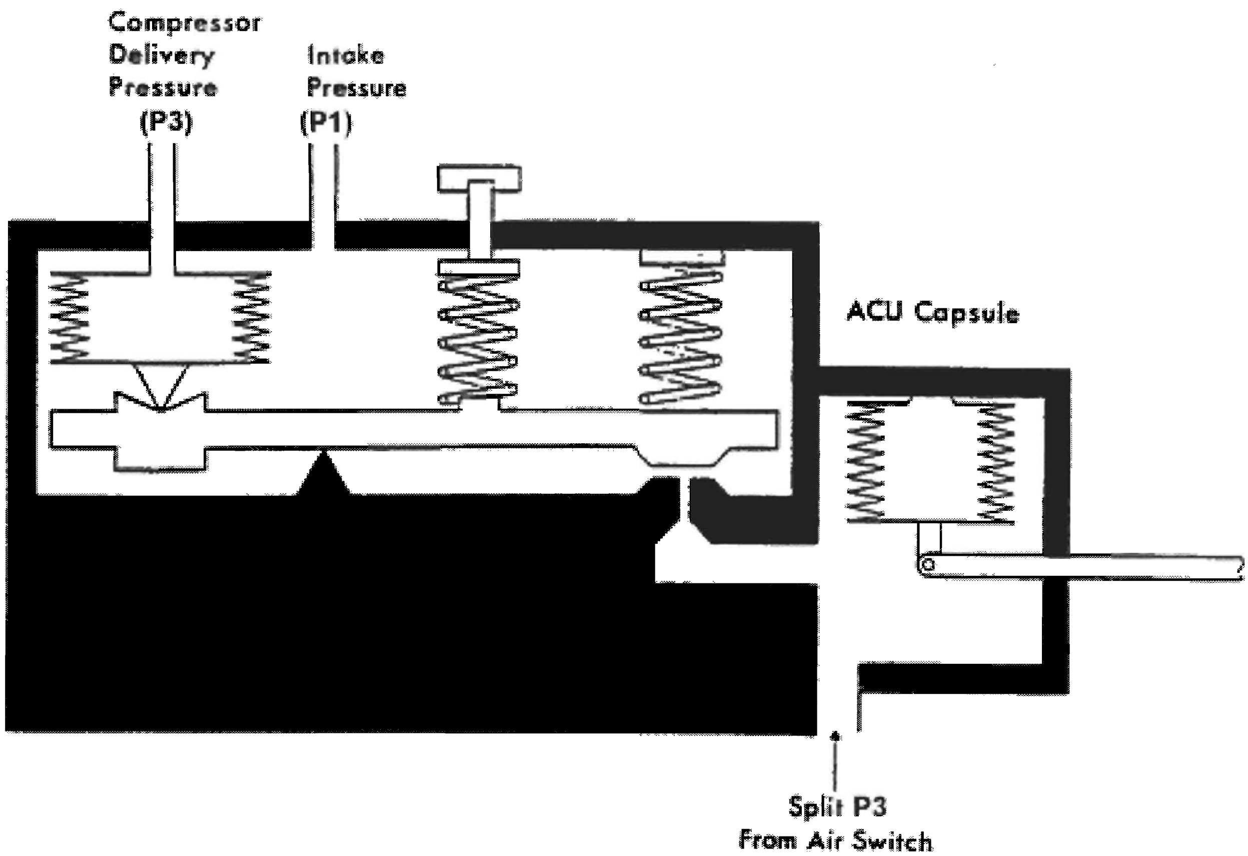

Figure 11.11: Power limiter

Overspeed Governor

The engine is protected against over-speeding by a governor, which, in hydro-mechanical systems, is usually fitted on the fuel pump and acts by bleeding off pump servo fuel when the governed speed is reached. On two-spool engines, the pump is driven from the HP shaft and the LP shaft is protected by either a mechanical governor or an electro-mechanical device, again acting through the hydro-mechanical control system. There are two types of pump-driven governors:

Centrifugal Governor

The centrifugal type of governor uses the centrifugal pressure of fuel in radial drillings in the fuel pump rotor to deflect a diaphragm at maximum speed. The diaphragm operates on a half-ball valve to reduce pump servo pressure and thus pump stroke. The disadvantage of this type is that it needs to be reset if fuel specific gravity changes. It is seldom used on modern engines.

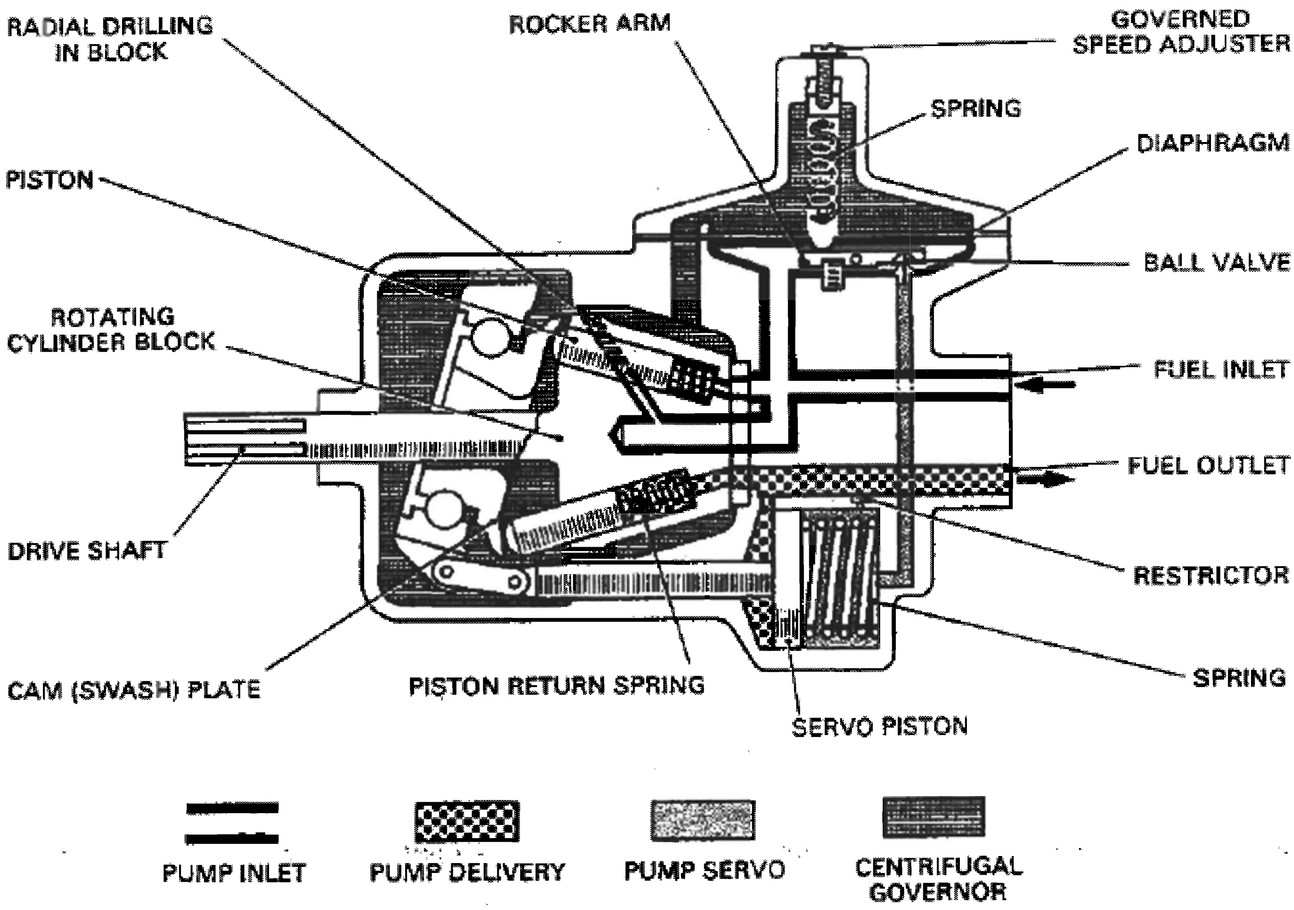

Figure 11.12: Centrifugal Governor

Centrifugal governors using bob weights are used as LP shaft governors on some engines. They will return fuel to low pressure when the LP shaft overspeeds see figure 11.13.

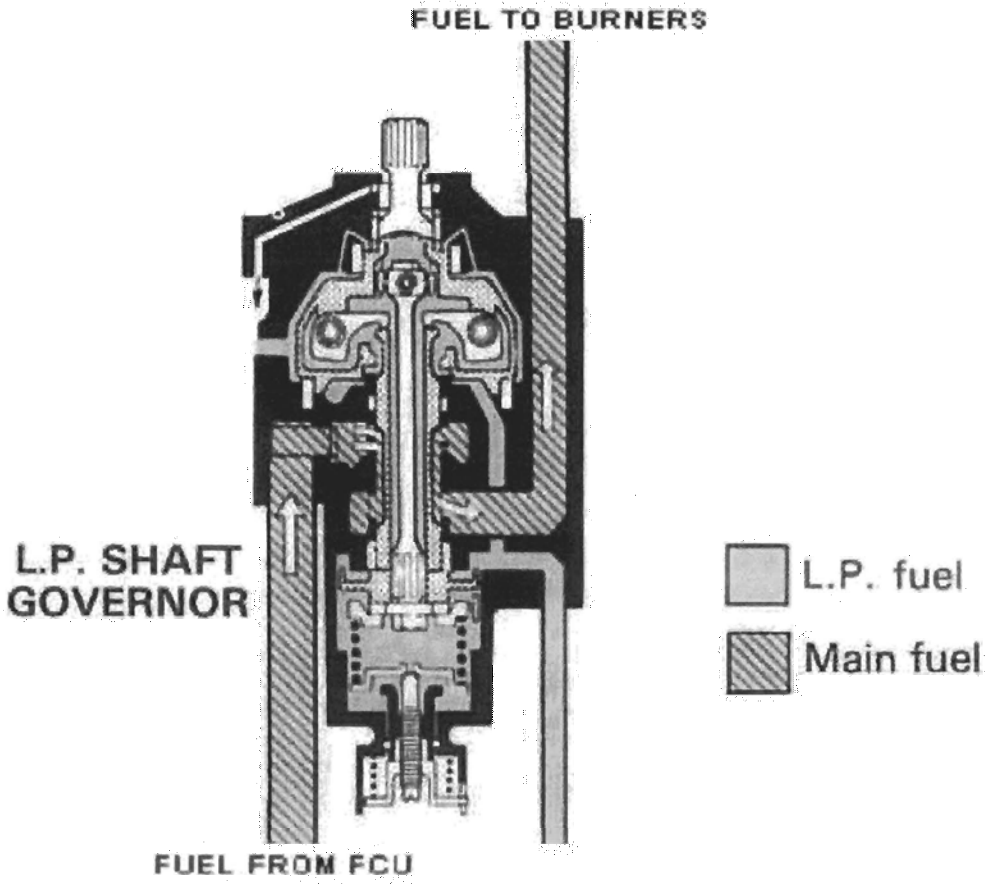

Figure 11.13: LP Shaft Governor

Hydro-mechanical Governor

In the hydro-mechanical governor the pump drive shaft rotates a rotor containing a half-ball valve on a lever arm (shown in the figure 11.14.). As engine speed increases, centrifugal force closes the valve, increasing the pressure of fuel in the governor housing (governor pressure) by restricting its flow to LP. When the maximum speed is reached, governor pressure is high enough to deflect a diaphragm, which opens the half-ball valve acting on pump servo. A hydro-mechanical governor does not require adjustment for changes in fuel specific gravity.

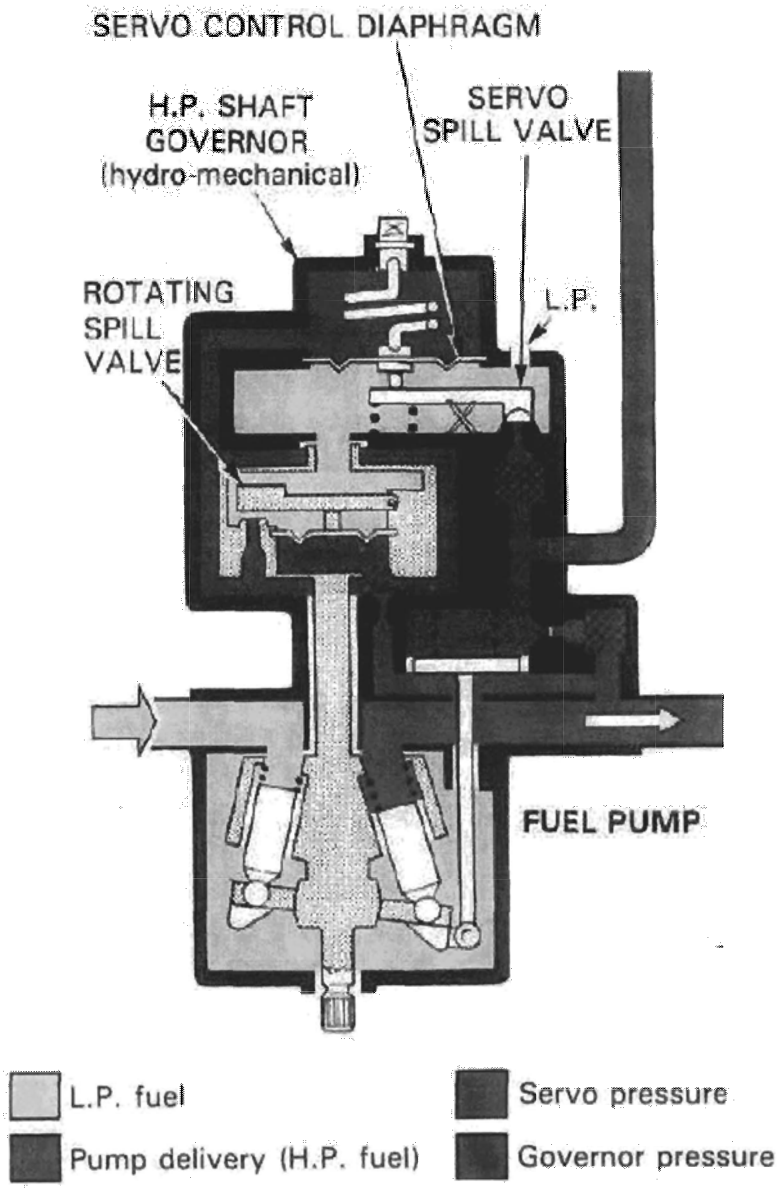

Figure 11.14: HP Hydro-Mechanical Governor

Systems

Fuel System Requirements

A gas turbine engine fuel system is required to:

- Provide fuel to the engine in a form suitable for combustion
- Provide control of fuel to enable the engine to operate under all conditions of the flight envelope.
- To provide control of fuel to enable stable acceleration and deceleration to take place
- To provide limit control to ensure the safety of the engine

Fuel System Components

The system will consist of a number of both manual and automatic control units and pumps. Some of the control units and pumps are driven by the engine gearbox. The control units may be hydro-mechanic or electronic. The system will consist of the following components:

- An engine driven LP Pump
- Fuel heater
- Fuel Cooled Oil Cooler (FCOC)
- Fuel Flowmeter
- LP Filter
- An engine driven HP Pump
- Fuel Control Unit (FCU.)
- Throttle and HP Fuel Cock (usually combined with the FCU)
- HP Fuel Filter
- Fuel nozzles

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Low Pressure Sub-System

Fuel systems are broadly composed of a Low Pressure System, and a High Pressure System. Figure 11.15 shows the components within the low pressure system.

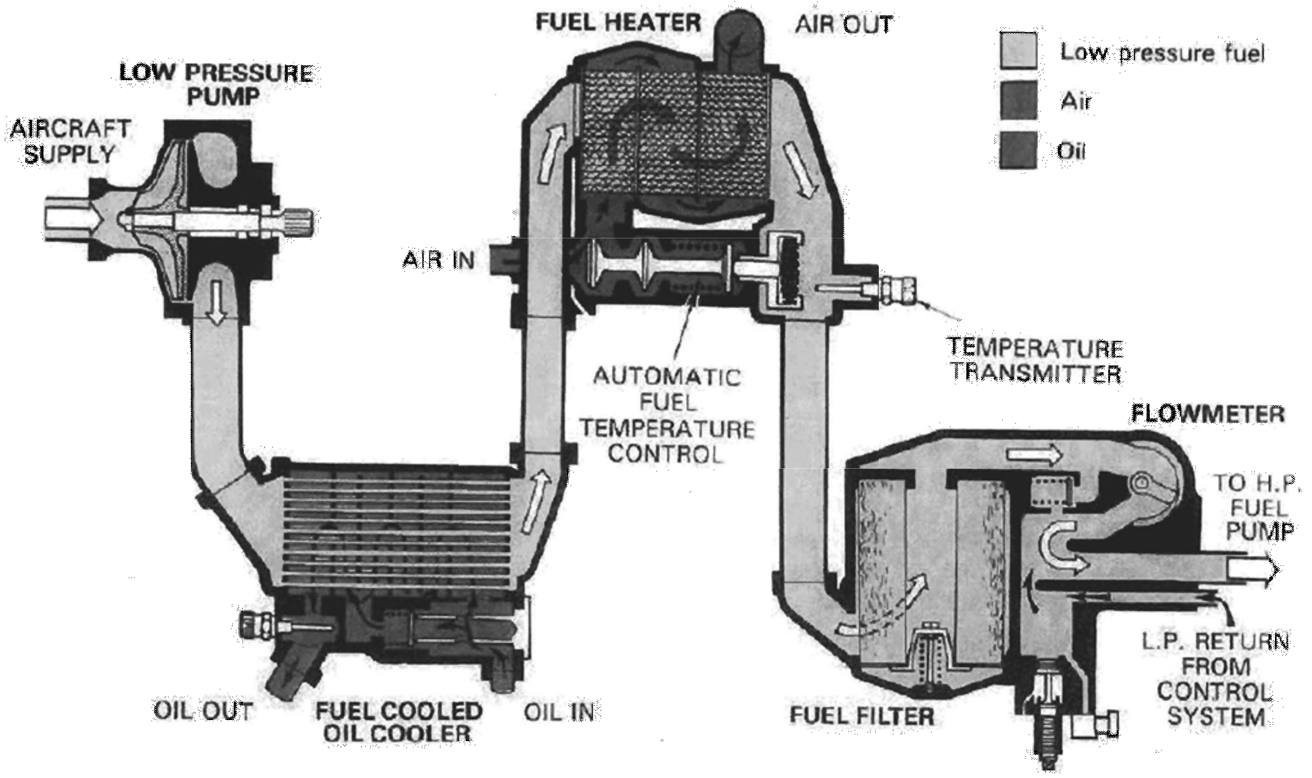


Figure 11.15: Components of the low pressure side of a fuel system

Engine driven Low Pressure Pump

This is fitted so that cavitation does not occur at the HP pump. It is likely to be either a **Vane type** pump or a **Centrifugal type** pump as shown in the diagram above.

Fuel Cooled Oil Cooler (FCOC)

The engine oil picks up considerable amounts of heat when operating. Fuel is often used to cool down the oil, which serves a dual purpose of ensuring that any water in suspension in the fuel will not freeze, causing a blockage when it is passed through the fuel filter. As a consequence the FCOC is always fitted upstream of the LP fuel filter.

Fuel Heater

This is fitted to ensure that the fuel is adequately heated for the same reason as that stated in the oil cooler above. It may not be needed however, therefore there is an automatic bypass valve which operates on the fuel temperature. When operating, a warning light will be illuminated on the flight deck. A fuel heater is not fitted to all engines.

Low Pressure Filter

Provides filtration before the HP system. Consists of a light alloy casing containing a paper or felt element. there will usually be sensors which detect the pressure drop across the filter. If the filter becomes blocked, the pressure drop will rise and a warning light will illuminate in the cockpit.

Fuel Flowmeter Transmitter

Provides signals of engine **fuel flow** and **fuel used** to the flight deck instruments. The signal may be generated by a moveable vane, mounted in the fuel flow path in such a way that its movement will be proportional to fuel flow. This movement is linked to a unit which develops an electrical signal which is sent to the indicator. In the event of a failure or blockage in this unit a bypass valve, operating under differential pressure will open. An alternative device uses a rotating turbine to measure fuel flow. See Chapter 15.14 (Engine Instrumentation) for details.

High Pressure Sub-System

Overview

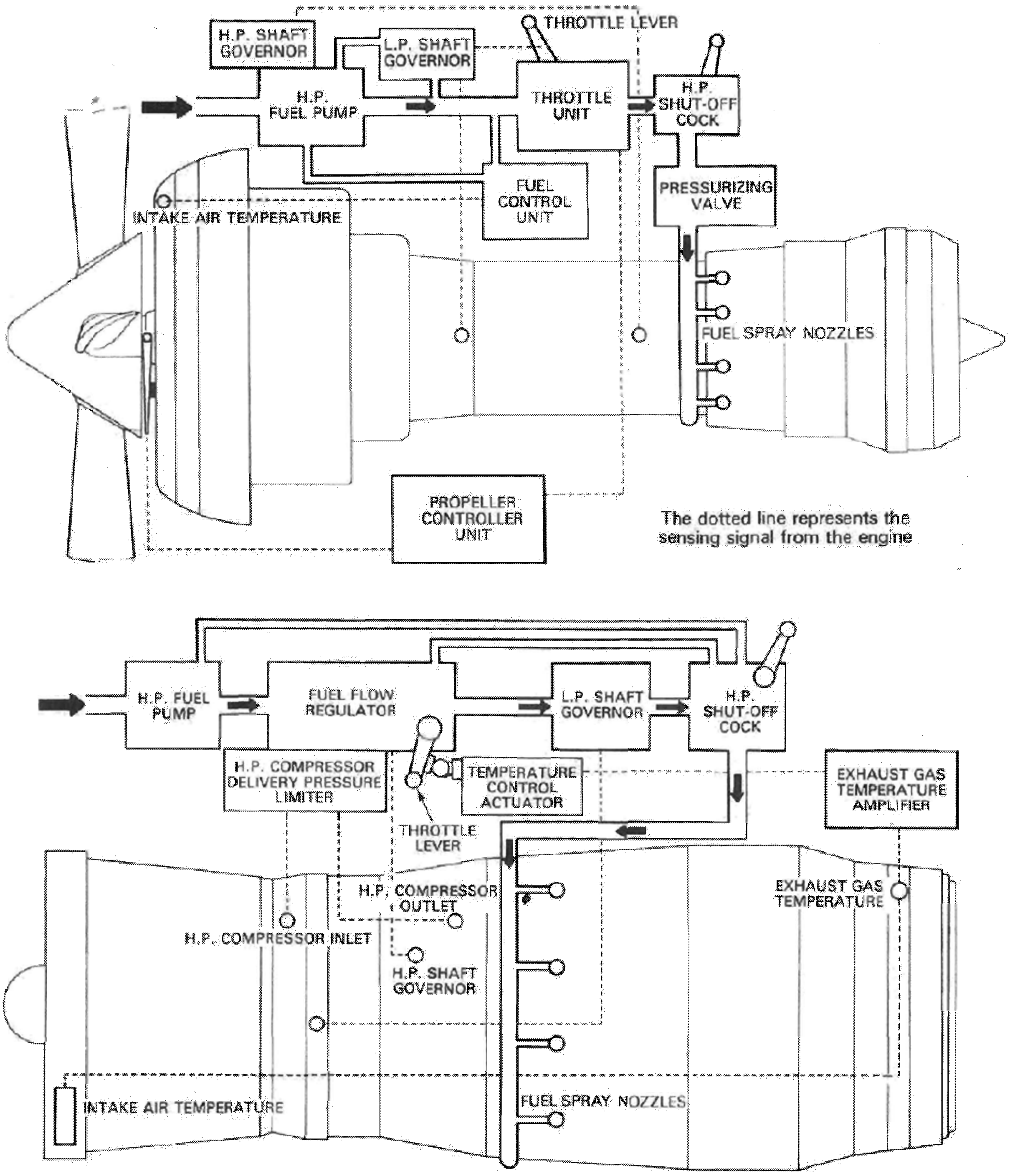


Figure 11.16: The main components within the high pressure system – Turboprop and turbojet engines

HP Fuel Control Systems

A typical high pressure (HP) fuel control systems for a turbo-jet engine is shown in simplified form above consisting of an HP pump, a throttle control and a number of fuel spray nozzles. In addition, certain sensing devices are incorporated to provide automatic control of the fuel flow in response to engine requirements.

The usual method of varying the fuel flow to the spray nozzles is by adjusting the output of the HP fuel pump. This is effected through a servo system in response to some or all of the following:

Throttle movement
Air temperature and pressure
Rapid acceleration and deceleration
Signals of engine speed, engine gas temperature and compressor delivery pressure.

Engine Driven High Pressure Fuel Pump

This pump will deliver the required fuel flow as determined by the FCU. A gear type pump, or a swash plate pump can be used to deliver high fuel pressure to the burners. The former for low fuel burner pressure systems (Spray nozzles) the latter for high fuel burner pressure systems (Duplex fuel nozzles).

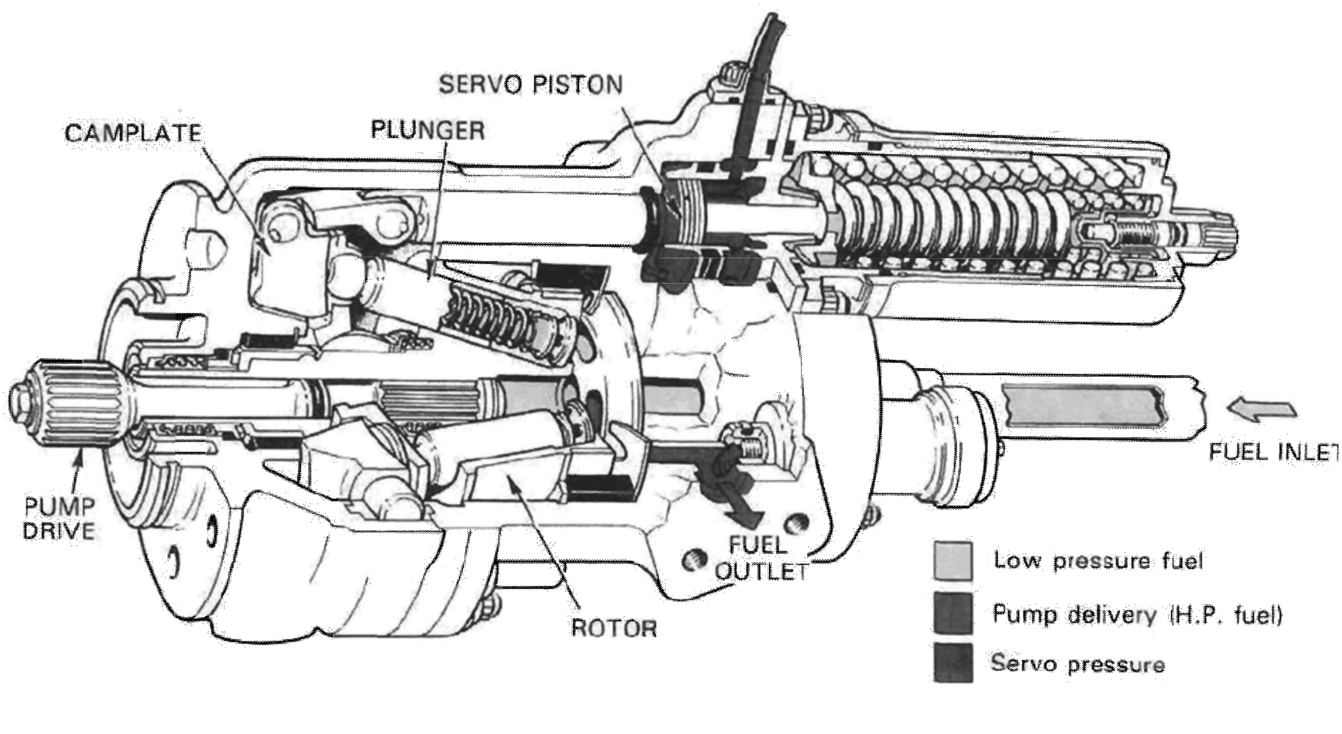


Figure 11.17: Plunger or Swash Plate Type HP Pump

The swash plate pump is driven by a gear train within the accessory or High Speed Gearbox. The pump consists of a rotor assembly fitted with several plungers, the ends of which project from their bores and bear on to a non-rotating cam-plate. Due to the inclination of the cam-plate, movement of the rotor imparts a reciprocating motion to the plungers, thus producing a pumping action. The stroke of the plungers is determined by the angle of inclination of the cam-plate. The degree of inclination is varied by the movement of a servo piston that is mechanically linked to the cam-plate and is biased by springs to give the full stroke position of the plungers. The piston is subjected to servo pressure on the spring side and on the other side to pump delivery pressure; thus variations in the pressure difference across the servo piston cause it to move with corresponding variations of the cam-plate angle and, therefore, pump stroke.

With the engine shut down the swash plate will be at maximum angle and hence the pump at maximum stroke and output. Minimum servo pressure will cause the swash plate to move to minimum stroke and zero output. Control of the servo pressure is either by half ball valves or kinetic knives. The fuel system shown overleaf utilizes half ball valves controlling servo pressure and hence pump output.

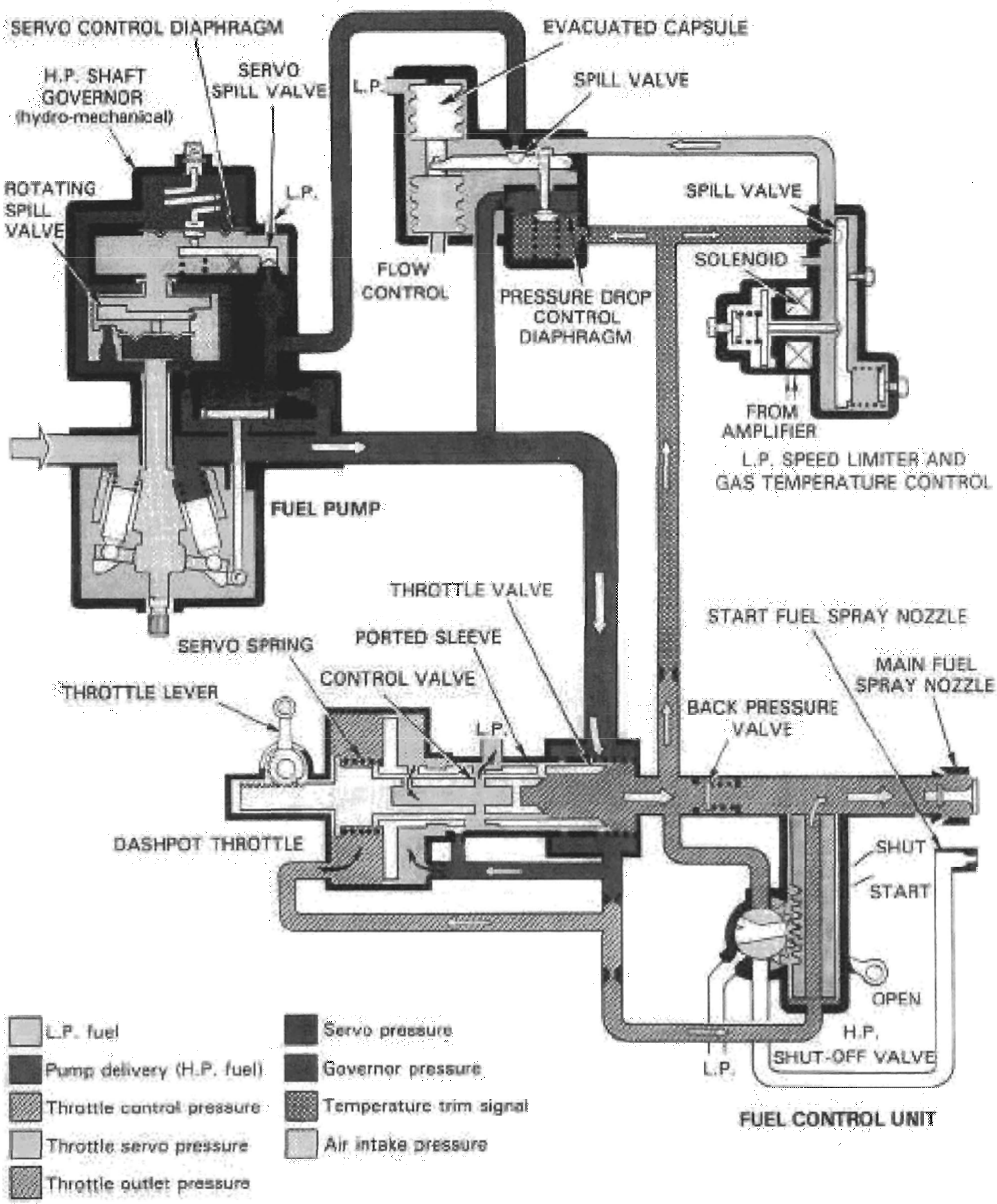


Figure 11.18: Turbo-Jet Pressure Control Fuel System

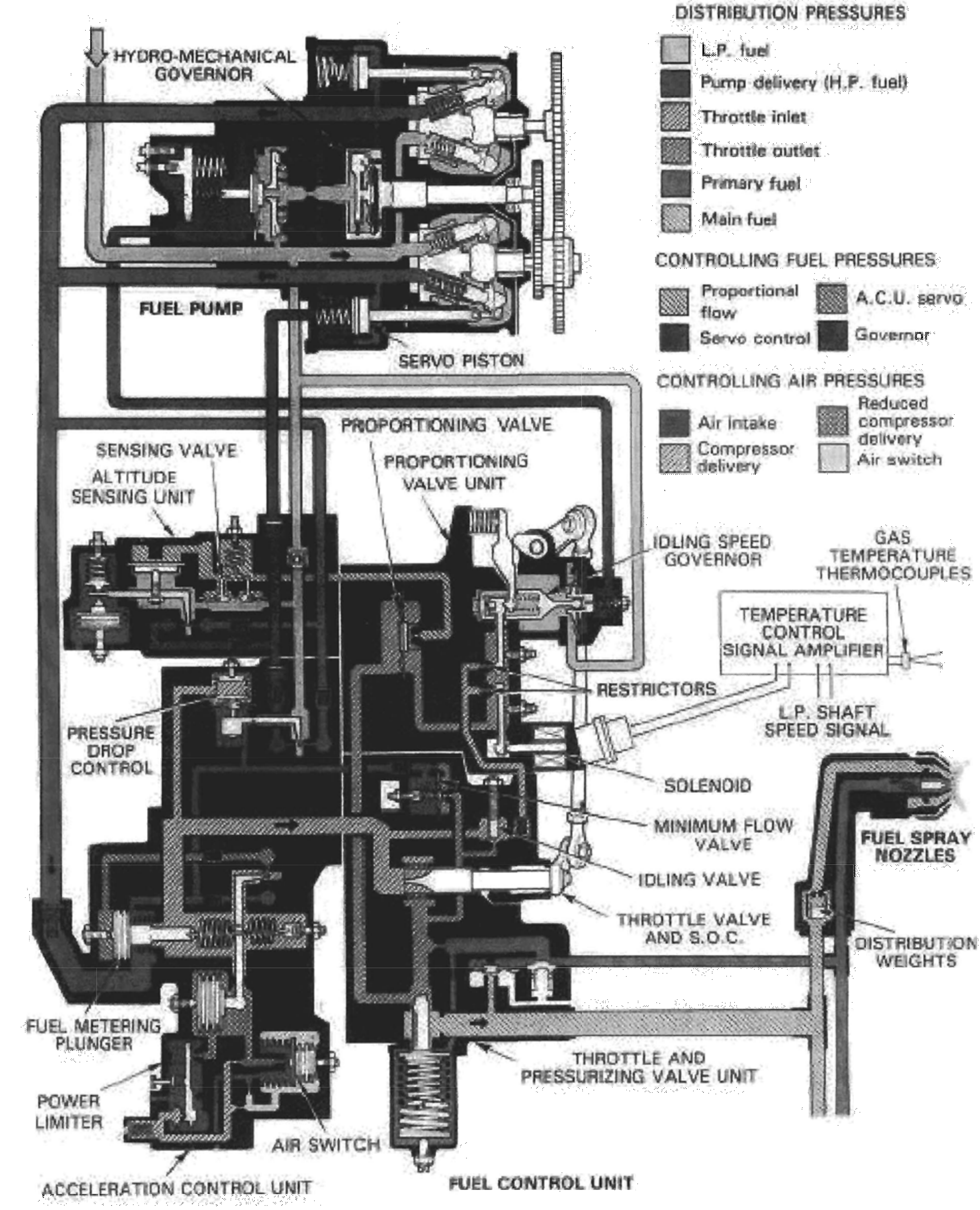


Figure 11.19: A Proportional Flow Control System

The proportional flow system is more compact than the earlier pressure drop system and is more tolerant of flow rate changes downstream of the throttle. The following discussion looks at the fuel flow regulating device in terms of air fuel ratios and signal inputs to the Fuel Flow Governor

The Fuel Flow Regulator Device

The fuel control is an engine driven accessory which can operate by mechanical, hydraulic, electrical, or pneumatic forces in various combinations. The purpose of the fuel control is to maintain a correct combustion zone air-to-fuel mixture ratio of 15:1 by weight. This ratio represents weight of combustor primary air to weight of fuel. Sometimes this is expressed as a fuel-air ratio of 0.067:1. All fuels require a certain proportion of air for complete burning, but at rich or lean mixtures the fuel will burn but not completely. The ideal proportion for air and jet fuels is 15:1, and it is called the stoichometric (chemically correct) mixture.

Quite often one can see the air-fuel ratio expressed as 60:1. When this occurs, the writer is expressing the air-fuel ratio in terms of the total airflow rather than of primary combustor airflow. If primary airflow is approximately 25 percent of total airflow, then 15:1 is 25 percent of 60:1. A gas turbine engine will experience a rich to lean mixture of about 10:1 during acceleration and 22:1 during deceleration. If the engine is using 25 per cent of its total airflow in the combustion zone, the mixture, when expressed in terms of total airflow, will be 48:1 on acceleration and 80:1 on deceleration.

When the pilot moves the fuel control power lever forward, fuel flow is increased. This increase in fuel flow creates increased gas expansion in the combustor which in turn raises the level of power in the engine. For the turbojet and turbofan, that means a thrust increase. For the turbo-prop and turbo-shaft, it means an increase in power to the output drive shaft. This could mean a speed increase at a given propeller load or a stabilized speed at an increasing blade angle and load.

As an engine ages, the air-fuel ratio of 15:1 will change as compression tends to deteriorate with increasing engine service time. But the engine needs its rated compressor pressure ratio (Cr) to remain efficient and stall free. When performance starts to decrease due to engine ageing, contamination, or damage, more power lever, fuel flow and compressor speed will be required to bring Cr back to normal. Thus a richer mixture results for a given Cr. Later, maintenance personnel may be required to take appropriate action to clean, repair, or replace the compressor or turbine as the engine nears its internal temperature limits

On a single compressor engine the fuel control is driven directly by the accessory gearbox and indirectly from the compressor. On the dual and triple spool engines, the fuel control is normally driven by the high pressure compressor.

Many signals are sent to the fuel control for the automatic control of the air-fuel ratio. How many signals come into play will depend on the engine, and whether or not electronics are involved.

The newer engines, with electronic engine controls (EEC), sense many more engine and aircraft parameters than a hydro-mechanical unit will on an older aircraft. A list of the most common signals sent to a hydro-mechanical fuel control are as follows:

HP Sub-System Inputs

Engine Speed Signal
Is given to the fuel control by a direct drive to the engine accessory gearbox through a flyweight governor within the control; used for both steady state fuel scheduling and acceleration/decelerating fuel scheduling (acceleration of most gas turbine engine is in the range of 5-10 seconds from idle to full power)

Inlet Pressure
A total pressure signal transmitted to a fuel control bellows from a probe in engine inlet, used to give the control a sense of aircraft speed and altitude as ram conditions in the inlet change

Compressor Discharge Pressure
A static pressure signal sent to a bellows within the control, us to give the fuel control an indication of mass airflow that point in the engine.

Burner Can Pressure
A static pressure signal sent to the fuel control from within the combustion liner There is a linear relationship between Burner Pressure and weight of airflow at this point in the engine. If burner pressure increases 10 percent, the mass airflow is increased by 10 percent and the burner bellows schedule 10 percent more fuel to maintain the core air-fuel ratio. The quick response this signal gives make it valuable in preventing stalls, flameouts, and over-temperature conditions.

Inlet Temperature
A total temperature signal from the engine inlet to the control, a temperature sensor connected by a capillary tube to the fuel control. It filled with a heat sensitive fluid or gas which expands and contracts as a function of inlet temperature. This signal provides the control with an airflow density value against which a fuel schedule can be established.

HP Sections

The function of the Fuel Flow regulator(or Fuel Control Unit) is to maintain the correct air/fuel ratio of 15:1 under any running/flying conditions. On determining the correct fuel flow ratio, the FCU then adjusts the HP pump spill valve or swash-plate angle (depending on type of pump used) and hence the fuel pump output. The FCU can be thought of as the following four sections;

Throttle Section
Will contain a valve under the direct control of the pilot. If the throttle is pushed fully open, fuel pressure is blocked from bleeding from the spring side of the servo piston. this will cause the servo-piston to move to the left and hence increase the pump output.

Barometric Section
Effectively measures the air pressure and the air temperature which enters the engine intake. If the air pressure drops, the fuel flow must drop by an equal amount, to maintain an air/fuel ratio of 15:1. In this case the Barometric Section will open a valve and allow fuel to bleed from the

spring side of the servo-piston. This will cause the servo-piston to move to the right and hence reduce the output of the pump. Any operation of this section is automatic and the pilots throttle lever does not move.

Acceleration/Deceleration Section

The accel/decel section will take over from the pilot if the pilot slam accelerates or slam decelerates**.** Slam acceleration is the act of advancing the throttle quicker than the rotating parts of the engine can accelerate. Hence there will be a sudden increase of fuel but no increase in compressor delivery pressure to maintain the air/fuel ratio of 15:1. Such a rich mixture would cause compressor surge. The opposite occurs during slam deceleration, but the effect is "flame-out".

If the pilot slam accelerates, another valve will open to bleed off pressure from the spring side of the servo-piston and allow the servo piston to move to the right and halt the increase in fuel flow due to the throttle valve closing, until the compressor has built up enough speed to allow the valve to close again. Any operation of this section is automatic and the pilots throttle lever does not move.

Limits section

A limits section is fitted to prevent the engine from exceeding its maximum safe values of R.P.M. (both LP and HP spools) and E.G.T. If any of theses sensed values exceeds a set maximum, another valve will instantaneously open to bleed pressure from the spring side of the servo-valve and lower the pump output, until the R.P.M. or E.G.T is once again under its limit. Any operation of this section is automatic and the pilots throttle lever does not move.

Fuel Nozzles

Fuel cannot be burned easily in a liquid state. It must be mixed with air in the correct proportions by atomization or vaporization. The fuel nozzles are always located at the front of the combustion chamber and are designed to inject and mix the atomized fuel with the torroidal vortex created by the combustion chamber.

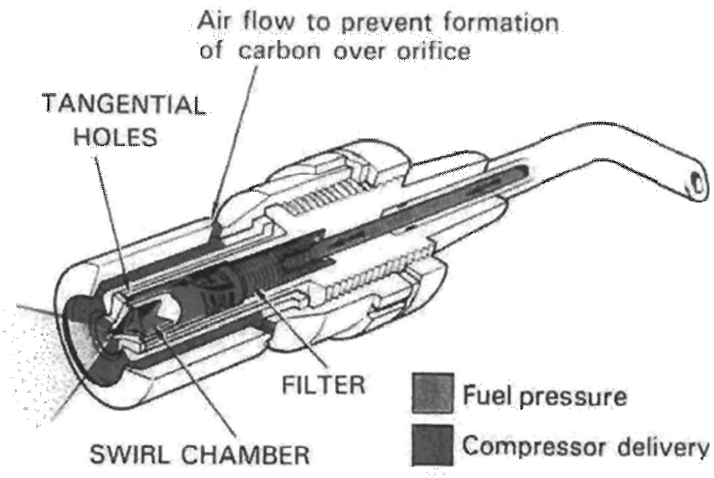
An early method of atomising fuel is to pass it through a "spin chamber" so fuel is swirled to convert its pressure into kinetic energy, and the fuel emerges in an atomised "cone" shape. This however required high pressure fuel to achieve good atomization. Since the fuel pumps were driven by the engine, such high pressures were only available at high engine RPM.

The efficiency of fuel atomization varies with the square of the pressure drop across the fuel nozzle. The fuel pressure for a large engine may be as high as 1500 pounds per square inch at take off RPM, but if at idle RPM the pressure is half of that speed, the fuel atomization efficiency will be one quarter - this is known as a SQUARE LAW.

The effect of different fuel pressures can be seen below;

Simplex Nozzle

This early type of nozzle used the above mentioned "spin chamber" to atomise the fuel, but suffered from the low pressure problems, especially as the efficiency of fuel atomization varies with the square of the pressure drop across the nozzle.



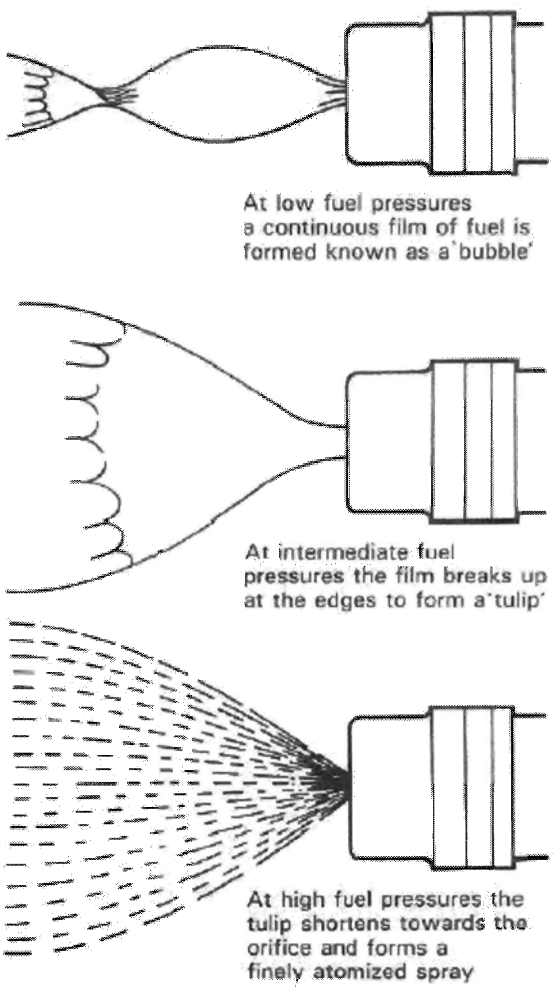


Figure 11.20: Simplex nozzle and spray patterns

Modern Fuel Nozzles

Many methods were tried to overcome the "square law" problem - such as, with the Simplex Nozzle, a second set of nozzles were fitted along side the main nozzles, but these were smaller and had a smaller orifice. These were satisfactory at low engine RPM, and were switched on only up to and slightly above idle speed, then switched off and the main nozzles allowed to take over. The following types of nozzle are all used on modern engines, and all of them overcome the "square law" problem.

Duplex Burner

Duplex nozzles (also called 'Duple' burners) use two separate fuel supplies - *primary* and *main*. to ensure good atomisation over a wide operating range of fuel pressures. The smaller *primary orifice* handles the lower flows alone and, with the *main orifice* the higher fuel pressures. The engine fuel system must use an *automatic pressurising valve* to apportion fuel flow to each manifold. At low fuel pressure (low engine RPM) the pressurising valve is closed and all the fuel flow is sent to the ***primary manifold***. As the fuel flow increases the pressurising valve progressively opens to allow fuel to the main as well as the primary manifold.

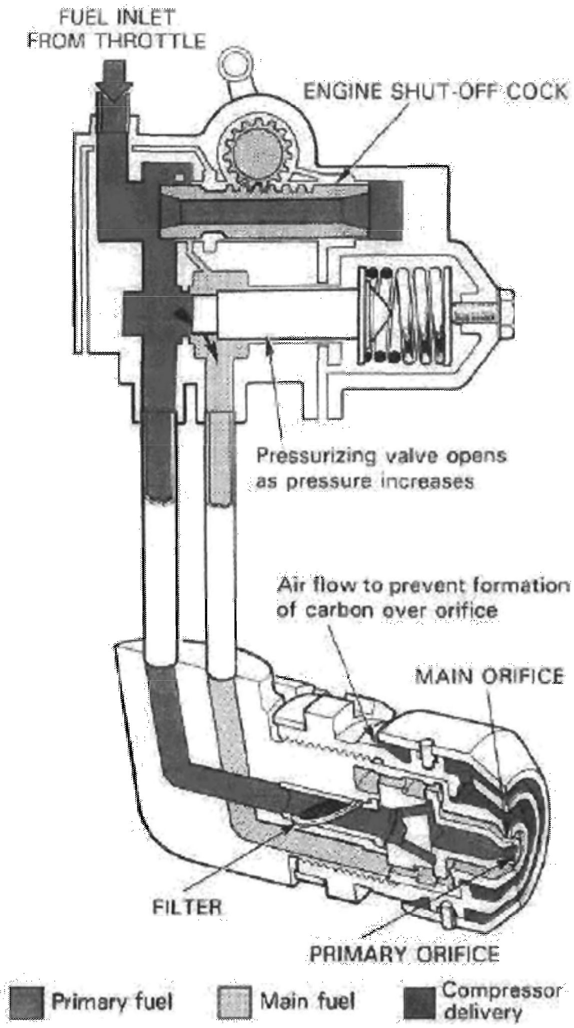


Figure 11.21: Duplex (or Duple) Burner

Vaporiser

In this method, fuel is sprayed from a feed tube and a small quantity of compressor delivery airflow is also fed into the vaporization tube to give the correct air/fuel ratio. The tubes bend through 180^0 and are heated by the combustion process. The heat from the combustion is essential to cause the fuel to change from liquid to vapour. Inside the tube is fitted with *Turbulators* (pins) to cause some deliberate turbulence to complete the fuel/air mixing. The mixture is fed "upstream" into the flame tube and the flame surrounds the vaporizing tube. This method is best suited to annular combustion chambers and indeed was developed for that purpose. However vaporizers have largely been superseded by spray nozzles in today's modern engines

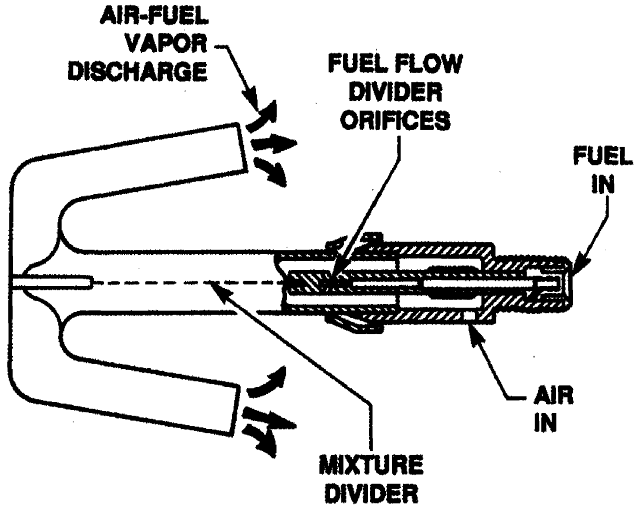


Figure 11.22: Section through Vaporiser

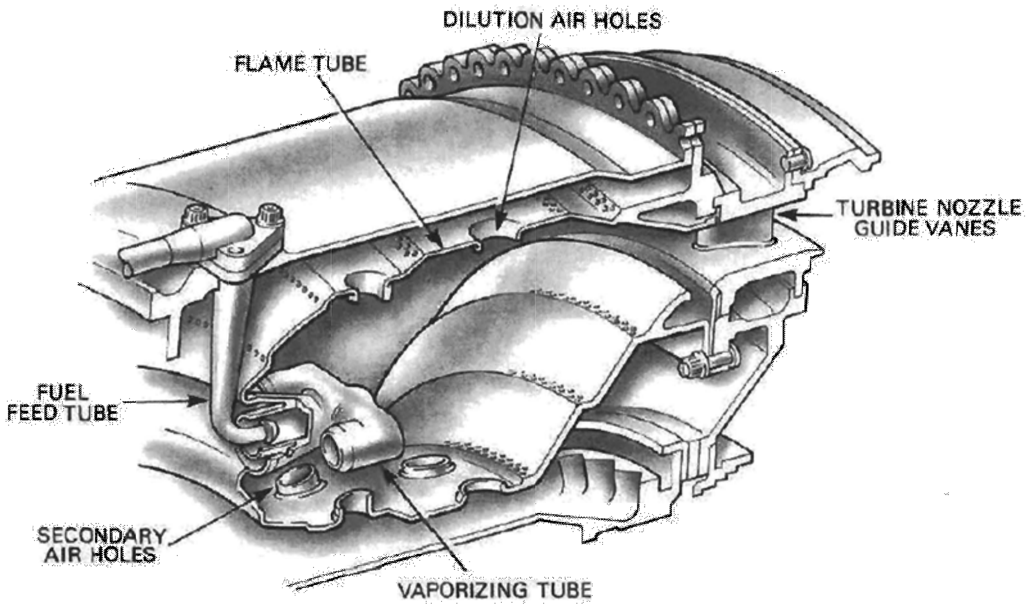


Figure 11.23: A vaporiser in situ in the combustion chamber

Airspray Nozzle

This type of nozzle uses some of the primary combustion airflow to carry the fuel into the combustion chamber. The fuel spray is aerated in a swirl chamber and this tends to avoid the uneven flow pattern which some other burners produce, thus reducing carbon formation and smoke. A second main advantage is that only low fuel pressures are needed which means that a lighter gear type pump can be used. Airspray nozzles are used on all modern high bypass engines, usually incorporated in annular combustion chambers.

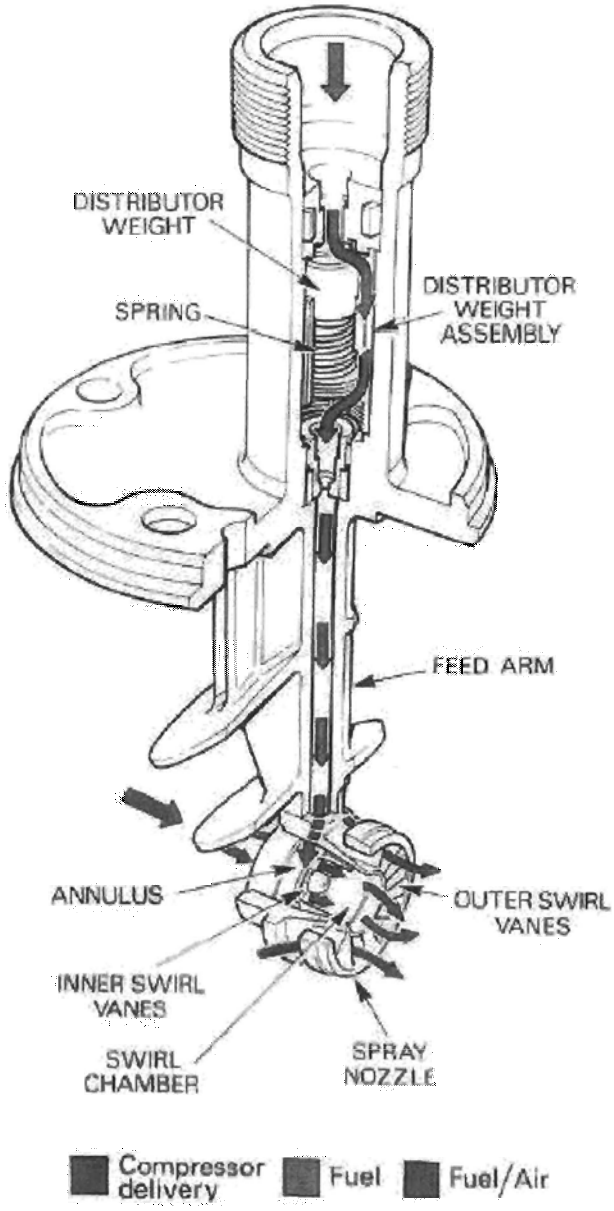


Figure 11.24: Fuel Spray Nozzle

Fuel Flow Distribution

In order that an even flow from all the burners is produced, despite the variation in **gravity head** around the engine, a **fuel flow distributor** is sometimes used. These are normally calibrated spring loaded weights fitted into the fuel lines in or close to the burners.

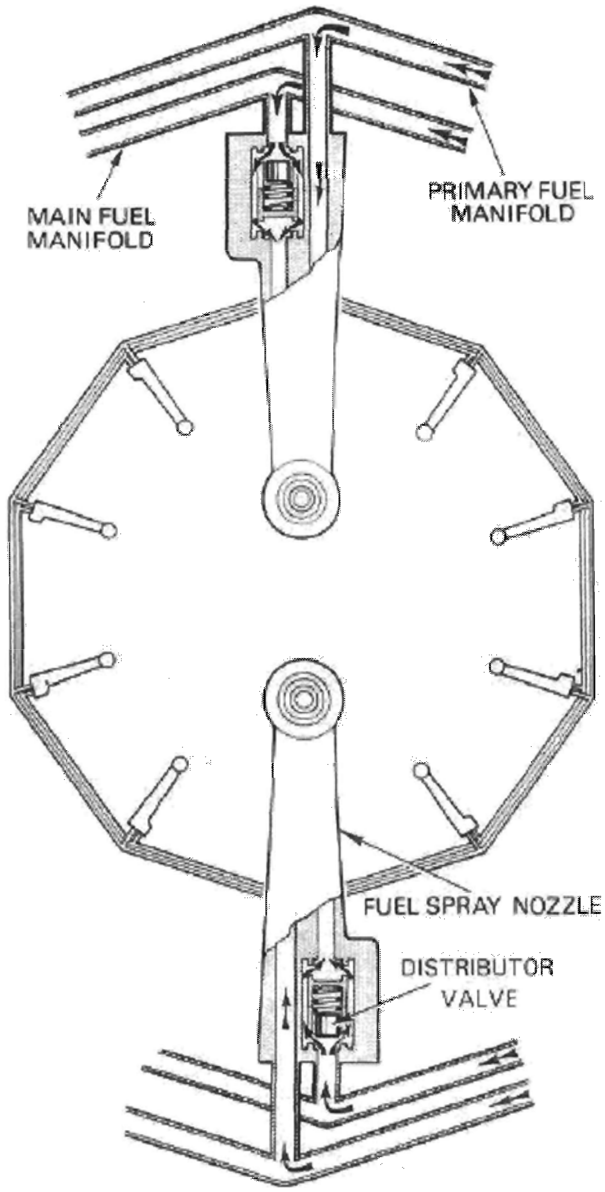


Figure 11.25: Fuel Flow Distributor

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Combustor Drain Valve

A combustor drain valve is a mechanical device located in the low point of a combustion case. It is closed by gas pressure within the combustor during engine operation and is opened by spring pressure when the engine is not in operation. This valve prevents fuel accumulation in the combustor after a false start or any other time fuel might tend to puddle at the low point.

A false start in this case is a no-start condition or hung-start condition which results in a fuel soaked combustor and tailpipe. Draining of fuel in this manner prevents such safety hazards as after shutdown -fires and hot starts. This drain also removes un-atomized fuel which could ignite near the lower turbine stator vanes causing serious local overheating during starting, when cooling airflow is at the lowest flow rate.

If the dump line is capped off as an ecology control, the fuel manifolds will drain through the lower nozzles and fuel will evaporate in the combustor or exit the combustor via the mechanical drain valve into an aircraft drain receptacle. This tank is either automatically or manually drained

Effect of a Change of Fuel

The main effect on the engine of a change from one grade of fuel to another arises from the variation of specific gravity and the number of heat units obtainable from a gallon of fuel. As the number of heat units per pound is practically the same for all fuels approved for gas turbine engines, a comparison of heat values per gallon can be obtained by comparing specific gravities.

Centrifugal governors

Changes in specific gravity have a definite effect on the early centrifugal pressure type of engine speed governor, for with an increase in specific gravity the centrifugal pressure acting on the governor diaphragm is greater. Thus the speed at which the governor controls is reduced, and in consequence the governor must be reset. With a decrease in specific gravity, the centrifugal pressure on the diaphragm is less and the speed at which the governor controls is increased; in consequence, the pilot must control the maximum RPM by manual operation of the throttle to prevent overspeeding the engine until the governor can be reset.

Hydro-Mechanical Governors

The hydro-mechanical governor is less sensitive to changes of specific gravity than the centrifugal governor and is therefore preferred on many fuel systems.

Pressure Drop Governor

The pressure drop governor in a combined acceleration and speed control system is density compensated, by the use of a buoyant material on the governor weights, resulting in fuel being metered on mass flow rather than volume flow.

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Electronic Engine Control (EEC)

Advances in gas turbine technology have demanded more precise control of engine parameters than can be provided by hydromechanical fuel controls alone. These demands are met by electronic engine controls, or EEC, of which there are two types: supervisory and full-authority.

Supervisory Electronic Engine Control

The first type of EEC is a supervisory control that works with a proven hydromechanical fuel control.

The major components in the supervisory control system include the electronic control itself, the hydromechanical fuel control on the engine, and the bleed air and variable stator vane control. The hydromechanical element controls the basic operation of the engine including starting, acceleration, deceleration, and shutdown. High-pressure rotor speed (N_2), compressor stator vane angles, and engine bleed system are also controlled hydromechanically. The EEC, acting in a supervisory capacity, modulates the engine fuel flow to maintain the designated thrust. The pilot simply moves the throttle lever to a desired thrust setting position such as full takeoff thrust, or maximum climb. The EEC adjusts the fuel flow as required to maintain the thrust compensating for changes in flight and environmental conditions. The EEC control also limits engine operating speed and temperature, ensuring safe operation throughout the flight envelope.

If a problem develops, control automatically reverts to the hydromechanical system, with no discontinuity in thrust. A warning signal is displayed in the cockpit, but no immediate action is required by the pilot. The pilot can also revert to the hydromechanical control at any time.

A Typical Electronic Engine Control System

A typical example of an EEC system is that used in many of the Pratt and Whitney 100 series engines currently in service. A brief explanation of how the system works, both in automatic and manual modes follow.

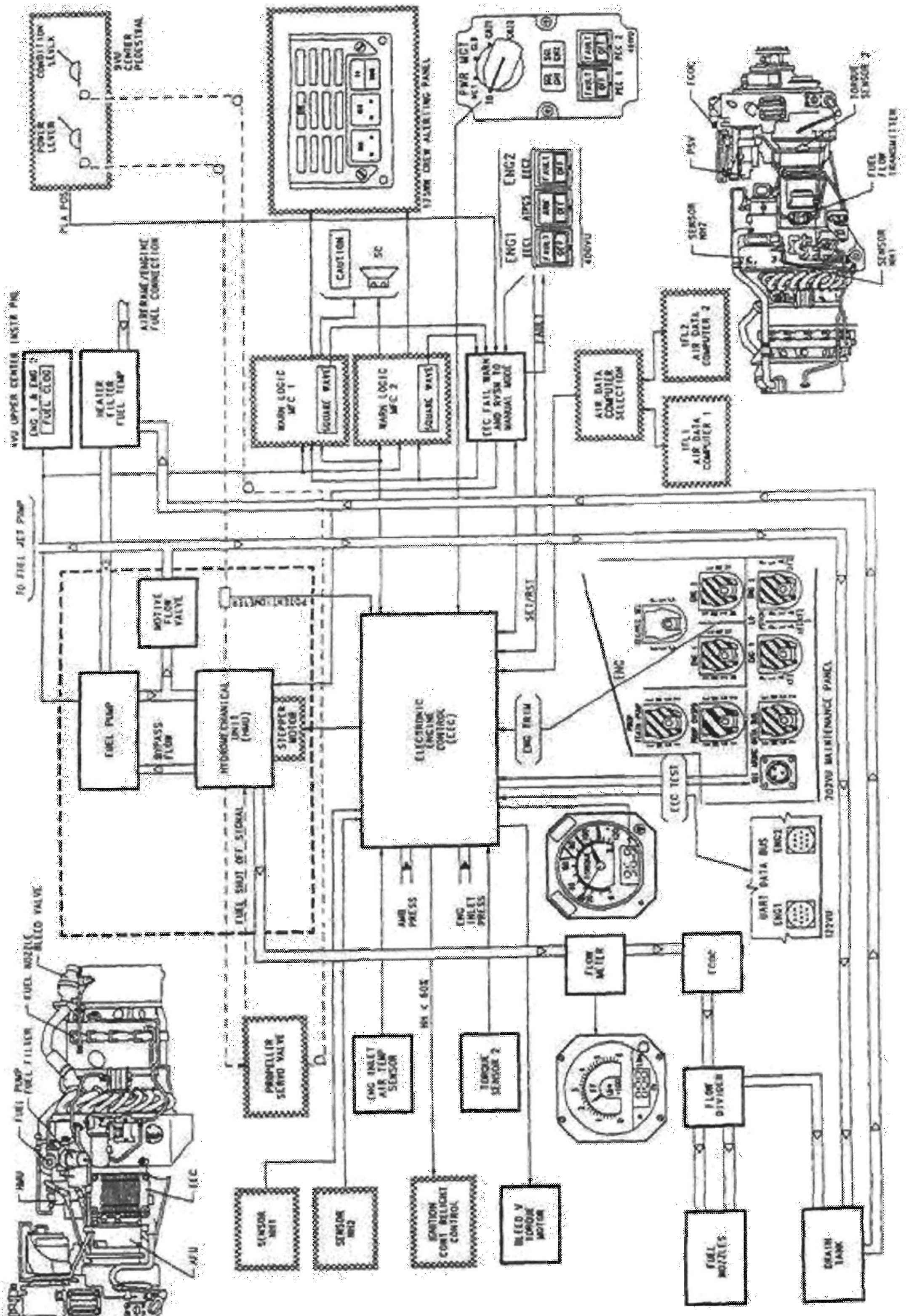

Figure 11.26: Pratt & Whitney 100 Series Fuel Control System Schematic.

Automatic Operation (EEC mode)
The EEC receives signals from various sources:

- Power Management Switch, enabling take off thrust, maximum continuous thrust, climb thrust or cruise thrust settings to be selected
- Engine inlet pressure and temperature
- Ambient pressure
- Air data computer inputs. (a computer that senses pitot pressure, static pressure and total air temperature)
- Engine RPMs – N_1 and N_2
- Power lever position. (via a potentiometer)
- Failure signals

Based on these input signals the EEC will output command signals to adjust and control:

- The Hydromechanical Fuel Control Unit via a stepper motor which adjusts the throttle metering valve.
- Ignition circuits.
- Bleed valves
- Torque gauge

Fuel Control
The fuel control is provided by the hydro-mechanical unit (HMU) The HMU is supplied by the HP fuel pump and provides the required fuel quantity to the nozzles.

In normal operation the fuel control is managed by the Electronic Engine Control (EEC). This enables accelerations and decelerations without engine surge or flame out whatever the displacement sequence of the power lever. The HMU is also mechanically connected to the power lever thus ensuring fuel control in case of failure of the EEC.

Hydro-mechanical Unit (HMU)

The HMU comprises:
- A stepper motor controlled by the EEC
- A lever which controls fuel shutoff
- A lever which controls the fuel flow

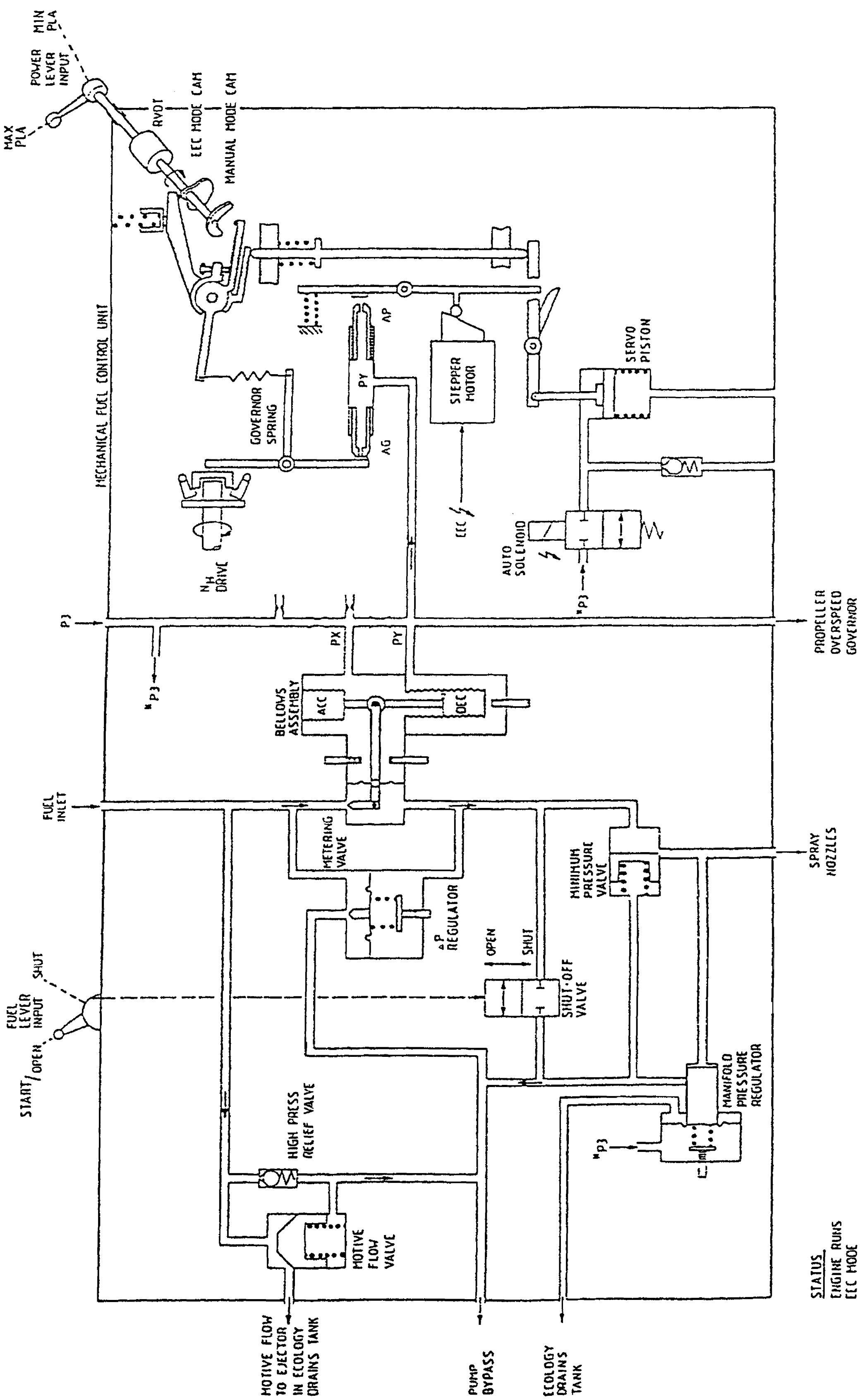

Figure 11.27: PW100 Series Fuel System Auto/Normal Mode

Operation
The fuel flow supplied to the nozzles is mainly obtained through two valves:

- a bypass valve
- a metering valve.

The fuel enters the HMU from pump outlet with a constant flow. This flow is split by the bypass valve into two flows, one for the nozzles (via the metering valve) and one bypass return flow to the pump. The position of the bypass valve is a function of the loss of fuel pressure caused by the metering valve. The metering valve is pneumatically actuated. In the pneumatic servo block, the reference pressure is the HP compressor outlet pressure, P_3. A controlled reduction of the P_3 pressure results in a variable P_y pressure which when opposed to a bellows device, moves the piston of the metering valve.

The pneumatic servo block is managed:

- in normal operation by the EEC
- in manual operation, by the power input lever.

Normal Operation (EEC Mode)
According to the input data (pressures, temperatures, speeds) and to the commanded power (power lever), the EEC controls a stepper motor located in the HMU.

The stepper motor regulates P_y pressure thus modulating the fuel flow as requested. A governor acts on the P_y pressure, thus setting an N_H speed limit function of the compression of a spring by a cam (EEC cam) connected to the power lever.

Manual Operation (Manual Mode)
P_y pressure is not regulated by the stepper motor but by the simultaneous actions of the NH speed governor and the spring, compressed by a second cam (manual cam) connected to the power lever.

Transfer from the EEC Mode to the Manual Mode.
In normal operation the EEC manages the fuel regulation. The manual operation is automatically connected when the operation in the EEC mode is switched off. A solenoid in the HMU selects the manual cam instead of the EEC cam and cancels the regulation control through the stepper motor.

Operation of the HMU in the fail mode
In case of failure of the EEC, the position of the stepper motor is "frozen". Whatever the increase of power through the power lever, the last N_H speed remains unchanged (the load applied by the spring on the N_H speed governor increases).For any power reduction through the power lever, the N_H speed decreases according to the curve of the EEC cam (decreasing spring load).

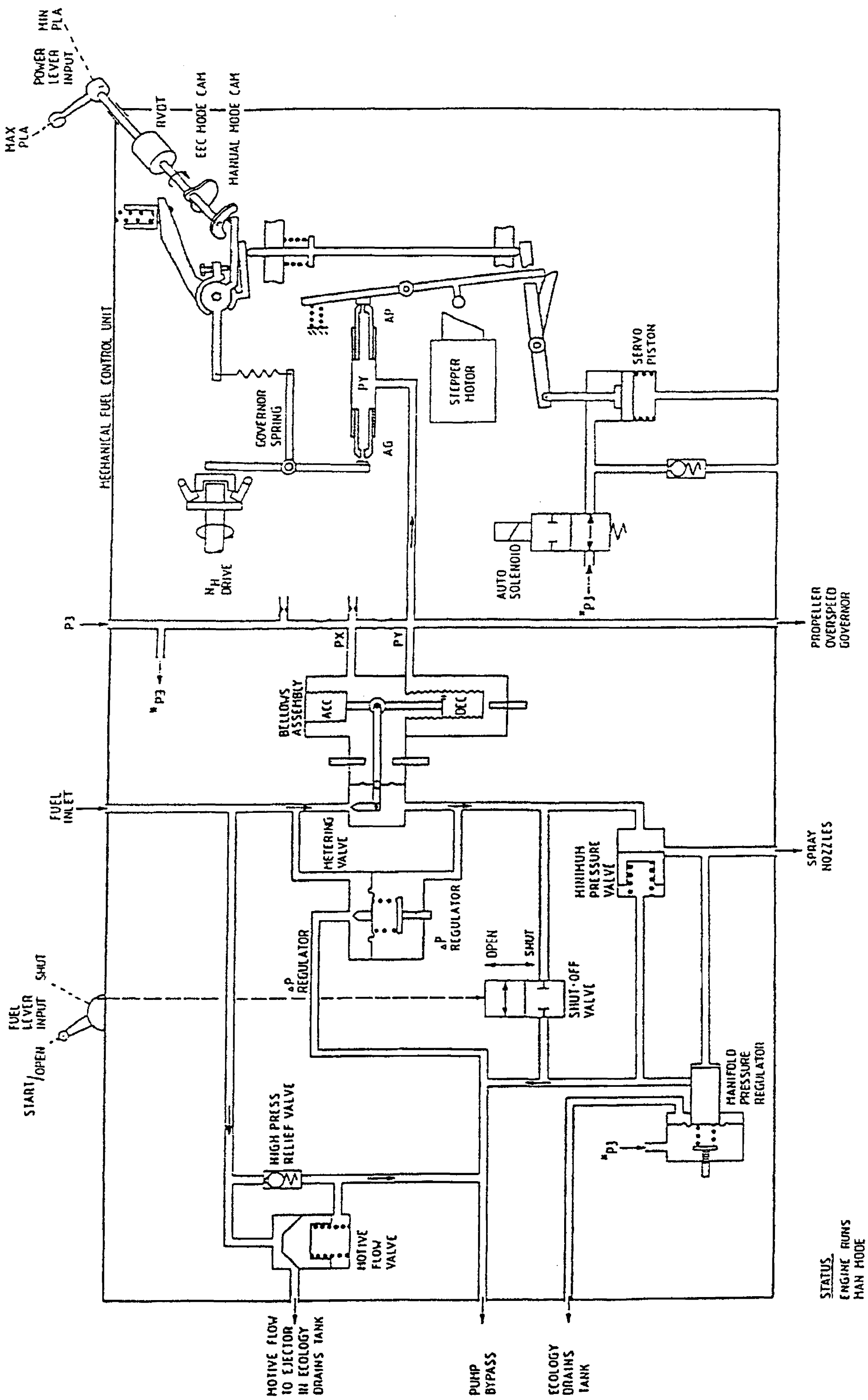

Figure 11.28: PW 100 Series Fuel System in Manual Mode

Full Authority Digital Engine Control

Overview

FADEC is the name given to the system that controls the engine on modern Gas Turbine Engines. This section discusses the common features of FADEC and also the different applications used by the large commercial passenger aircraft engine manufacturers, Rolls Royce and General Electric and their derivatives IAE and CFM.

FADEC replaces the hydro-mechanical fuel control systems as exemplified by the Rolls Royce Spey or JT8D.

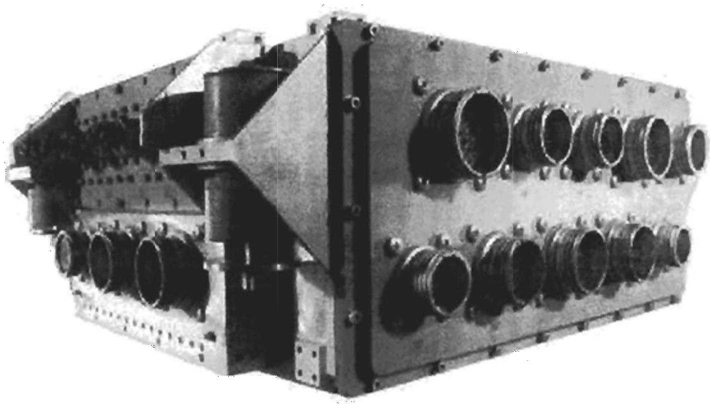

Figure 11.29: A typical FADEC unit

Benefits of FADEC:

1 Substitution of Hydromechanical control system reduces weight and hence fuel consumption.
2 Automation brings reduced pilot workload
3 Optimized engine control reduces maintenance and optimizes fuel consumption
4 Optimized airflow control allows the engine to work nearer the surge line thus increasing thrust whilst reducing the chance of surge or flameout.

A FADEC system consists of

Sensors
A Central Processor Unit called an Electronic Engine Control (EEC) or an Engine Control Unit (ECU)
An Hydro Mechanical Unit. (HMU).

The Central Processor Unit, for the purposes of this document will be referred to as the ECU

A FADEC system has the following inputs:

1 Analogue signals from electrical sensors.
2 Digital signals, usually on an ARINC 429 Data Bus, from aircraft computers such as the Air Data Computer (ADC), Thrust Management Computer (TMC) and Flight Management Computer (FMC).
3 Thrust lever signals are transmitted by Rotational Variable Differential Transformers mechanically connected to a conventional thrust drum that is moved by the Manual Thrust Lever and the Auto Thrust Servo Motor.
4 Pressure inputs – apart from those received from the ADC. P_0 and P_S3 (Compressor Delivery Pressure) signals are tapped directly into pressure transducers located within the ECU.
5 Feedback signals from any moving mechanical device, such as Thrust Reverser, Variable Stator Vanes (VSVs) and Variable Bypass Valves, utilize Linear or Rotary Variable Differential Transducers (LVDTs or RVDTs).

Sections of a FADEC system

Engine Control Unit (ECU)

The ECU is a dual channel processor that computes all functions of the FADEC system based on its inputs and stored data and then commands the HMU to take appropriate actions. The ECU also provides ARINC 429 data to the FMC TMC and EICAS (Boeing) or ECAM (Airbus) cockpit display computers.

Hydro Mechanical Unit (HMU)

The HMU provides an interface between the electrical analogue output from the ECU and the fuel. It is achieved by an Electrical Hydraulic Servo Valve (EHSV) actuating a Fuel Metering Valve (FMV), thus controlling fuel supply to the burners. In addition the HMU will have EHSVs controlling fuel muscle pressure to VSVs and VBVs if fitted.

Figure 11.30 shows a simple schematic overview of the FADEC system.

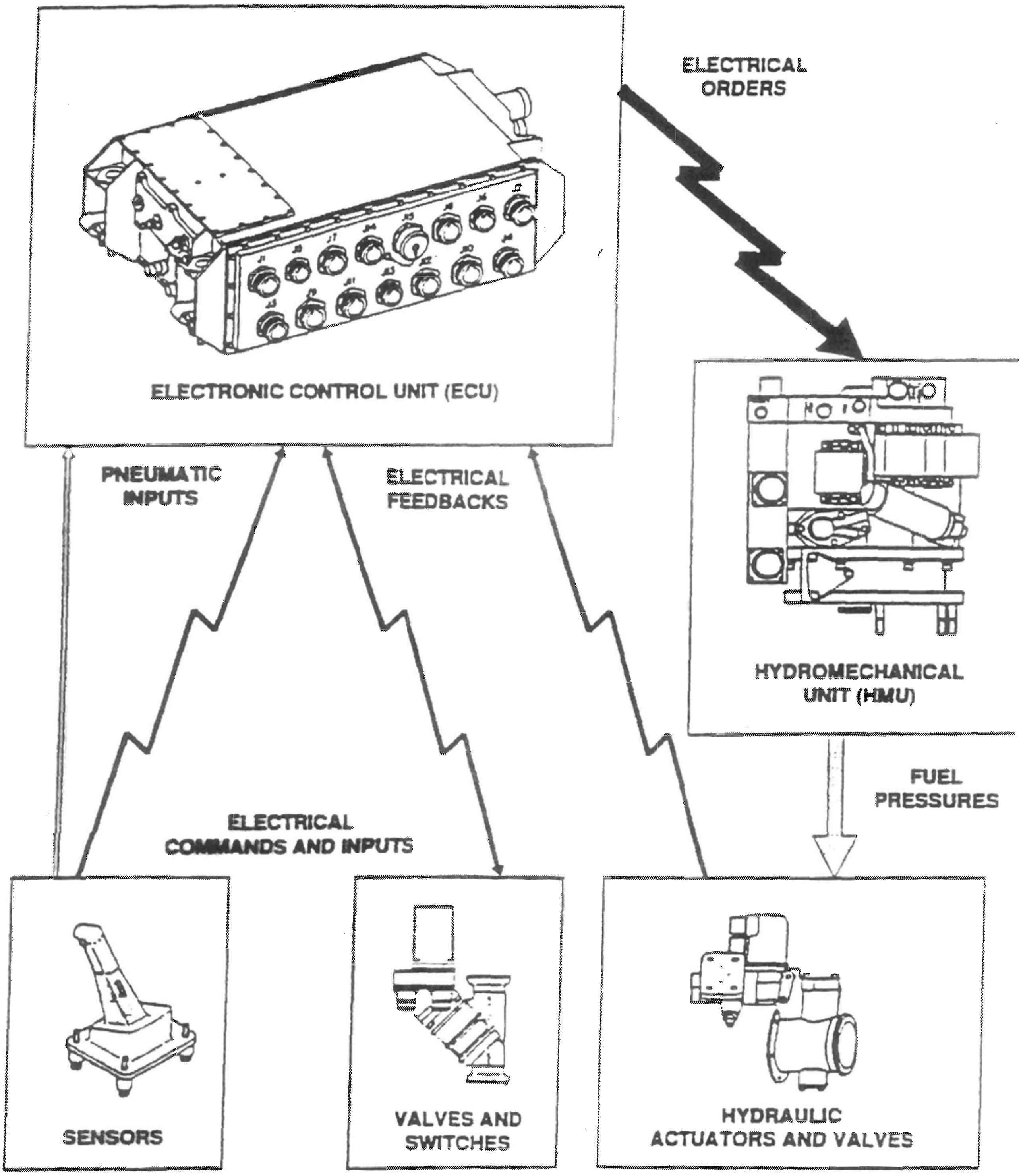

Figure 11.30: FADEC Schematic Overview

Figure 11.31 shows the flow paths for a CFM 56-5 Engine, which is a typical FADEC engine. Please note the following:

1. FADEC is a very useful tool for gathering information for a condition monitoring system. Customers can choose whether to have Condition Monitoring for their system, therefore the sensors required are customer options and are marked *.
2. TLA stands for Thrust Lever Angle. This signal is received from the RVDT fitted to the thrust lever drum. However this angle is sometimes quoted as the TRA (Throttle or Thrust Resolver Angle)
3. The ECU is powered by its own alternator or by aircraft 28VDC Aircraft Bus for Starting Testing and Maintenance. 115VAC aircraft power is required for the AC Ignitor circuit.

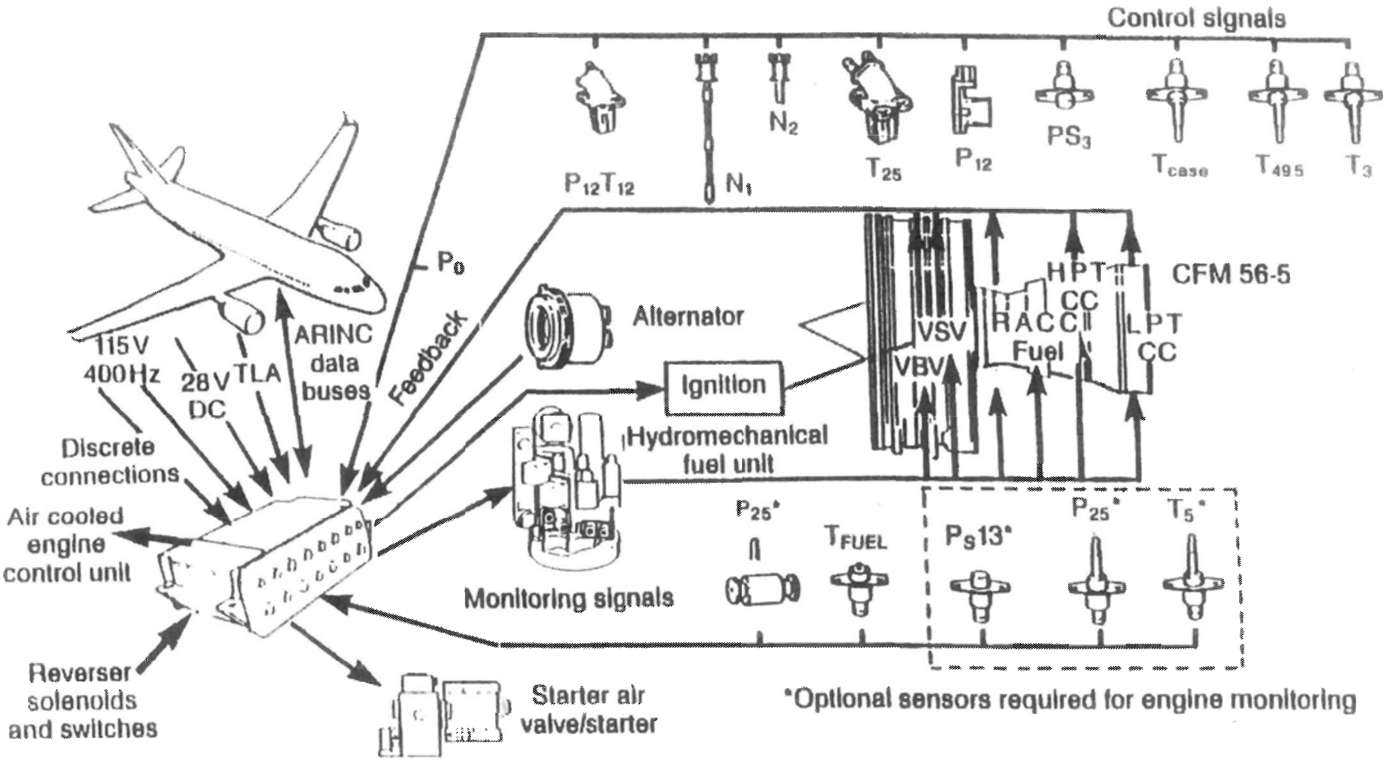

Figure 11.31: CFM 56–5 Airframe – ECU – Engine Flow Paths

The Engine Control Unit (ECU)

The ECU is a dual channel processor housed within a single container, however all hardware within the container is partitioned into the two channels.

Normally mounted on the fan casing cooling is either by natural Fan Case Cooling Air or directly by a dedicated Fan Air Ducting

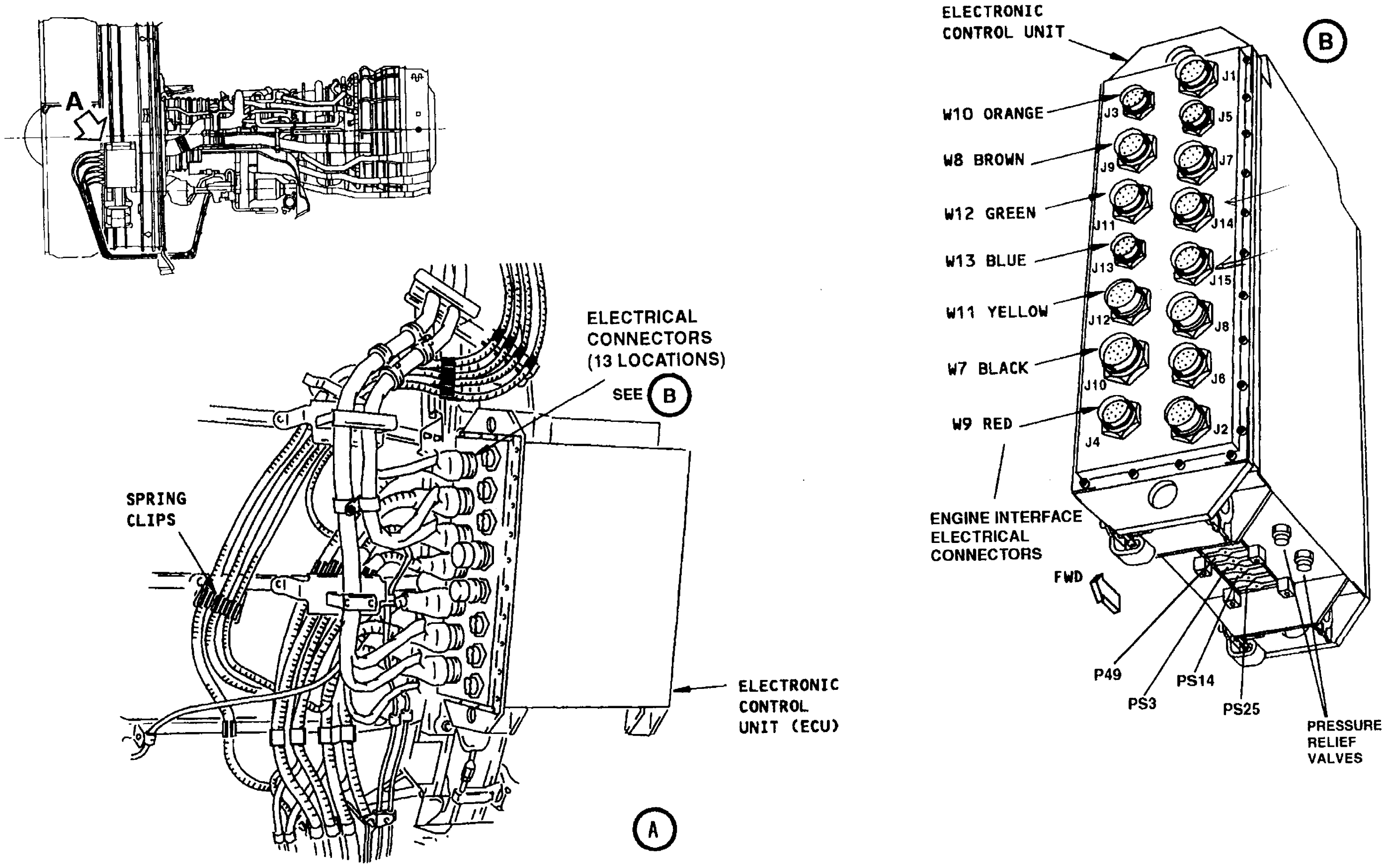

Figure 11.32: ECU Location and Connectors (CF6-80C2 FADEC) – similar for all other High Bypass Gas Turbine Engines

ECU Architecture

Dual Channel

The FADEC System is fully redundant built around two independent control channels. Dual Input, dual outputs and automatic switching from one channel to the other eliminate any dormant failure.

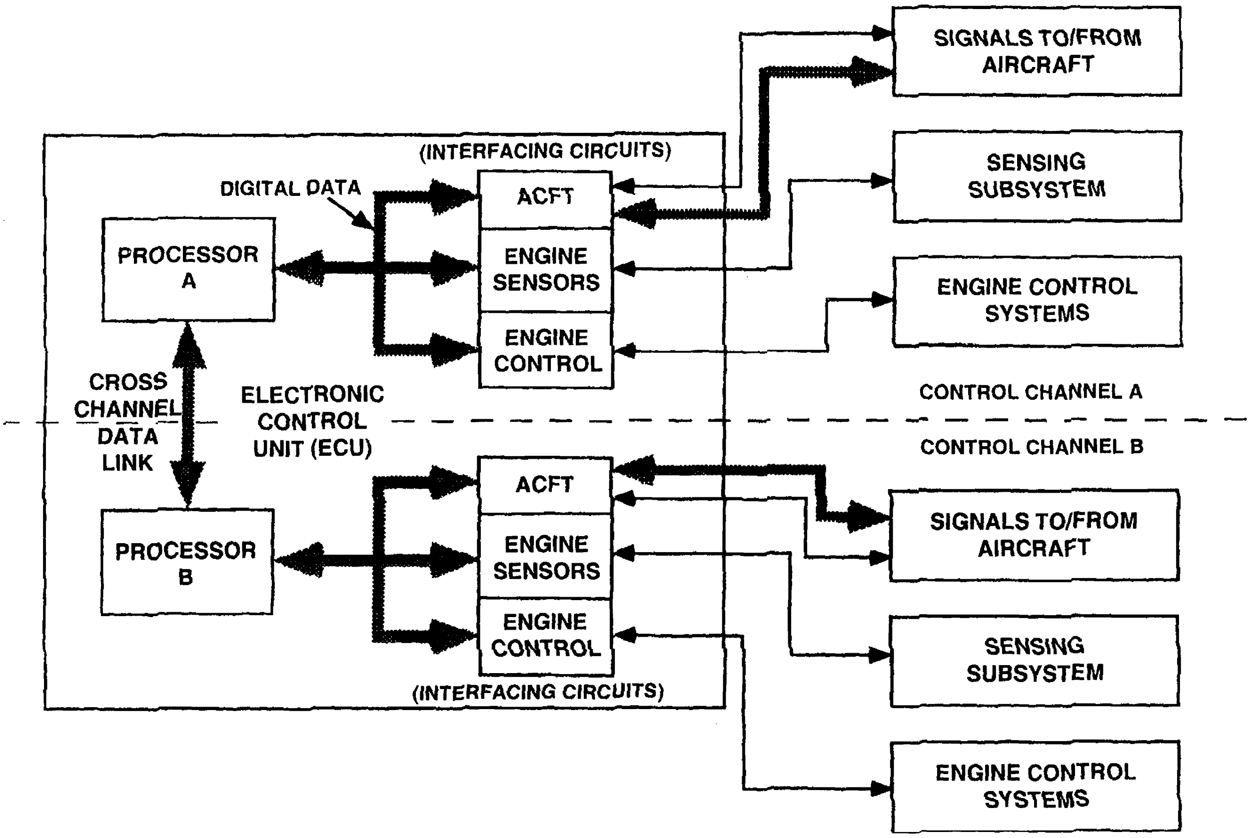

Figure 11.33: ECU Dual Channel Philosophy

Channel Selection

The ECU will always select the "healthiest" channel as the Active channel based on a fault priority list. The fault priority list contains critical faults such as; processor, memory or power failures, and other failures that involve a channel's capability to control the FMV, VSV, or VBV torque motor(s). During engine run status, each channel within the ECU will determine whether to be in the active state or standby state every 30 milliseconds based on a comparison of it's own health and the health of the cross-channel. Either channel can become active if its health is better than the cross-channels health; likewise it will become standby if its health is not as good as the cross-channel. If the two channels have equal health statuses, the channels will alternate Active/Standby status on each engine shutdown and the standby channel will become the active channel on the next start.

- **Channel Transfer**
  Assuming the opposite channel is of equal or greater health, channel Active/Standby transfer will occur after the engine has been run above 76% N2 and subsequently shutdown (N2 less than 35%).

Dual Inputs
Electrical Inputs:
All command inputs to the FADEC system are duplicated.

Only some secondary parameters used for monitoring and indicating are single (e.g. the EGT input on the CF6 engine).

To increase the fault tolerant design, the parameters are exchanged between the two control channels via the cross channel data link.

Pressure inputs
Pressure tappings from the engine are plumbed directly into the ECU, either discretely to each channel or a single tapping that is split within the ECU and then sent to discrete channel transducers.

Hardwired Inputs
Information exchanged between aircraft computers and the ECU is transmitted over digital data buses. In addition signals are hardwired directly from the aircraft where a computer is not used. (Thrust Reverser feedback via RVDTs or TLA via an RVDT)

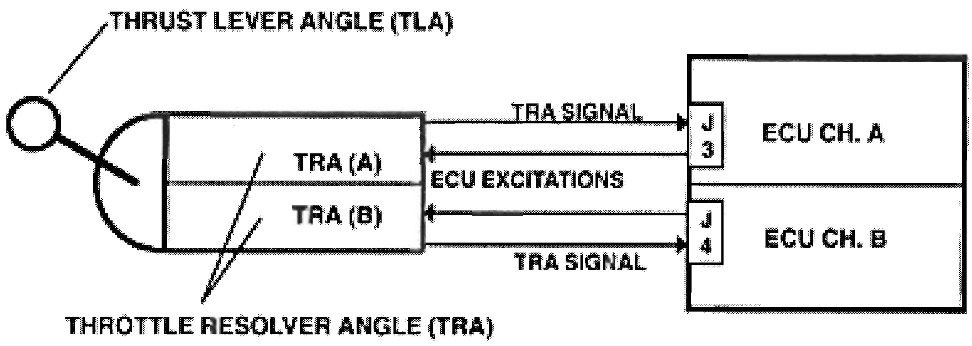

Figure 11.34: Example Hardwired Dual Input Device – Thrust Lever Angle RVDT's

Dual Outputs
All the ECU outputs are double but only the channel in control supplies the engine control signals to the various receptors such as torque motors, actuators or solenoids. Further information on output signal receivers can be found below in the HMU section.

BITE Capability

The ECU is equipped with BITE, which provides maintenance information, and test capabilities via an aircraft mounted component called MCDU (Airbus) or PIMU (Boeing).

The ECU performs a self-test on power up, and self monitors during operation. In addition operation of a ground test switch powers up the ECU and hence a real time ground test is carried out when this switch is operated. For Boeing airframes the ECU stores faults in the ECU volatile memory until the aircraft lands. On landing the faults are streamed to a Propulsion Interface Monitoring Unit (PIMU). There is a PIMU for each engine. The PIMU holds the fault until a BITE test is carried out. An EICAS message will advise maintenance staff to carry out this procedure even if the pilot has not noticed the problem.

AIRBUS faults will be stored in the MCDU in real time.

BITE interrogation is airframe specific and cannot be covered in a generic FADEC publication.

Using the BITE system, the ECU can detect and isolate failures in real time and hence allows switching of engine control from the faulty channel to the healthy one.

Fail Safe Control

If a standby channel is faulty and the channel in control is unable to ensure one engine function, this control is moved to a fail-safe position.

Example

> If the standby channel is faulty and the channel in control is unable to control VBV position, the valves are operated to the open position.

Main Interfaces

To perform all its tasks the ECU interfaces with aircraft computers, either directly or via the Engine Interface Monitoring Unit (EIMU). Principle among these are the aircraft Left and Right Air Data Computers which supply data , notably Ambient Temperature (T_{amb}); Total Air Temperature (TAT); Static Pressure (P_s0) and Total Pressure (P_T). All of these are required to determine that the thrust commanded remains constant for the ambient conditions and that thrust and EGT limits are not exceeded.

Limits Protection

The ECU has a dual channel limit protection section comprising max limits for N1 N2 and N3 (RR only) In addition various max limits are protected depending on the system, most commonly Compressor Delivery Pressure(P_s3)

Thrust Regulation

Thrust regulation on high bypass engine is calculated using ADC inputs to calculate the required fuel to provide the commanded thrust. The thrust is measured in terms of N1 speed or EPR (RR Trent). For the EPR engine in the event of EPR signal failure then it reverts to control by N1.

As a back up there is a mechanical high pressure compressor (HP2 or HP3) governor located within the HMU

Thrust Control Modes

Systems vary, therefore below are three typical systems:

CF6 FADEC Control Modes

In the event that an ADC signal is lost then the ECU will use the opposite channel signal. In the event that the channels inputs do not agree as to which signal is accurate then the ECU will revert to an ***alternate*** mode using the last known ambient pressure signal. This is also known as the ***soft reversionary*** mode.

The soft reversionary mode can cause throttle stagger as the other engine is still operating in the normal mode. To prevent this the ECU mode switches can be pushed for both engines, to select ***hard reversionary mode*** which means they are using the fixed cornerpoint ambient temperature for that engine. Because T_{amb} may be higher than cornerpoint there is now a danger of overboosting the engine. Consequently the pilot will always throttle back before selecting hard reversionary and subsequently be aware of his max N1 indication to prevent overboosting or over temping the engine.

R.R. Trent FADEC Control Modes

The primary thrust control loop uses EPR .In the event that EPR computation is impossible then the ECU reverts to the N1 mode where N1 is used to control thrust. In the N1 mode Auto Throttle is no longer available.

CFM 56 FADEC Control Modes

The engine operates in one of three thrust modes, AUTO - MEMO -MANUAL Entering/exiting these three modes is controlled by inputs to the Engine Interface Unit (EIU).

a) Auto Thrust Mode

The auto thrust mode is only available between idle and Max Climb Thrust when the aircraft is in flight.

After take-off the throttle is pulled back to the max climb position, the auto thrust system will be active and the Automatic Flight system will provide an N1 target to provide either -

Max Climb Thrust.
An Optimum Thrust.
A Minimum Thrust.

An Aircraft Speed (Mach Number). In association with the auto pilot.

b) Memo Mode

The Memo Mode is entered automatically, from Auto mode if the N1 target is invalid.
One of the instinctive disconnect buttons on the throttle is activated.
Auto thrust is disconnected by the EIU.

In the memo mode, the thrust is frozen to the last actual N1 value and will remain frozen until the throttle lever is moved manually, or, auto thrust is reset.

c) Manual Thrust Mode

This mode is entered any time the conditions for Auto or Memo are not present in this mode. Thrust is a function of throttle lever position.

Power Supplies

Permanent Magnet Alternator (PMA)
A dual coil Permanent Magnet Alternator driven from the External or Accessory Gearbox powers the ECU. The dual output is fed independently to the two Channels. The PMA can provide all power requirements once the engine is running above 15% N2 (N3 for RR Engine).

28V DC Aircraft BUS
For engine starting an aircraft 28V DC supply is used. In addition a 28V DC Bus supplies power for ground testing the system and for back up in the case of the primary 28V DC Bus failing. Aircraft 28 V DC is also always available in the event of PMA supply failing to both channels.

28V DC is applied to the ECU when:

The start switch is activated
The Fuel switch is placed to on (for an in-flight windmilling start)
When ground test power is applied

115V AC 400Hz
The aircraft supplies a 115V AC 400HZ power source to each channel for ignition excitor # 1 and ignition excitor # 2. The inputs are routed to the exciters or terminated within the ECU by switching relays.

It should be noted that if the ECU has a double channel failure then the engine will not start as the exciters can only be powered via the ECU.

Hydro Mechanical Unit (HMU)

Primary outputs from the ECU are directed to the torque motors of the EHSVs located on the HMU and to the torque motor controlling the primary fuel metering valve.

The fuel metering subsystem is completely contained in the HMU. The HMU is mounted on the front, right side of the accessory gearbox. It is driven by a mechanical connection to the gearbox. The HMU responds to electrical signals from the ECU to meter fuel flow for combustion and to modulate servo fuel flow to operate the engine air systems. The HMU also receives signals from the aircraft fuel control system to control an internal high pressure fuel shutoff valve (HPSOV).

There are four external electrical connectors for electrical interfaces with the aircraft and ECU. Four fuel ports connect the HMU with the fuel pump and fuel nozzles. There are five hydraulic connections for control interfaces with the engine fuel and air systems. Each hydraulic interface is controlled by an electro-hydraulic servo valve (EHSV) that varies servo fuel pressure in response to EEC signals. The fuel connections to the HMU are:

- Fuel inlet from the fuel pump
- Fuel discharge to the fuel nozzles
- Fuel bypass discharge to the fuel pump
- Servo fuel inlet from the servo fuel heater.

The hydraulic connections from the HMU are:

- Servo fuel pressure to the low pressure turbine case cooling (LPTCC) valve
- Servo fuel pressure to the high pressure turbine case cooling (HPTCC) valve
- Servo fuel reference pressure to the LPTCC and HPTCC valves
- Servo fuel pressure to the variable bypass valves (VBVs)
- Servo fuel pressure to the variable stator vanes (VSVs).

The electrical connections to the HMU are:

- Fuel control signals from EEC channel A
- Fuel control signals from EEC channel B
- HPSOV solenoid inputs from the fuel control valves
- HPSOV position indication outputs to the EEC.

The HMU has three hydraulic circuits:

A fuel metering circuit
A bypass circuit
A servo control circuit.

The fuel metering circuit controls fuel flow to the fuel nozzles in the engine combustor. It has a fuel metering valve and a high pressure fuel shutoff valve (HPSOV). Unmetered fuel from the fuel pump goes to the FMV. Metered fuel from the FMV goes to the HPSOV. If the HPSOV is open, metered fuel is routed to the fuel nozzles.

The bypass circuit is composed of a bypass valve, a differential pressure (delta P) regulator, and an overspeed governor. The fuel pump supplies more fuel than needed for the metered fuel flow. The bypass circuit returns excess fuel to the fuel pump.

The servo control circuit divides the fuel supply from the servo fuel heater into regulated and unregulated servo flows. These flows operate actuators located both inside and outside of the HMU. The circuit has a servo regulating and distribution section and five electro-magnetic servo valves. One of these servo valves supplies servo pressure for FMV control and is discussed below. The other servo valves control pressure to engine air system actuators as listed previously.

Fuel Metering Valve

A fuel metering valve (FMV) inside the HMU controls fuel flow to the nozzles. The hydraulically driven metering valve is controlled by the fuel metering valve EHSV. The EHSV has two coils, one for each EEC channel. The controlling EEC channel increases current through its EHSV coil to hydraulically open the FMV. If neither coil has power, the FMV closes. The FMV has two position-indicating resolvers. One resolver is excited by, and provides a position feedback signal to, EEC channel A. The other resolver goes to EEC channel B.

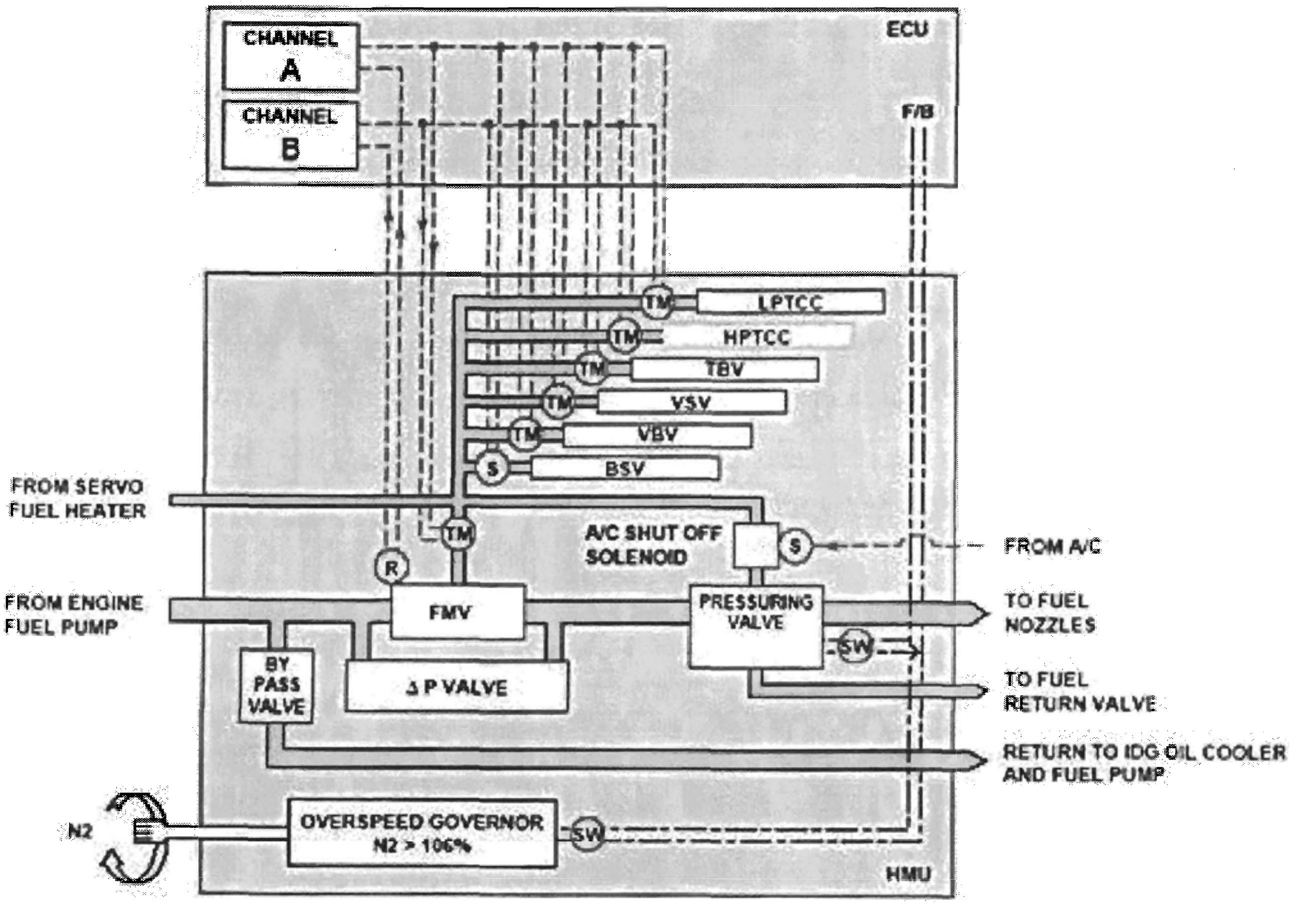

Figure 11.35: Typical HMU System

Glossary of Terms

ACFT	Aircraft
ADC	Air Data Computer
BITE	Built In Test Equipment
ECAM	Electronic Centralized Aircraft Monitoring (Airbus version of EICAS)
ECU	Engine Control Unit
EEC	Electronic Engine Control
EGT	Exhaust Gas Temperature
EHSV	Electro Hydraulic Servo Valve
EICAS	Engine Indicating and Crew Alerting System (Boeing version of ECAM)
EIMU	Engine Interface Monitoring Unit
EIU	Engine Interface Unit
EPR	Engine Pressure Ratio
FADEC	Full Authority Digital Engine Control
FMC	Flight Management Computer
FMV	Fuel Metering Valve
HMU	Hydro-Mechanical Unit
HPSOV	High Pressure Shut Off Valve
HPTCC	High Pressure Turbine Case Cooling
LPTCC	Low Pressure Turbine Case Cooling
LVDT	Linear Variable Differential Transformer (or Transducer)
MCDU	Maintenance Display Control Unit
PIMU	Propulsion Interface Control Unit
PMA	Permanent Magnet Alternator
P_o	Atmospheric Pressure
P_s3	Compressor Delivery Pressure
P_T	Total Pressure
RACC	Rotor Active Clearance Control
RVDT	Rotary Variable Differential Transformer (or Transducer)
T_{amb}	Ambient Temperature
TAT	Total Air Temperature
TLA	Thrust (or Throttle) Lever Angle
TMC	Thrust Management Computer
TRA	Thrust (or Throttle) Resolver Angle
VBV	Variable Bleed Valves
VSV	Variable Stator Vanes

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TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.12 Air Systems

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.

Table of Contents

Module 15.12 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 Reference**	**Level**
		B1
Air Systems	15.12	2
Operation of engine air distribution and anti-ice control systems, including internal cooling, sealing and external air services.		

Module 15.12 - Air Systems

Engine Bleed Air

"Engine Bleed" is referring to the tapping of pressurised air from the compressor at various stages. Usually there are three positions along the compressor from which air is tapped as the diagram below shows. The different temperatures and/or pressures of the three tappings make the air useful for different things. Generally air is tapped for different reasons as follows:

Airframe customer bleed air e.g:

- ECS
- Main Engine Starter
- Air Driven Hydraulic Pumps

And engine requirements:

- Internal Engine Cooling Air
- Active Clearance Control
- Hot Air Anti Icing

It should be noted that the above are all parasite airflows and are detracting from total thrust.

NB This section does not refer to compressor control by the use of Bleed Valves and IGVs.

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Engine Bleed Air Distribution

Customer Bleed Air

Customer bleed air is usually tapped from the HP compressor. In the engine above it is tapped from 10th stage. It is cooled and pressure regulated before it passes into the aircraft pneumatic system to supply air as required throughout the airframe.

Some larger engines bleed air from 2 stages of the HP compressor for customer bleed, an early stage and usually the last stage. In this case if the pressure drops in the bleed air duct the last stage will supply if not the early stage will supply, thus conserving high pressure Compressor Delivery Pressure air.

Air is drawn from the compressor at various places to provide air for Airframe needs such as cabin pressurisation and wing and tail anti/de ice. It can also be used within the fuel control system to meter fuel, and in the compressor bleed valve system to control the bleed valves. It can provide heating air for fuel heaters and muscle air to drive air motors in pumps (both for the engine and the airframe) and it can power thrust reversers.

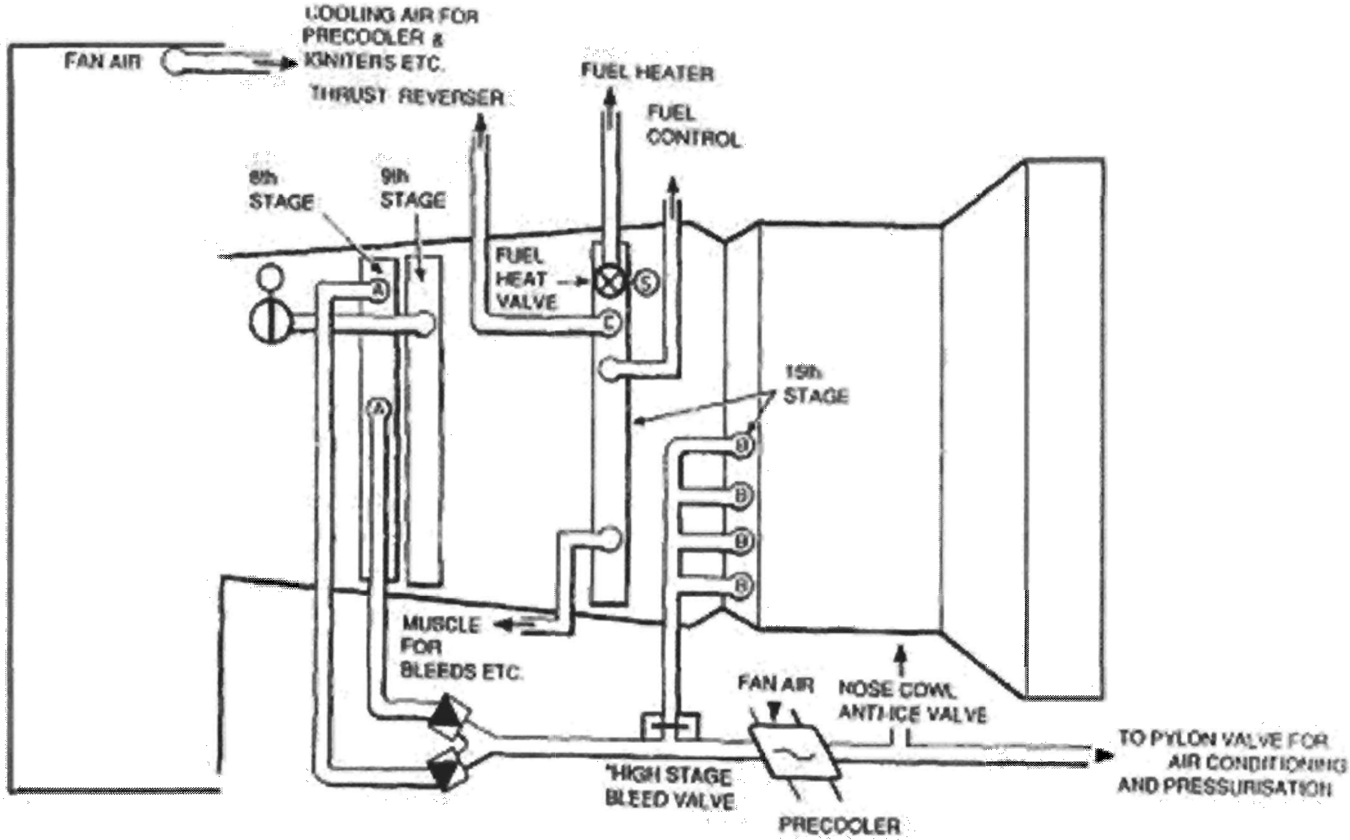


Figure 12.1: External air schematic (JT9D)

Internal Engine Cooling

Air is tapped from various compressor stages and from the fan air supply in the case of high bypass air to provide cooling and sealing to the internal parts of the engine. It is important that very hot surfaces are not cooled by cold air as the thermal shock can cause structural failure.

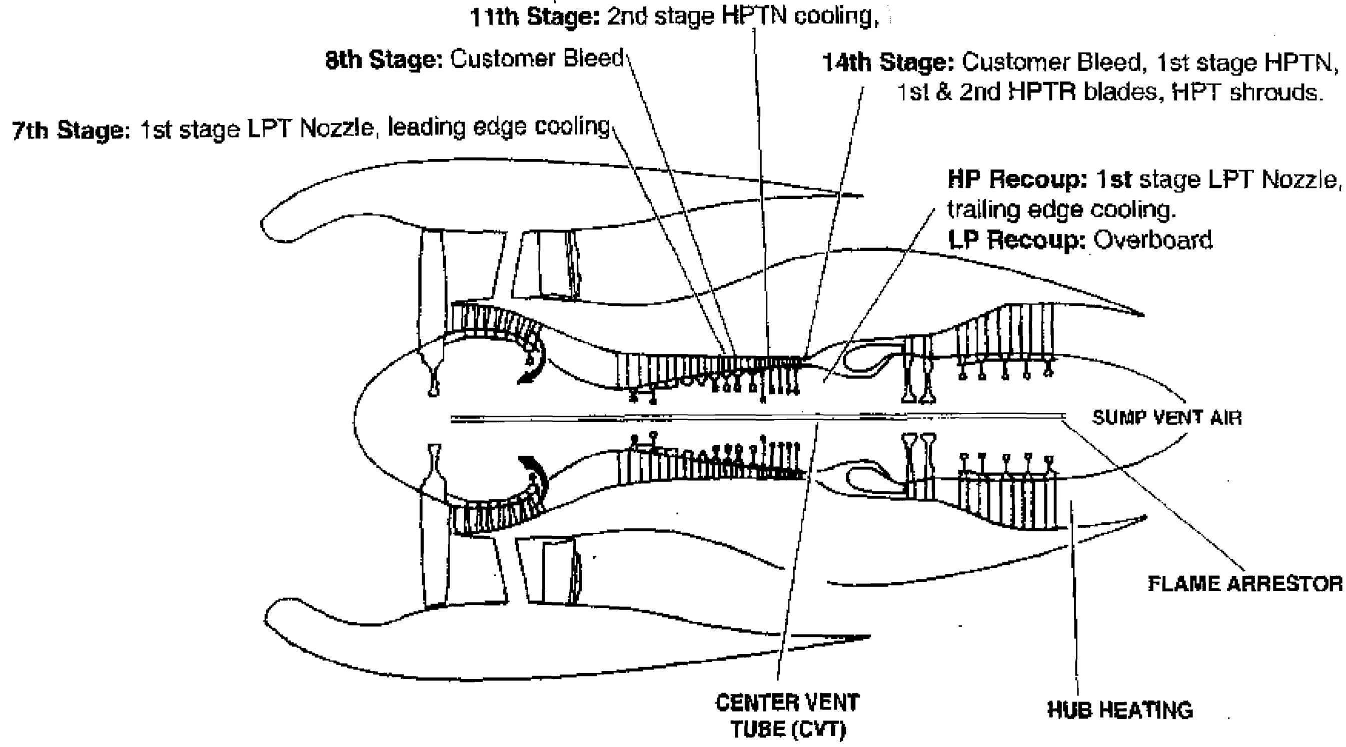


Figure 12.2: CF6 – 80 C2 Cooling Air Tappings

Note that in addition to the bleeds shown above fan air is tapped from holes in two of the fan outlet struts and are ducted into the bore of the engine passing to the LP turbine discs.

Cooling

Turbine Blades and Nozzle Guide Vanes

As we have already seen, the thrust of the engine is determined by the maximum allowable RPM of the engine. Centrifugal force is one limit to the RPM, but before this limit is reached, the maximum turbine temperature limit is normally reached, due to the quantity of fuel being burned. Clearly then, if the turbine components could be manufactured from a more heat resistant material, or they could be cooled more effectively, then an increase in fuel could be scheduled, which would result in an increase in RPM. and hence thrust.

Cooling allows the components to operate in a thermal environment 600 to 800^{0}F above the melting points of the alloys used in their construction. With cooled blades the maximum Turbine Inlet Temperature (TIT) is currently 3000^{0}F. The following cooling methods are utilised:-

Convection Cooling - is the passing of compressor bleed air through hollow portions of the turbine blade or vane. The cooling air either exits from the top to join the main gas flow, or exits via **gill holes** to become **film cooling**.

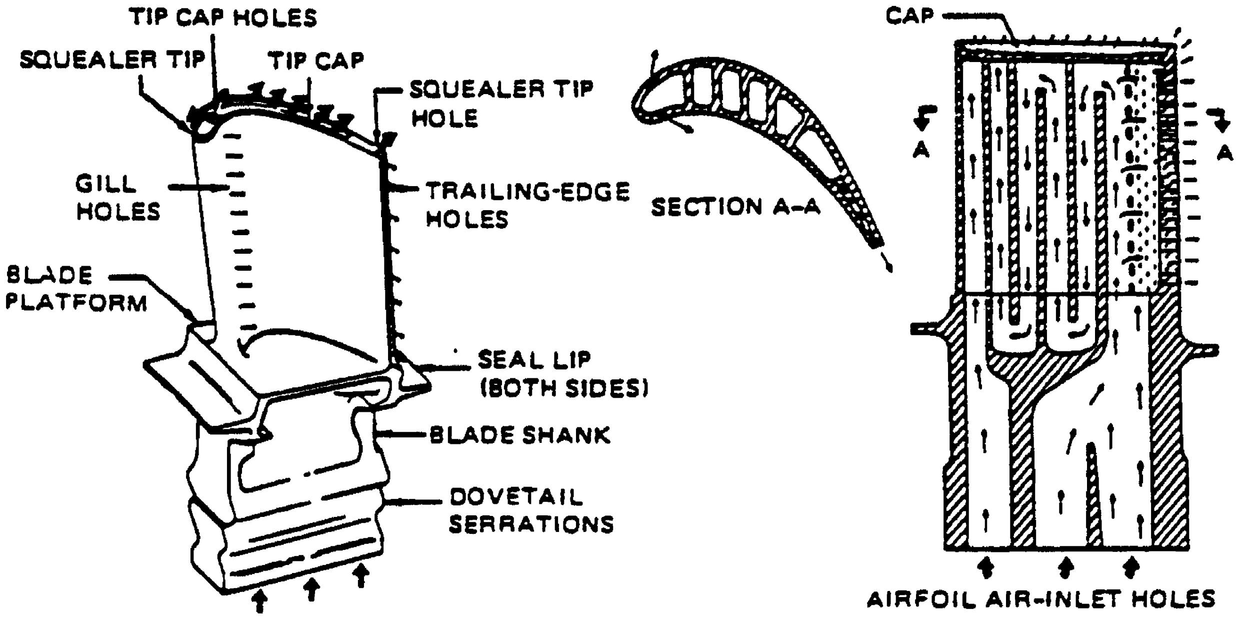


Figure 12.3: CF6-50 HP Convection & Film Cooled Turbine Blades

Film Cooling - is an <u>external</u> film of compressor bleed air which carries away the hot gasses before they have time to make contact with the surface of the blade or vane. It is usually associated with convection cooling.

The use of film cooled components, manufactured by modern investment casting techniques, have enabled a complete turbine assembly to be built which never comes into contact with the hot engine gasses.

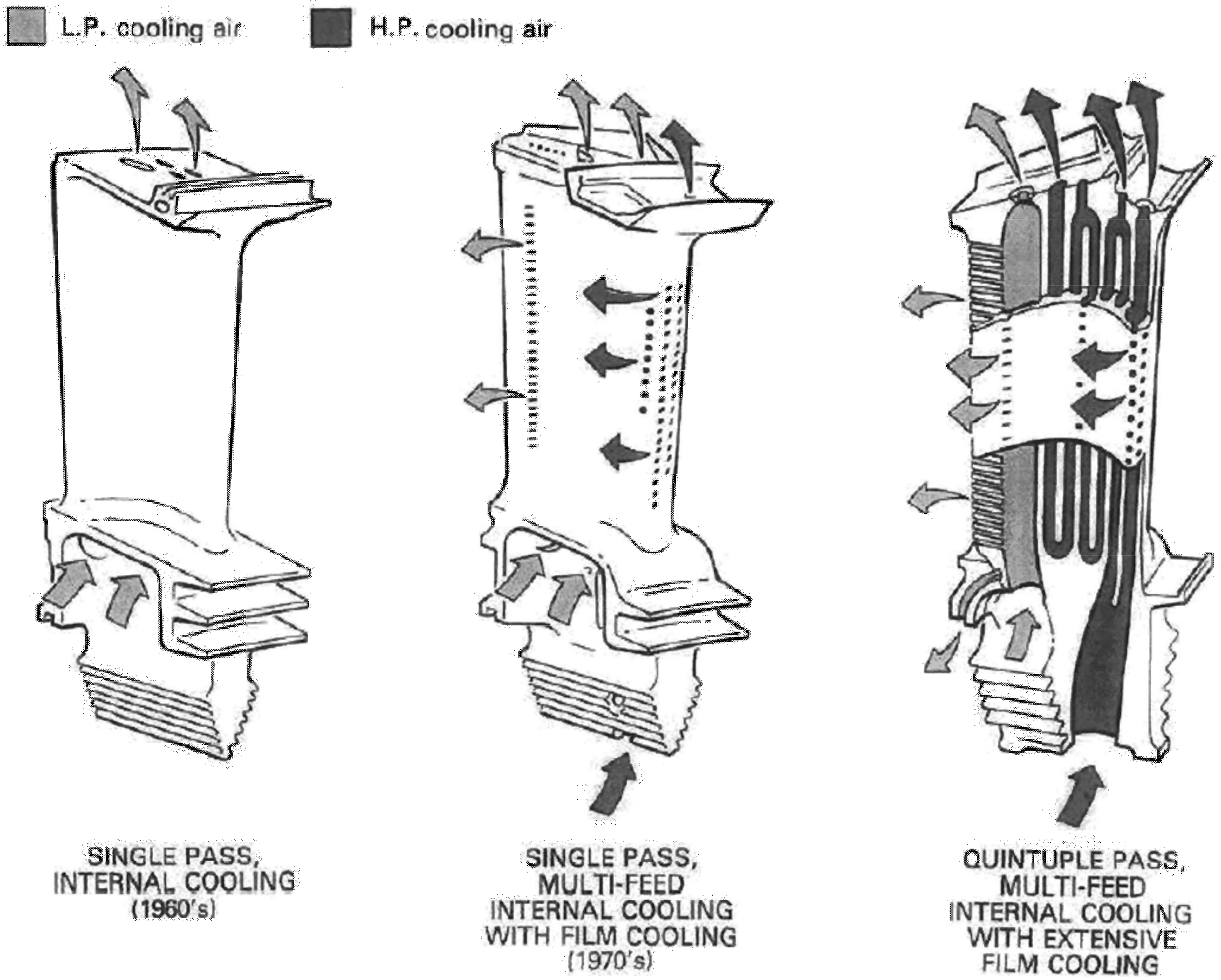
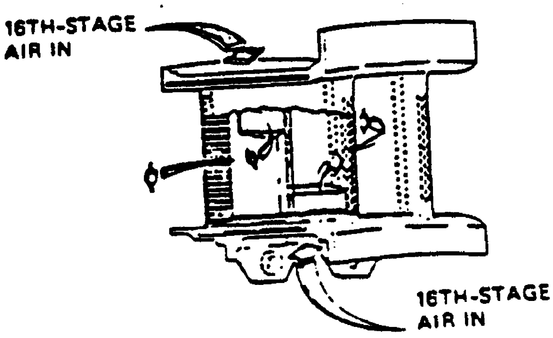


Figure 12.4: Typical turbine blade cooling

Impingement Cooling - It has been found that cooling air which is simply "passing over" the hot surface is not as efficient as cooling air which "hits" or impinges the surface at 90° to it. Therefore, very complex designs of blades and vanes have been developed which direct the cooling air at 90° to the internal surface of the blade or vane



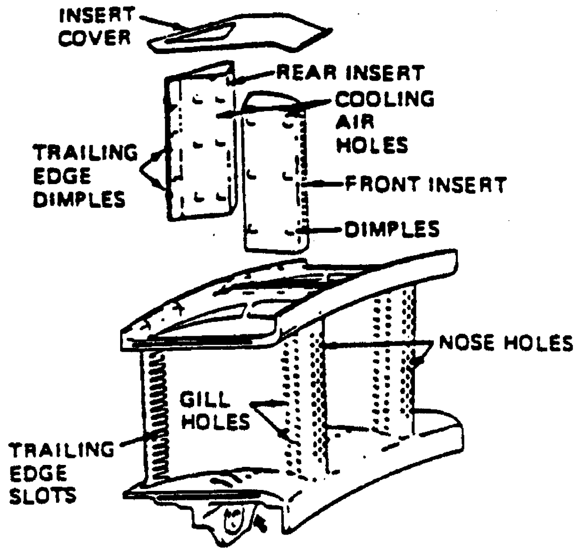


Figure 12.5: Impingement Cooled, Nozzle Guide Vanes also showing Platform and Nozzle Film Cooling.

Exhaust

It is often necessary to cool the exhaust section of the gas turbine engine. A common method of doing this is an **Insulation Blanket and Cooling Film**

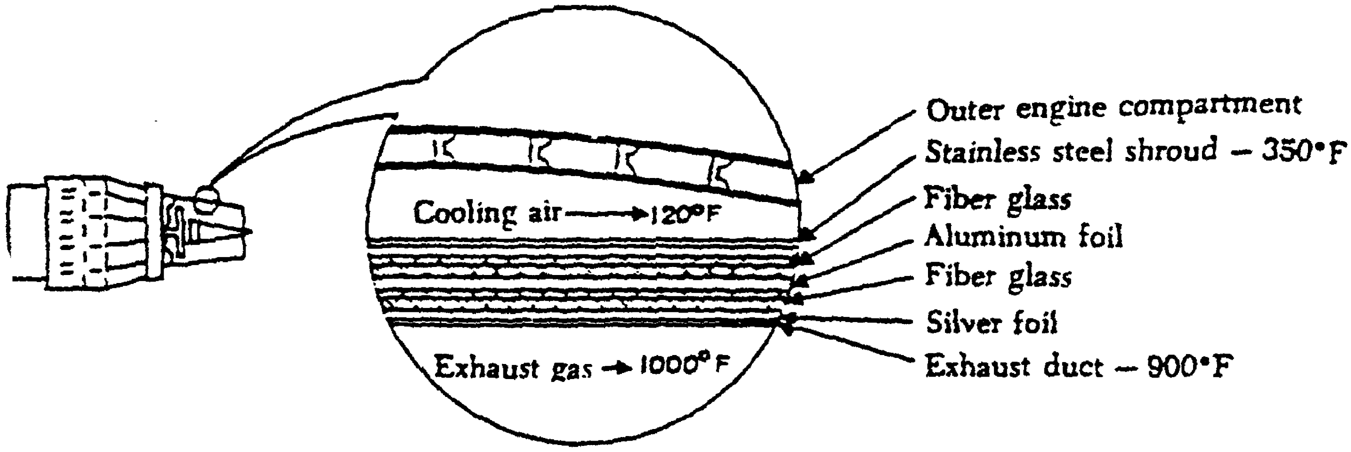


Figure 12.5: Cooling air used to cool the exhaust

External Skin of Engine

Cooling of the external skin of an aero-engine is achieved by suitable design of the aircraft airframe; the layout will depend upon where the engine is fitted and what kind of engine compartment is used. Normally, the cooling and ventilating of an engine bay or pod is achieved by ducting atmospheric air round the engine and spilling it back to atmosphere through suitably placed outlets (see figure 12.6.). The air is usually taken from a ram inlet but provision is also made to provide a cooling and ventilating airflow during ground running periods. Another function of the cooling airflow is to remove flammable vapours from the engine compartment to reduce the fire risk.

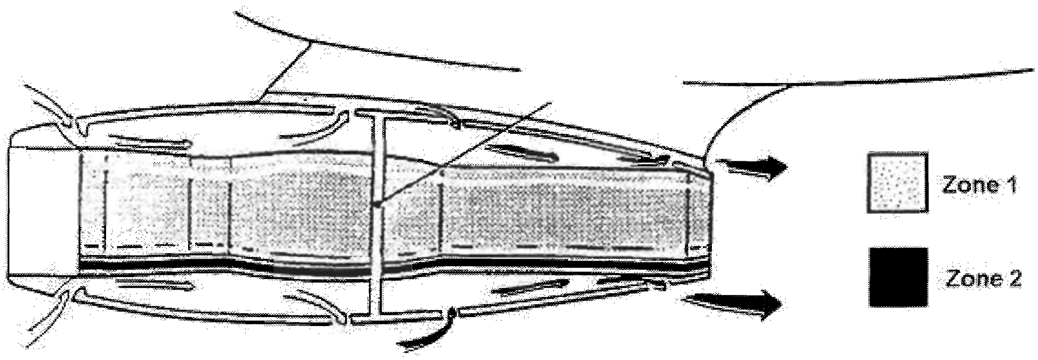


Figure 12.6: External cooling

Cooling of Accessories

A number of aircraft accessories produce sufficient heat in normal use to require a cooling system to prevent overheating. A good example is the aircraft electrical generator, which produces considerable heat under normal operating conditions. Such accessories can be cooled by ram airflow when the aircraft is flying, but will require an alternative cooling airflow when the aircraft is on the ground. For ground running and taxiing, the generator for example, is cooled by an airflow that is taken from the engine compressor. This air is blown through nozzles to produce a venturi effect area of low pressure. The low pressure then induces a continuous cooling flow of atmospheric air through the normal ram air passages. This is adequate for cooling most accessories during ground running. Figure 12.7 illustrates a generator cooling system. These are sometimes referred to as ejectors or eductors

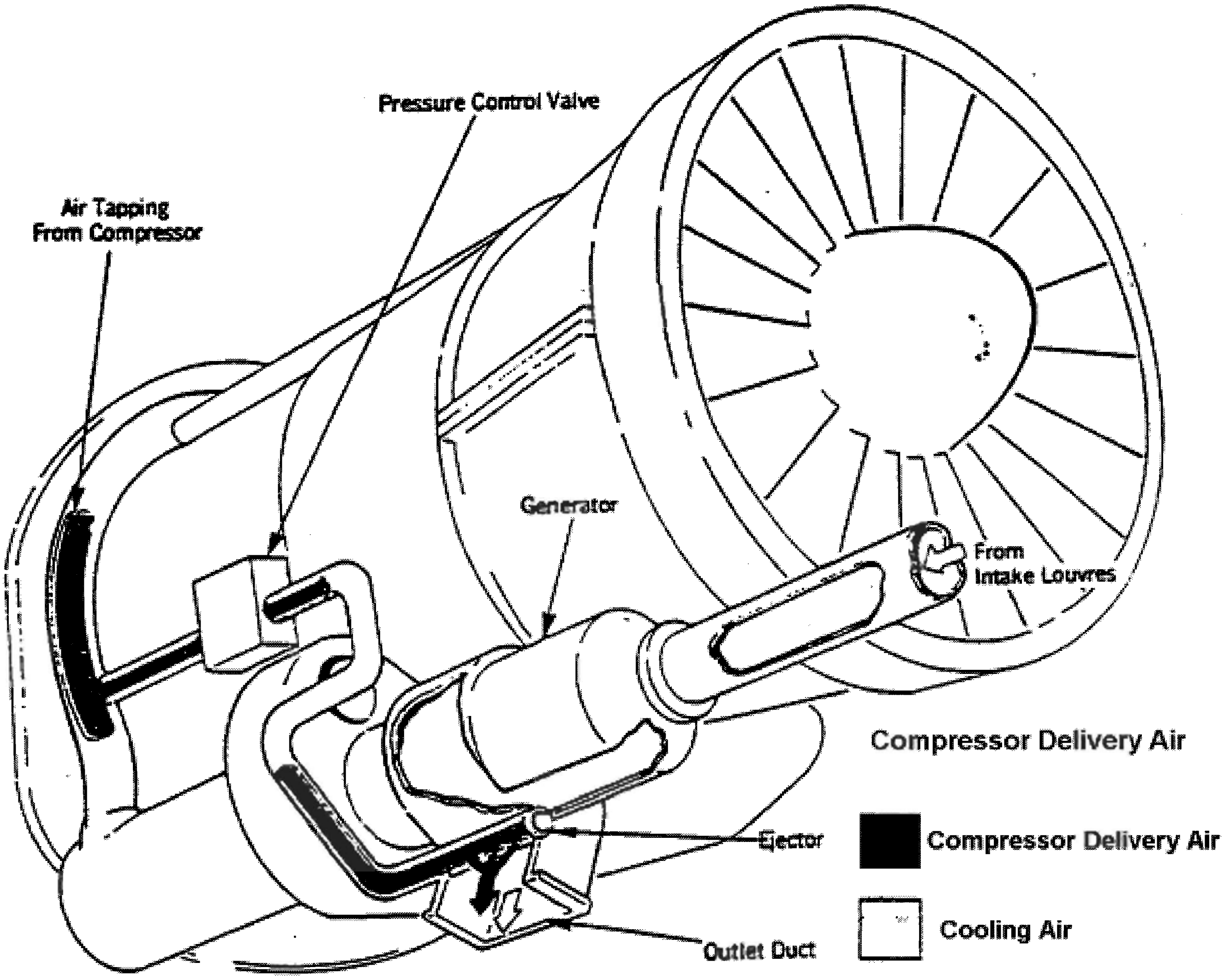


Figure 12.7: HP Air powering a jet eductor to draw air through a generator at low speed

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External Air Tappings

Engines vary as to the number of external air tappings and their usage. The following notes are taken from the Pratt and Whitney JT9D but have been simplified to provide a more generic coverage.

Fan Air

Utilised for the pre-cooling of air conditioning air, cooling the ignition system and on some engines, the Passive and Active tip clearance control.

HP Compressor – IP Air (8^{th} and 9^{th} Stage)

Utilised for pneumatic cabin bleeds at concise RPM's on the JT9D, this can also supply air for nose cowl anti-icing on other engines. The nose cowl anti-icing may have a separate manifold from another compressor stage.

Pressure Relief

Should the high pressure stage bleed valve fail in the open position, a pressure relief valve is provided to protect the pre-cooler from over-pressure damage. The valve normally would include a pressure switch connected to a PRESS RELIEF warning on the pneumatics display on the flight deck. The operating pressure would be in the region of 100 psi. If the valve opens the vented air escapes through a spring-loaded door on the cowl (blow out panel).

Temperature Control

The system normally consists of a pre-cooler temperature sensor and controller, pre-cooler and control valves. This system stabilises the air going to the airframe system, by keeping it constant at a value that the engine can achieve at all power settings. The valves are normally part of the pre-cooler and flow of the fan air is regulated by the opening or closing of the valves.

When temperature at the bleed air outlet of the pre-cooler exceeds its limit (160°-180°C) the pneumatic pressure is vented from the actuators to move the cooling air valves toward the open position.

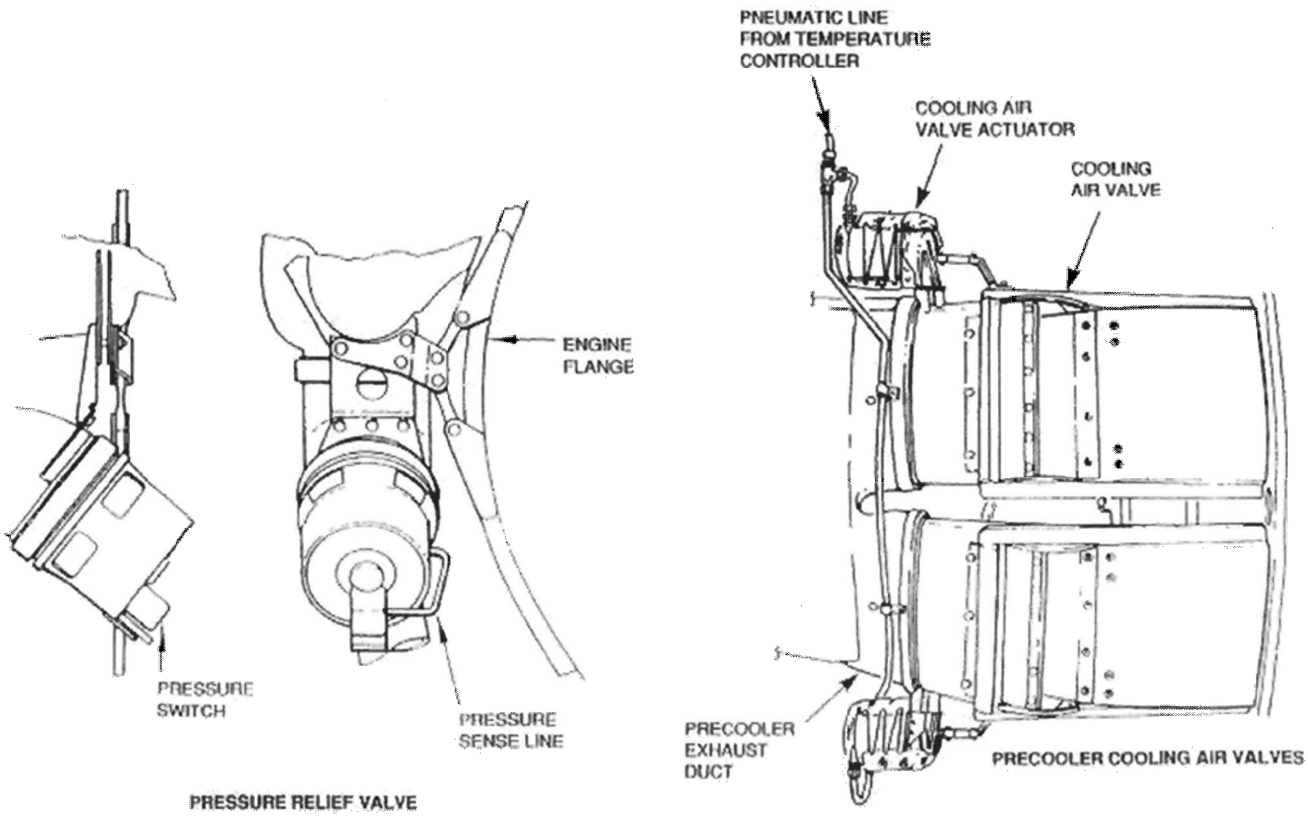

Figure 12.8: Pressure and temperature control

Internal Sealing

Abraidable Lined Labyrinth Seal

Consist of a set of teeth bearing upon a honeycomb lining. The gap between the honeycomb and the teeth is constantly varying with temperature and sometimes they make contact with each other. For this reason the honeycomb is abraidable and replaceable at major overhauls. High pressure compressor bleed air is used to force back any oil which tries to escape past the seal.

Seals between two rotating shafts are more likely to come into contact with each other due to flexing of the shafts - this would produce large amounts of heat due to friction. Here the abraidable lining is replaced by a film of oil, which does not produce as much friction.

Thread Type Seal

Like the name implies, this consists of a thread, which, as the thread rotates, compressor bleed air is fed outwards by the thread action (similar to a rifle barrel) whilst any oil trying to escape is repelled. The opposing surface may also be abraidable and replaceable.

Hydraulic Seals

Hydraulic seals are formed by a seal fin immersed in an annulus of oil which has been created by centrifugal forces .Any difference in air pressure inside and outside of the bearing chamber is compensated by a difference in oil level either side of the fin. ***Air does not pass across this seal.***

Ring Type Seal

This consists of a metal ring inside a housing that allows the ring to move radially. Although this is not the best type of seal as far as actual "sealing" is concerned, it is not affected by radial movements of the rotating assembly, as are the previous examples of seal.

Carbon Seal

A common type of seal which is abraidable and replaceable at major overhauls. The presence of particles of carbon in an oil filter is an indication of one of the carbon seals breaking up.

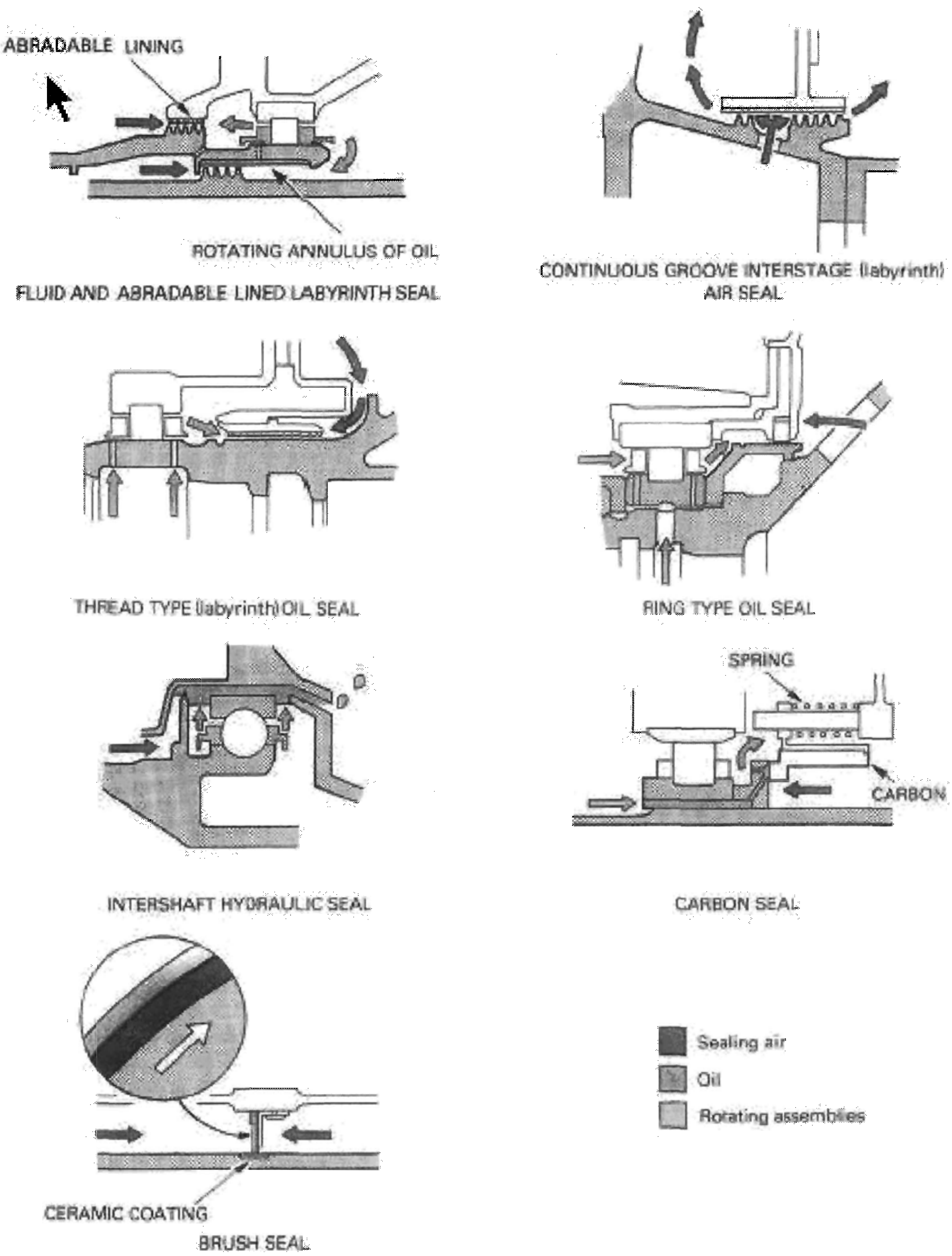

Figure 12.9: Internal Seals

Clearance Control

Since the efficiency of the turbine depends a large extent upon the clearance between the turbine blade tips and their shroud, it has been found possible on some engines to control this gap within certain limits.

The system works by a system of pipes known as the "cooling manifold" as shown. Bleed air is channelled through the pipes in varying amounts in order to cool the turbine casing and thus reduce the turbine blade tip clearance as necessary. The system is sensitive to turbine temperature and a valve will automatically channel the desired rate of cooling air depending upon the turbine temperature.

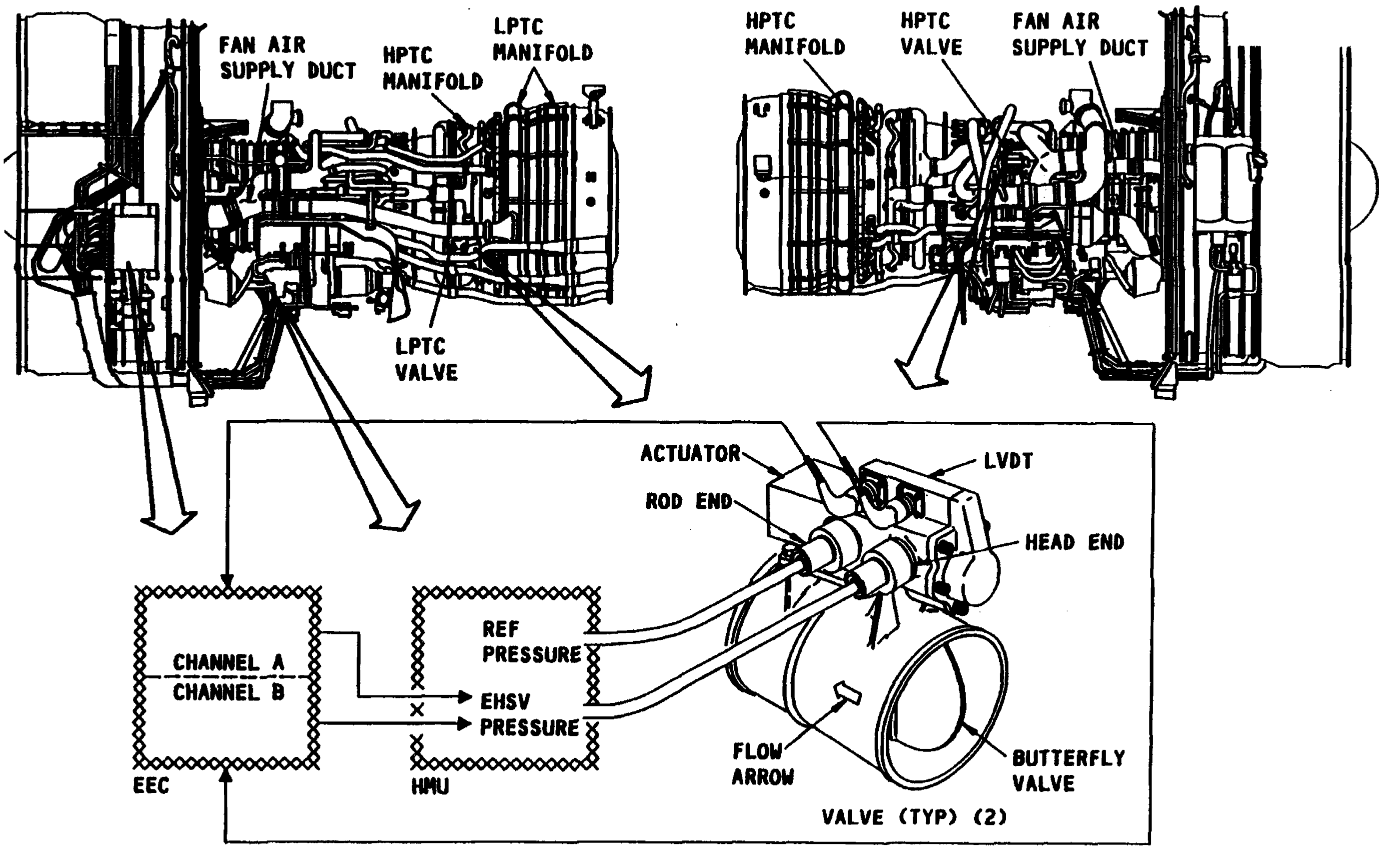

Figure 12.10: Turbine Case Cooling (Active Clearance Control)

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Control of Axial Bearing Loads

Engine shafts experience varying axial gas loads which act in the forward direction on the compressor and in a rearward direction on the turbine. The shaft between them is therefore always under tension and the difference between them is carried by a single thrust bearing. To remove the excessive loading from this bearing in extreme rearward thrust conditions, compressor bleed air acts on a forward area as shown:-

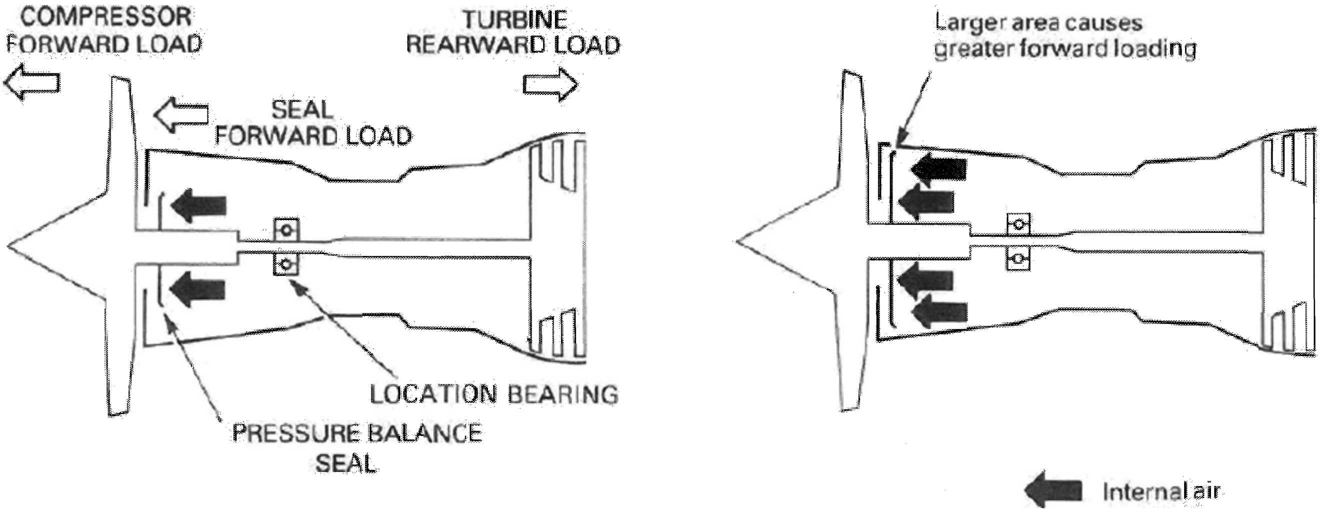

Figure 12.11: Relief of axial bearing loads by pressure balance

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Hot Air Anti Ice Systems

Large Gas Turbine Engines usually use hot air to prevent icing. It is controlled from the flight deck and is used when icing conditions prevail.

Icing conditions are defined as a temperature below +10°C with visible moisture (fog, mist etc)

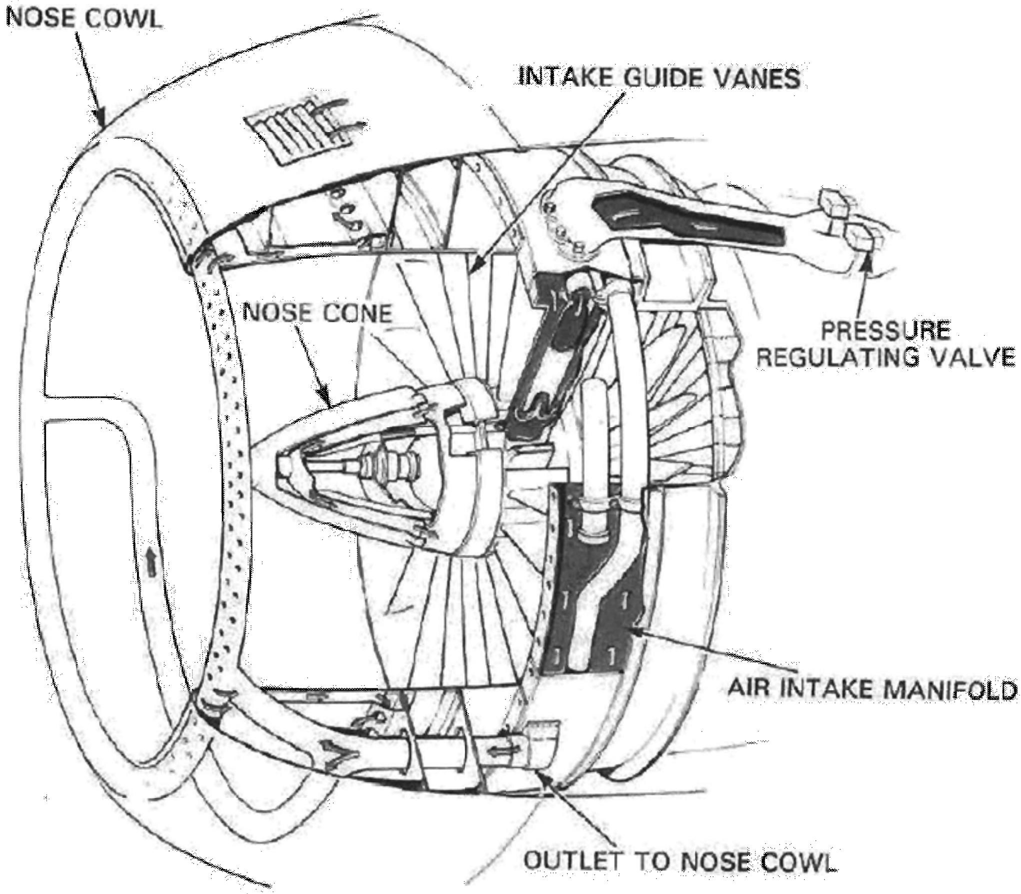

Figure 12.12: Anti-ice of the nose cowl, spinner and inlet guide vanes

The hot air system provides surface heating of the engine and/or powerplant where ice is likely to form. The protection of rotor blades is rarely necessary, because any ice accretions are dispersed by centrifugal action. If stators are fitted upstream of the first rotating compressor stage these may require protection. If the nose cone rotates it may not need anti-icing if its shape, construction and rotational characteristics are such that likely icing is acceptable. Rolls Royce use a flexible rubber tip to their spinners that stop ice forming.

The hot air for the anti-icing system is usually taken from the high pressure compressor stages. It is ducted through pressure regulating valves, to the parts requiring anti-icing. Spent air from the nose cowl anti-icing system may be exhausted into the compressor intake or vented overboard.

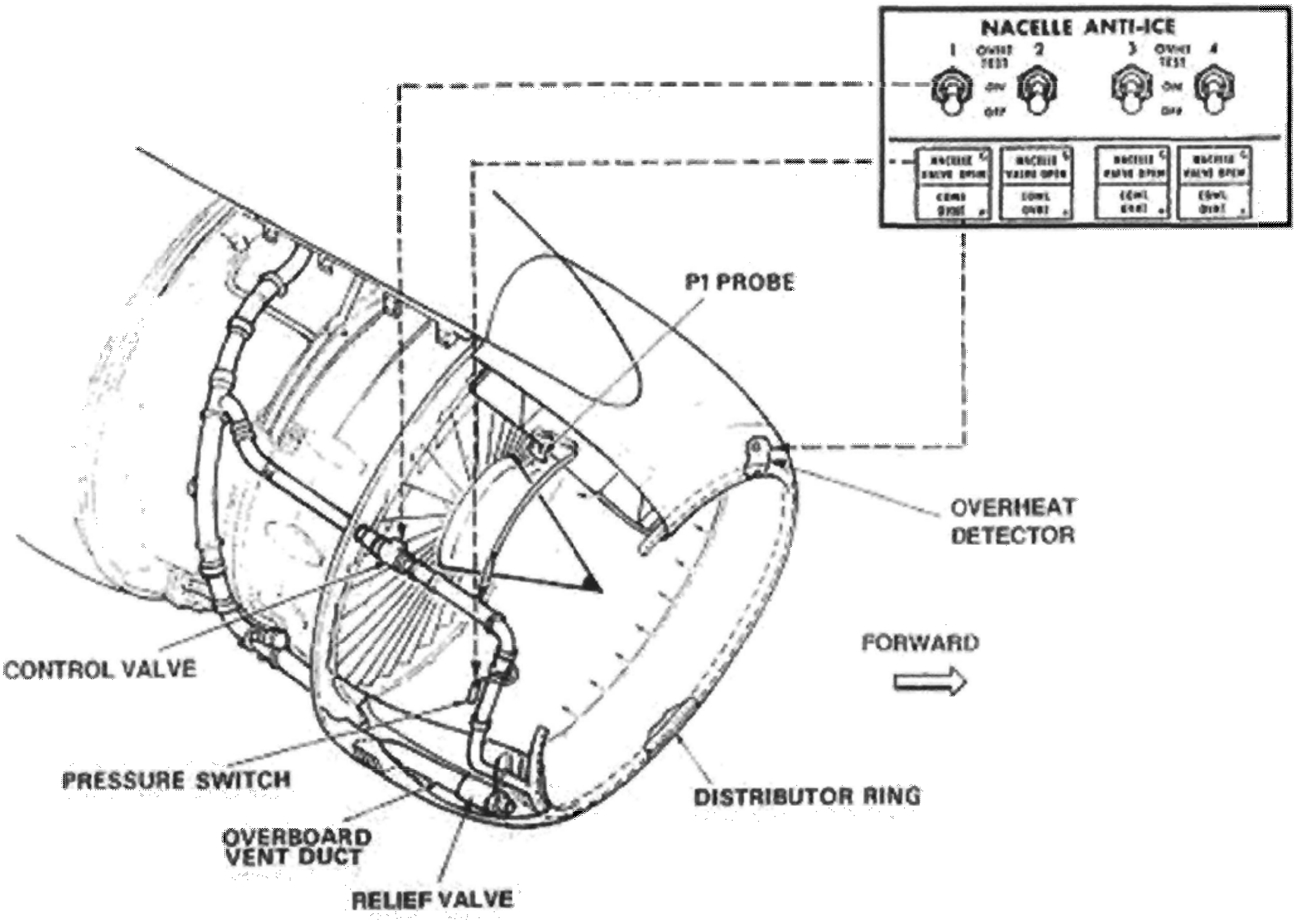

Figure 12.13: Intake anti-ice control

If the nose cone is anti-iced its hot air supply may be independent or integral with that of the nose cowl and compressor stators. For an independent system, the nose cone is usually anti-iced by a continuous unregulated supply of hot air via internal ducting from the compressor.

The pressure regulating valves are electrically actuated by manual selection, or automatically by signals from the aircraft ice detection system. The valves prevent excessive pressures being developed in the system, and act also as an economy device at the higher engine speeds by limiting the air off take from the compressor, thus preventing an excessive loss in performance. The main valve may be manually locked in a pre-selected position prior to take-off in the event of a valve malfunction, prior to replacement.

TTS Integrated Training System

Module 15
Licence Category B1

Gas Turbine Engine

15.13 Starting and Ignition 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.

Table of Contents

Module 15.13 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 Reference	Level
		B1
Starting and Ignition Systems	15.13	2
Operation of engine start systems and components;		
Ignition systems and components;		
Maintenance safety requirements.		

Module 15.13 - Starting and Ignition Systems

Start Sequence

Cranking the Engine

Two separate systems are required to start a gas turbine engine, a means to rotate the compressor/turbine assembly and a method of igniting the air/fuel mixture in the combustion chamber. Ideally the process is automatic after the fuel supply is turned on and the starting circuit brought into operation.

The starter motor is capable of cranking the engine to a speed slightly higher than that at which sufficient gas flow is generated to enable the engine to accelerate under its own power.

At an early stage in the cranking operation, the igniter plugs in the engine combustion chamber are supplied with electrical power, followed by the injection of fuel when fuel pressure has built up sufficiently to produce an atomized spray.

Light-up normally occurs at this point and the engine assisted by the starter motor; accelerates to self-sustaining speed.

Self-Sustaining Speed

This is the speed at which the energy developed by the engine is sufficient to provide for continuous operation of the engine without the starting device.

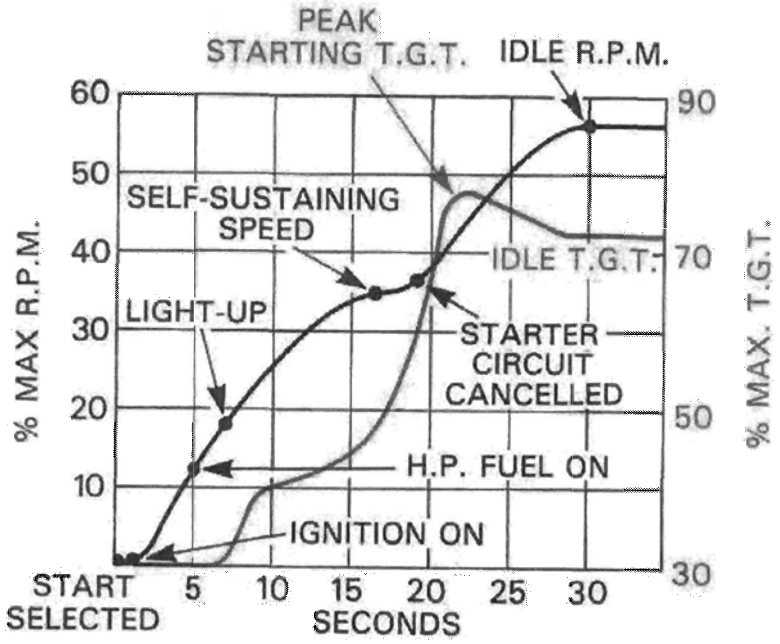

Figure 13.1: Typical engine start sequence

Idle RPM

This speed is slightly above self-sustaining and is often referred to in the form of a percentage of compressor speed, and on the ground is about 60% of the high pressure compressor, i.e. 60% N2 or N3. Note that on modern systems idle rpm is a throttle position (normally fully aft). Idle RPM varies with altitude and can be increased under certain flight conditions, for example on the approach or with anti icing switched on.

Precautions

If engine acceleration is retarded, the possibility of a light-up occurring reduces at low engine speed, and would result in overfuelling and a high turbine gas temperature. The power supply to the starter should always be checked before starting, and must not be less than the minimum figure quoted in the aircraft Maintenance Manual. Facing the aircraft into wind will assist with engine acceleration, particularly in the case of turbo-prop aircraft, the propellers of which are normally provided with a special fine blade angle for starting and ground running.

There are many different methods used to crank the engine to self-sustaining speed, depending on the operational requirements of the particular aircraft.

Where speed of starting is of the utmost importance, on fighter aircraft for instance, a cartridge or mono-fuel turbine starter can be fitted. These devices are not used on civil aircraft however, due to the high cost and the handling difficulties involved.

Start Control

The start master switch does not just switch the starting system 'ON'. On some aircraft will prepare the aircraft electrical system for the start operation i.e. starter motors require a very high current for starting which is usually too much for a single Transformer rectifier (TRU), so it will parallel the DC systems. To ensure that a start is not carried out on a single TRU, it will place all the AC power systems onto one generator, so if it fails the start is aborted. It will also ensure that the engine gauging systems are all powered for the start in all conditions.

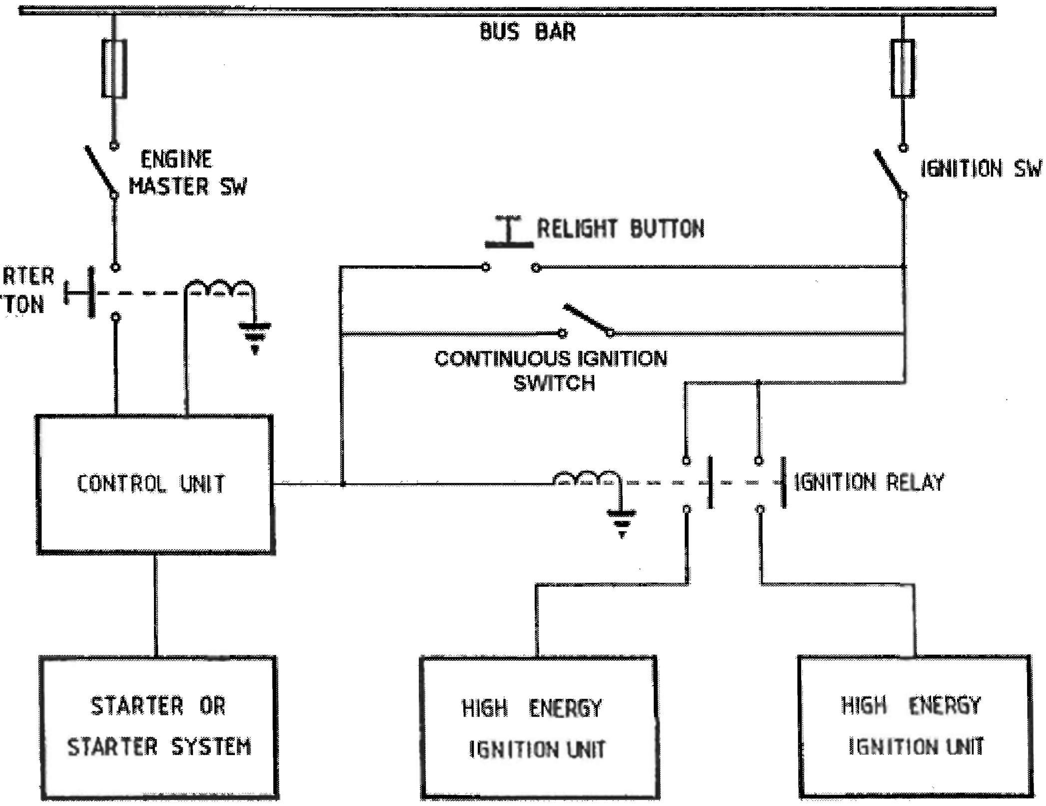

Figure 13.2: Typical starting control system

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Starters

The two main methods used on transport aircraft are:

Electric starters – fitted to Turbo-Prop and small turbo jet engines
Air starters – fitted to large turbo jet and turbo fan engines

Starter Motor Requirements

The starter motor must produce a high torque and transmits it to the engine rotating assembly in a manner that provides smooth acceleration from rest up to a speed at which the gas flow through the engine provides sufficient power for the engine turbine to take over.

Cranking and Fuel Flow

As soon as the starter has accelerated the compressor sufficiently to establish an airflow through the engine, the ignition is turned on, followed by the fuel. The exact sequence of the starting procedure is important since there must be sufficient airflow through the engine to support combustion before the fuel/air mixture is ignited. At low engine cranking speeds, the fuel flow rate is not sufficient to enable the engine to accelerate, and for this reason the starter continues to crank the engine until after self-accelerating speed has been attained.

Starter Cut-Off Before Self-Sustaining Speed

If assistance from the starter were cut off below the self-accelerating speed, the engine would either fail to accelerate to idle speed, or might even decelerate because it could not produce sufficient energy to sustain rotation or to accelerate during the initial phase of the starting cycle.

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Electric Starters

Direct Cranking Gas Turbine Starters
Direct cranking electric starting systems are similar to those used on reciprocating engines. Starter- generator starting systems are also similar to direct cranking electrical systems. Electrically, the two systems may be identical, but the starter generator is permanently engaged with the engine shaft through the necessary drive gears, while the direct cranking starter must employ some means of disengaging the starter from the shaft after the engine has started.

On some direct cranking starters used on gas turbine engines no overload release clutch or gear reduction mechanism is used. This is because of the low torque and high speed requirement for starting gas turbine engines.

Starter Engagement

Starter Jaw - A common method of coupling the starter drive to the engine is by means of a jaw on the starter, which moves axially into engagement with a similar jaw on the engine gearbox during initial starter rotation. Axial movement of this jaw is effected either by helical splines on the starter drive shaft, as shown below, or by the pressure of a solenoid operated push rod in the starter motor

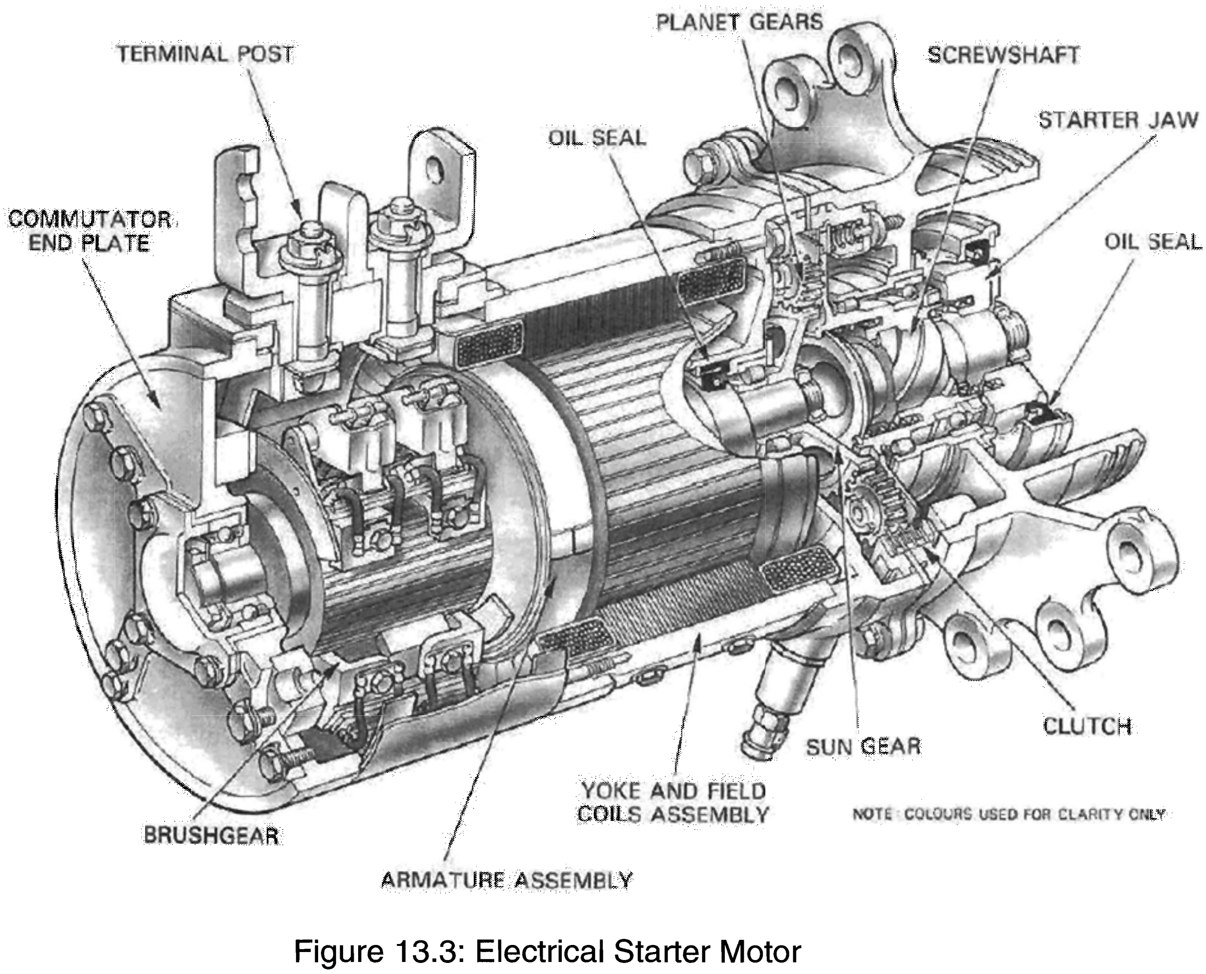

Figure 13.3: Electrical Starter Motor

Sprag Clutch - Alternative methods of engagement are the ratchet drive and sprag clutch, in which the ratchet pawls or sprags rotate with the engine. Engagement and disengagement are effected centrifugally, engagement by the engine taking place whenever its speed falls below idling.

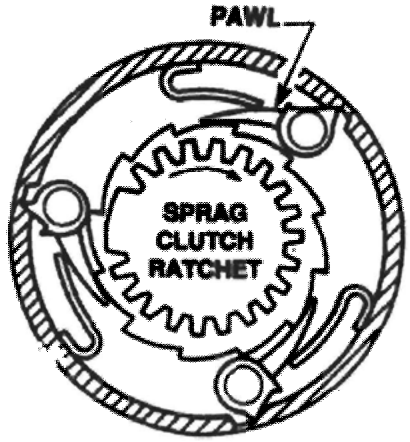

Figure 13.4: Typical sprag clutch

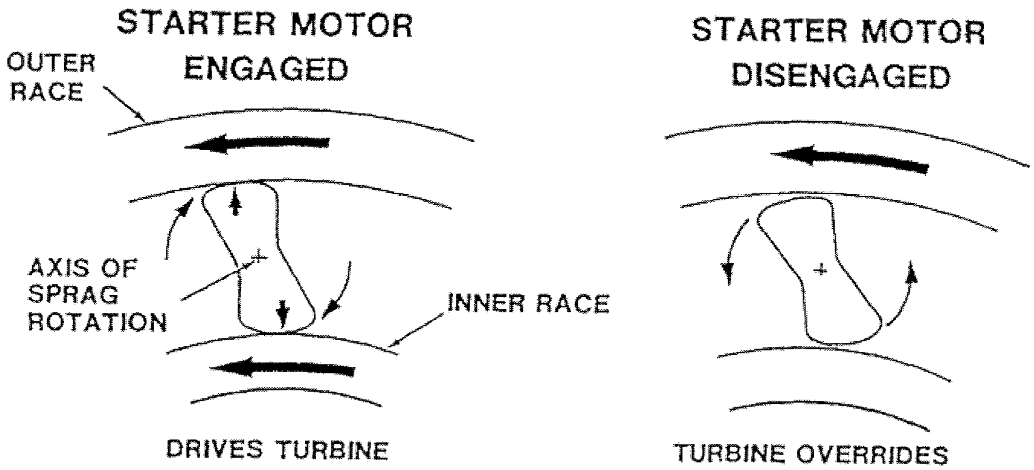

Figure 13.5: Another type of sprag clutch

Low Voltage Starting System
Operation of the starting cycle is normally controlled by either of two methods. On some aircraft the high initial starter current is used to engage an overspeed relay and hold-in solenoid; when the engine begins to accelerate under its own power, the starter current decreases and the hold-in solenoid breaks the circuit automatically.

In the low voltage system shown opposite, the hold-in solenoid is called the main relay.

The electrical supply may be of a low or high voltage, and it is passed through a system of relays and resistances to allow the full voltage to be progressively built up as the starter gains speed. It also provides the power for operation of the ignition system. The electrical supply is automatically cancelled when the starter load is reduced after the engine has satisfactorily started, or when the time cycle is completed.

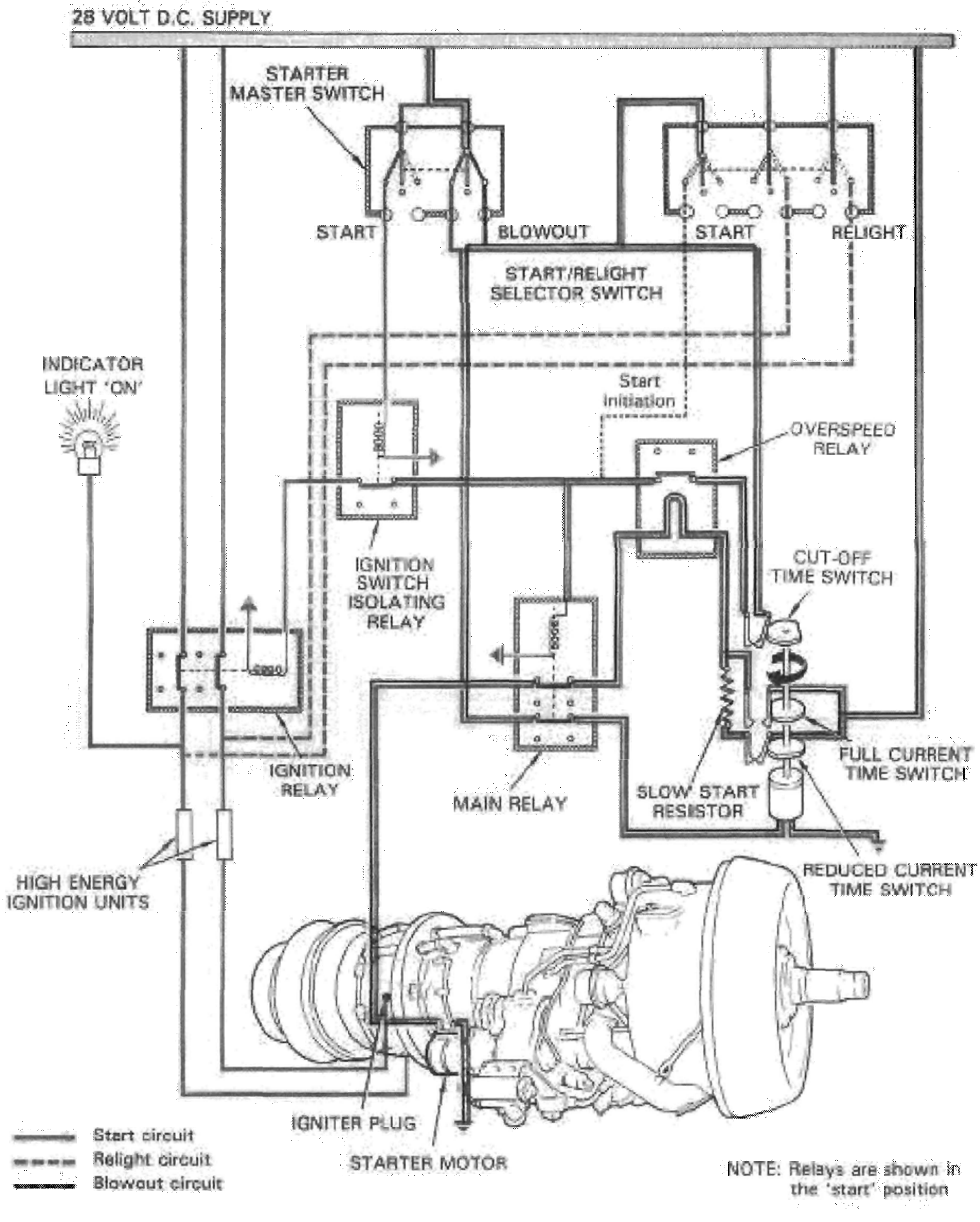

Figure 13.6: Low Voltage Starting System

Starter Generator Systems

Many gas turbine aircraft are equipped with starter generator systems. These starting systems use a combination starter generator which operates as a starter motor to drive the engine during starting, and, after the engine has reached a self-sustaining speed, operates as a generator to supply the electrical system power.

The starter generator unit, shown below, is basically a shunt generator with an additional heavy series winding. This series winding is electrically connected to produce a strong field and a resulting high torque for starting.

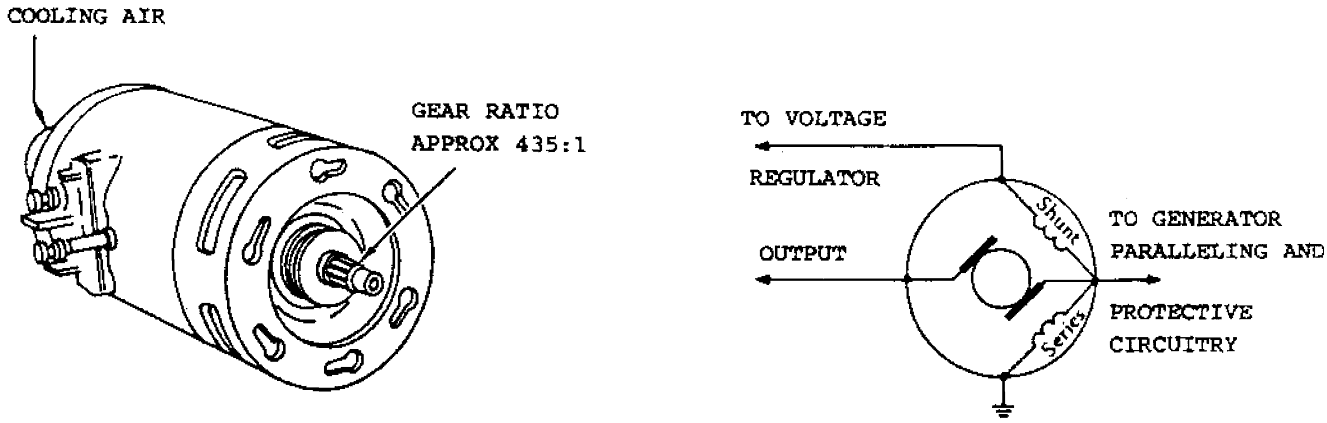

Figure 13.7: Starter Generator

Starter generator units are desirable from an economical standpoint, since one unit performs the functions of both starter and generator. Additionally, the total weight of starting system components is reduced, and fewer spare parts are required.

Operation

The unit is similar to a direct cranking starter since all of the windings used during starting are in series with the source. While acting as a starter, the unit makes no practical use of its shunt field. A source of 24 volts and 1500 amperes is usually required for starting.

Installation

On a typical aircraft installation, one starter generator is mounted on each engine gearbox. During starting, the starter generator unit functions as a DC starter motor until the engine has reached a predetermined self-sustaining speed. Aircraft equipped with two 24 volt batteries can supply the electrical load required for starting by operating the batteries in a series configuration.

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Air Starters

Air Turbine Starter

For large gas turbine engines, starter motors are mainly Air Turbine types. The power from the turbine assembly is transmitted through a reduction gear and sprag clutch engagement mechanism, to drive the engine rotating assembly. The engagement mechanism will allow the starter to 'run down' after an engine start.

Starting air is supplied via the aircraft ducting to a selected engine.

The distribution of air is normally achieved by electrically operated valves, switch controlled, from the flight deck.

Air for starting may be obtained from various sources, as follows:-

a ground supply truck,

an auxiliary power unit

an engine compressor tapping, from an existing running engine

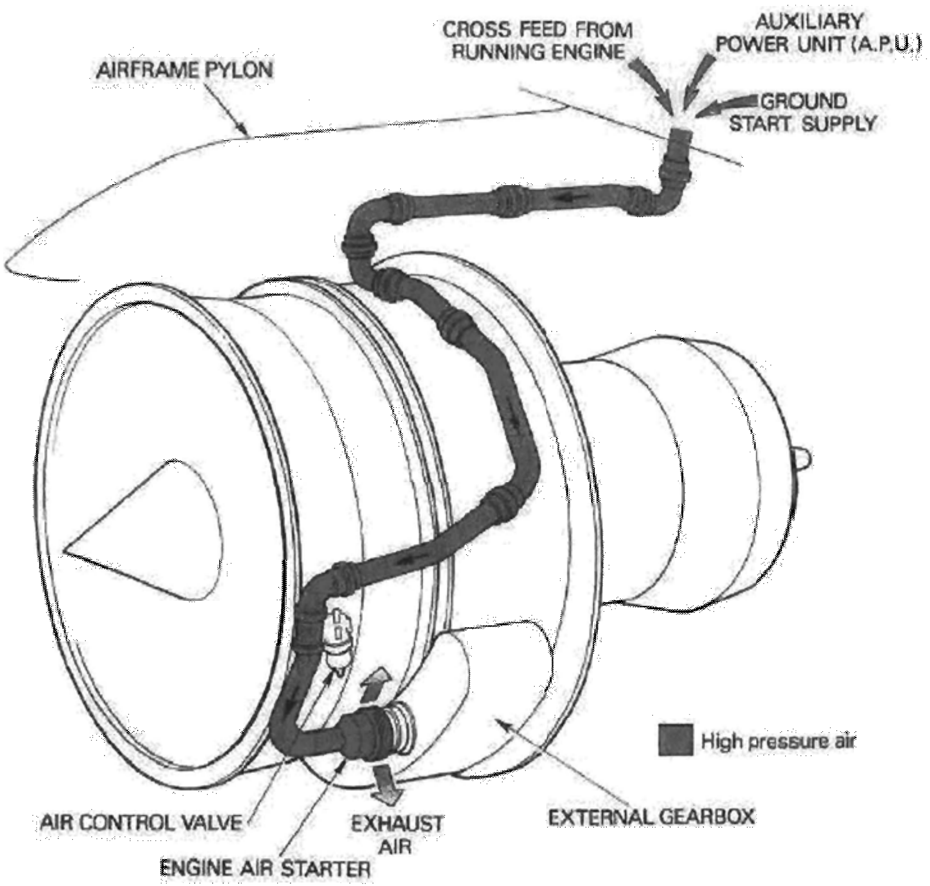

Figure 13.8: Air Starter System Layout – Boeing 757

Air turbine starters are designed to provide a high starting torque from a small, lightweight source. A typical air turbine starter weighs from one quarter to one-half as much as an electric starter capable of starting the same engine. It is also capable of developing twice as much torque as the electric starter.

The typical air turbine starter illustrated overleaf consists of an axial flow turbine, which turns a drive coupling through a reduction gear train and a starter clutch mechanism.

Air Starter Operation
Introducing air of sufficient volume and pressure into the starter inlet operates the starter. The air passes into the starter turbine housing, where it is directed against the rotor blades by the nozzle vanes, causing the turbine rotor to turn. As the rotor turns, it drives the reduction gear train and clutch arrangement, which includes the rotor pinion, planet gears and carrier, sprag clutch assembly, output shaft assembly, and drive coupling.

Sprag Clutch Operation
The sprag clutch assembly engages automatically as soon as the rotor starts to turn, but ' disengages as soon as the drive coupling turns more rapidly than the rotor side. When the starter reaches this over-run speed, the action of the sprag clutch allows the gear train to coast to a halt. The output shaft assembly and drive coupling continue to turn as long as the engine is running.

Starter Shut-Off
A rotor switch actuator, mounted in the turbine rotor hub, is set to open the turbine switch when the starter reaches cut-out speed. Opening the turbine switch interrupts an electrical signal to the pressure-regulating valve. This closes the valve and shuts off the air supply to the starter.

As the starter speeds up towards an over-speed, the ball weights centrifuge out forcing up the bell housing breaking the micro-switch.

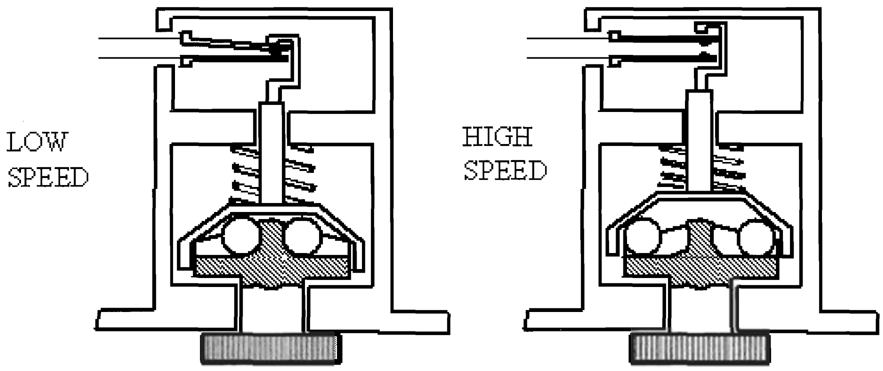

Figure 13.9: Starter speed switch operation

Starter Construction
The turbine housing contains the turbine rotor, the rotor switch actuator, and the nozzle components, which direct the inlet air against the rotor blades. The turbine housing incorporates a turbine rotor containment ring designed to dissipate the energy of blade

fragments and direct their discharge at low energy through the exhaust duct in the event of rotor failure due to excessive turbine overspeed.

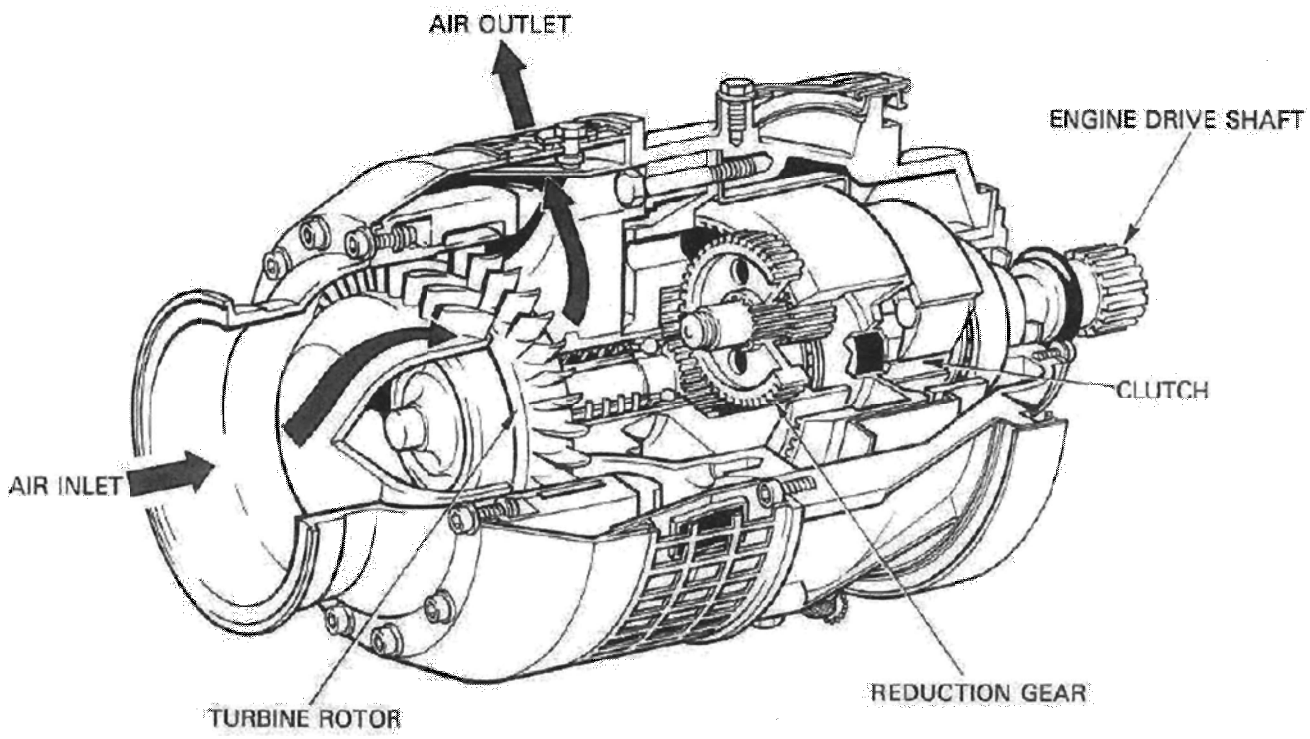

Figure 13.10: A turbine air starter

The ring gear housing which is internal, contains the rotor assembly. The switch housing contains the turbine switch and bracket assembly.

Also contained in the transmission housing are the reduction gears, the clutch components, the flyweight cut out switch and the drive coupling as shown below.

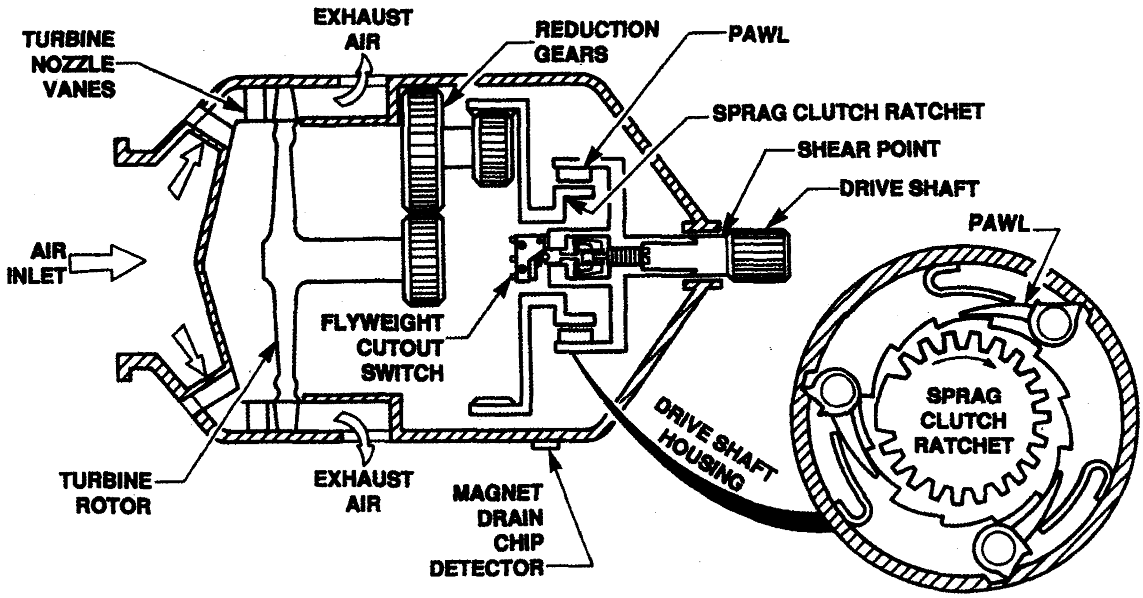

Figure 13.11: Air Starter

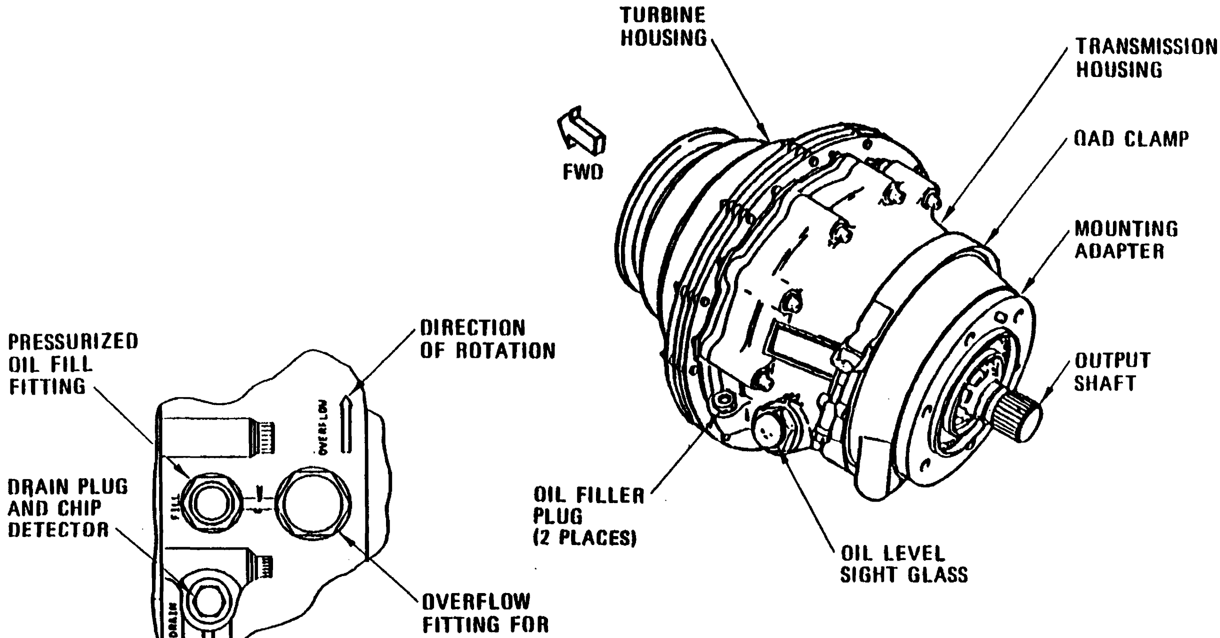

Figure 13.12: Air Starter Installation

The transmission housing also provides a reservoir for the lubricating oil. Oil is added to the transmission housing sump through a port at the top of the starter. This port is closed by a vent plug containing a ball valve, which allows the sump to be vented to the atmosphere during normal flight, but prevents loss of oil during inverted flight. The housing also incorporates two oil-level holes, which are used to check the oil quantity. A magnetic drain plug in the transmission drain opening attracts any ferrous particles, which may be in the oil.

Starter Attachment
To facilitate starter installation and removal, a mounting adapter is bolted to the mounting pad on the engine. Quick-detach clamps join the starter to the mounting adapter and inlet duct. Thus, the starter is easily removed for maintenance or overhaul by disconnecting the electrical line, loosening the clamps, and carefully disengaging the drive coupling from the engine starter drive as the starter is withdrawn.

Air Starter Valve
The air for starting is directed through a combination pressure-regulating and shut-off valve in the starter inlet ducting. This valve regulates the pressure of the starter operating air and shuts off the air supply when the maximum allowable starter speed has been reached.

The pressure-regulating and shut-off valve consists of two sub-assemblies:-

the pressure-regulating valve,
the pressure-regulating valve control.

Pressure Regulating and Shut-Off Valve Operation
The regulating valve assembly consists of a valve housing containing a butterfly-type valve. The shaft of the butterfly valve is connected through a cam arrangement to a servo piston. When the piston is actuated, its motion on the cam causes the rotation of the butterfly valve. The slope of the cam track is designed to provide a small initial travel and high initial torque when the starter is actuated. The cam track slope also provides a more stable action by increasing the time the valve is open.

System Control
The control assembly is mounted on the regulating valve housing and consists of a control housing in which a solenoid is used to stop the action of the control crank in the 'off' position. The control crank links a pilot valve, which meters pressure to the servo piston, with the bellows connected by an air line to the pressure sensing port on the starter.

Initiation
Turning on the starter switch energizes the regulating valve solenoid. The solenoid retracts and allows the control crank to rotate to the 'open' position. The control crank is then rotated by the control rod spring moving the control rod against the closed end of the bellows. Since the regulating valve is closed and downstream pressure is negligible, the bellows can be fully extended by the bellows spring.

As the control crank rotates to the open position, it causes the pilot valve rod to open the pilot valve allowing upstream air, which is supplied to the pilot valve through a suitable filter and restriction in the housing, to flow into the servo piston chamber. The drain side of the pilot valve, which bleeds the servo chamber to the atmosphere, is now closed by the pilot valve rod and the servo piston moves inboard.

This linear motion of the servo piston is translated to rotary motion of the valve shaft by the rotating cam, thus opening the regulating valve. As the valve opens, downstream pressure increases. This pressure is bled back to the bellows through the pressure-sensing line and compresses the bellows. This action moves the control rod, thereby turning the control crank and moving the pilot valve rod gradually away from the servo chamber to vent to the atmosphere.

When downstream (regulated) pressure reaches a preset value, the amount of air flowing into the servo through the restriction equals the amount of air being bled to the atmosphere through the servo bleed and the system is in a state of equilibrium.

Rotation
When the valve is open, the regulated air passing through the inlet housing of the starter impinges on the turbine, causing it to turn.

Starter Cut-Out
When starting speed is reached, a set of flyweights in a centrifugal cut-out switch actuates a plunger which breaks the ground circuit of the solenoid.

Valve Closed
When the ground circuit is broken and the solenoid is de-energized, the pilot valve is forced back to the 'off' position, opening the servo chamber to the atmosphere. This action allows the actuator spring to move the regulating valve to the 'closed' position.

When the air to the starter is terminated, the outboard clutch gear, driven by the engine, will begin to turn faster than the inboard clutch gear, and the inboard clutch gear, actuated by the return spring, will disengage the outboard clutch gear, allowing the rotor to coast to a halt. The outboard clutch shaft will continue to turn with the engine.

Manual Starting
Sometimes the solenoid on the start valve becomes unserviceable, so provision is made to enable the aircraft to be started manually. This can be by manually depressing the solenoid valve or turning the butterfly itself.

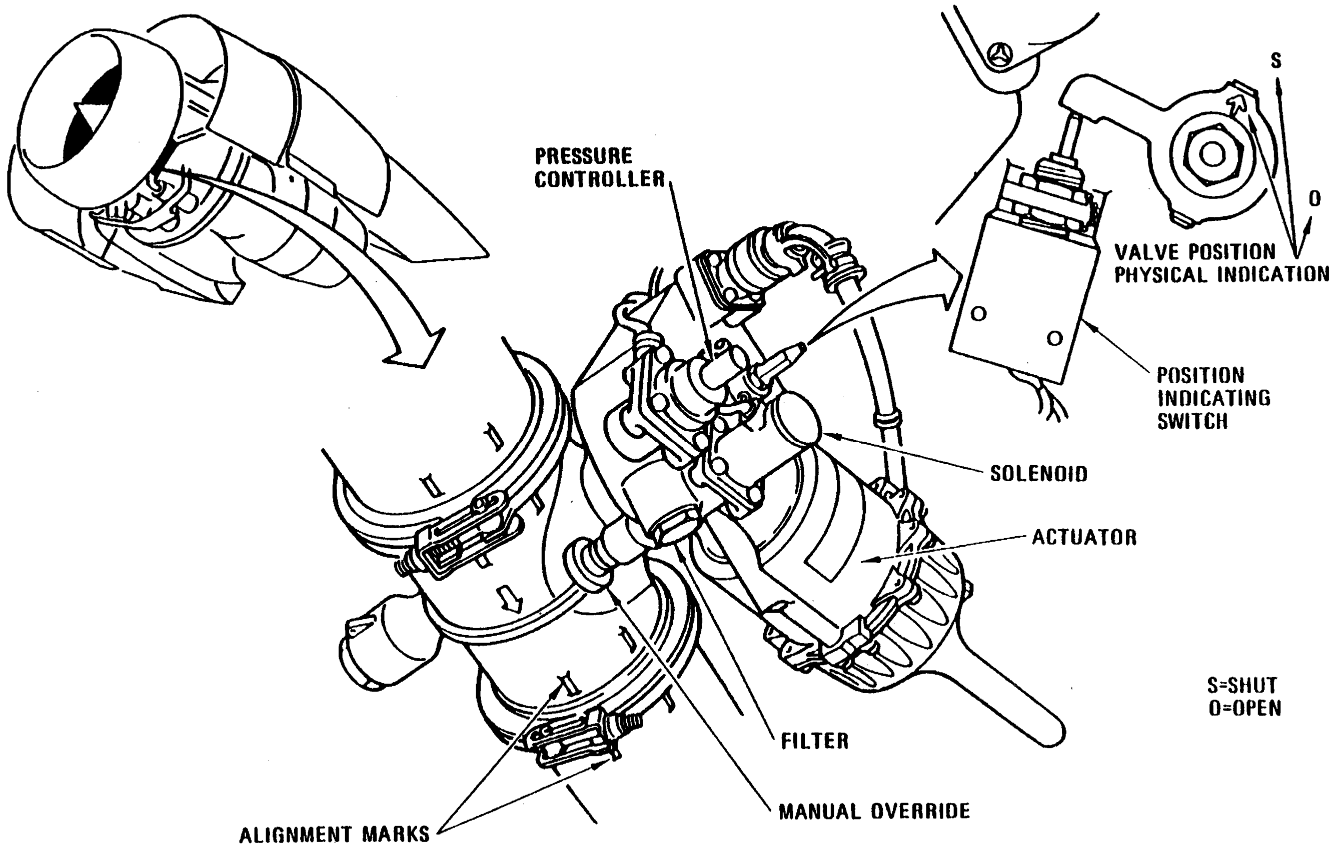

Figure 13.13: Starter control valve

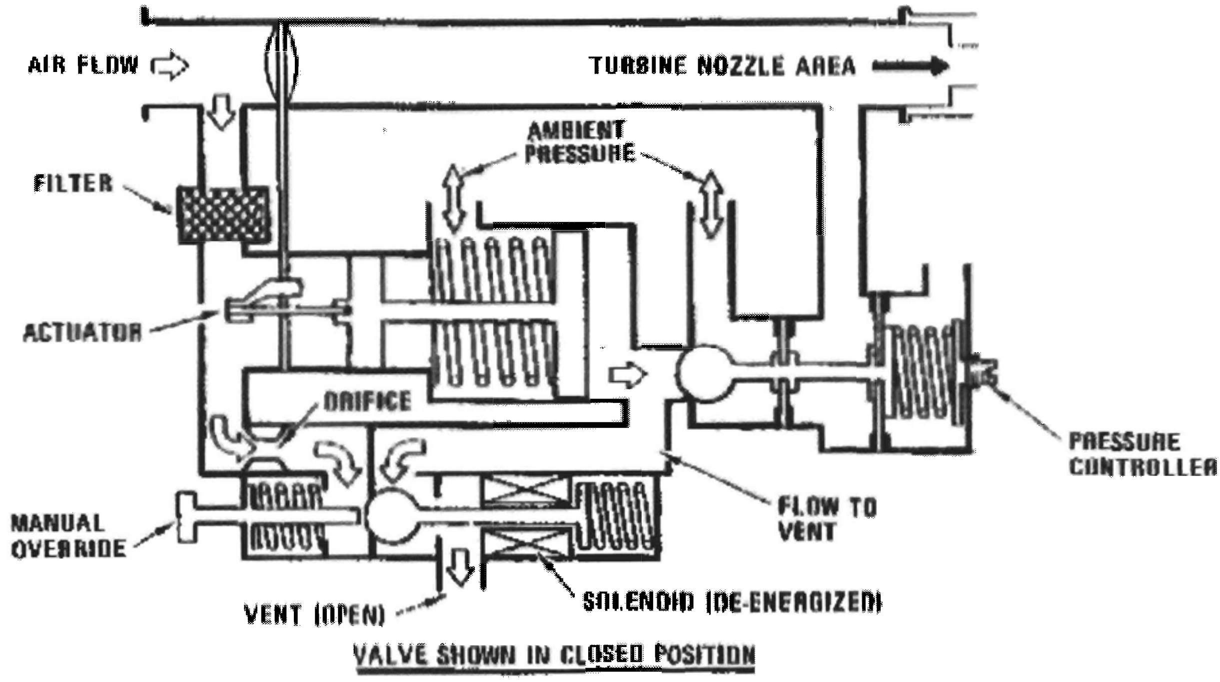

Figure 13.14: Starter Control Valve installation and schematic

Manual Start Procedure
The following procedure is typical of a manual start.

1. Gain access to the affected start valve.
2. Upon command from the flight deck, operate manual override handle to OPEN.

WARNING: WHEN MANUALLY OPERATING THE START VALVE, HAND AND ARM COVERS MUST BE WORN. HOT AIR EXHAUSTING FROM STARTER COULD RESULT IN INJURY TO PERSONNEL.

3. After engine has started and upon the command from the flight deck, operate the manual override handle to CLOSED.

Starter Running Limitations
All air starters have run time limitations to prevent overheating. The limits are very generous for even considerable dry cranking operation. For example 5 minutes on then 10 minutes off is one example, but they all vary and the AMM should be consulted for a particular type.

A Start System Example

A300 Starting System

The following example of an engine start is taken from the training manuals for an A300-134 fitted with GE 6-50 engines.

Procedure

The engines are equipped with air starters.

The air to start the engine is provided by:-

The APU, the ground connectors, or the other engine, if it is already running.

The starting system has provision for:-

Engine start.

Engine crank.

Continuous ignition.

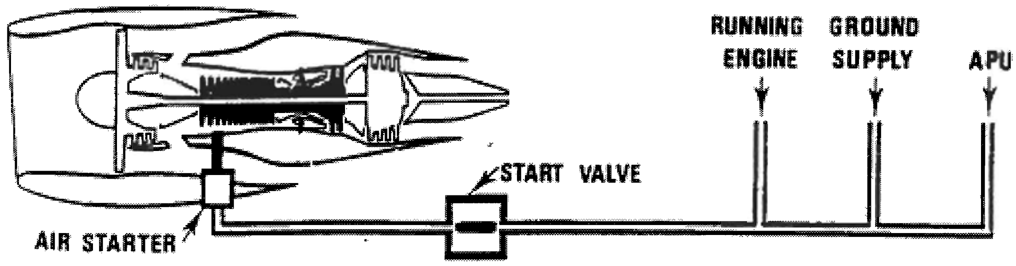

Figure 13.15: A300 starting system – overview

The control panel

The control panel is located on the overhead panel.

Figure 13.16 shows the start panel with, at the top, the ignition selector which controls the two ignition systems of each engine. The selector has three positions: CRANK in the vertical position, then ground START ignition A or B when turned to the left and continuous RELIGHT when turned to the right.

At the bottom of the panel is the master switch with ARM and START/ABORT positions.

Finally on each side, one yellow push-to-start button for each engine with its corresponding start valve position light, which is blue and is marked OPEN.

The ignition system is supplied by two different electrical circuits.

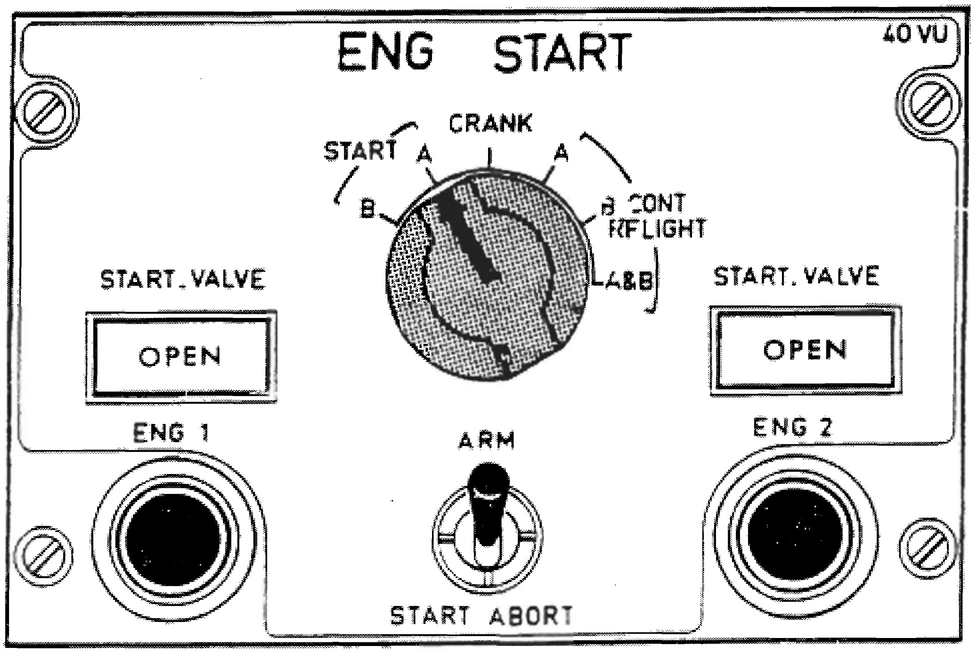

Figure 13.16: Engine start panel

115 VAC is used to energise the exciter and is controlled through the HP fuel shut off valve lever, the ignition selector and the ignition relay.

The ignition relay is energised by 28 VDC when the master switch is in the ARM position and the start button is pushed.

Starting is achieved in the following manner:-

Set the ignition selector to A or B.

Set the master switch to "ARM".

This arms the ignition circuit and closes the air conditioning system if it is open. The amber lights in the push-to-start buttons will illuminate during this transit.

When the air conditioning valves are closed, the lights in the push-to-start buttons extinguish and the operator can push the start button which will latch. This increases the APU rpm to 100% to provide sufficient air for starting.

It also arms the ignition circuit and finally, provided that pneumatic power is available, it opens the start valve and the blue OPEN light illuminates.

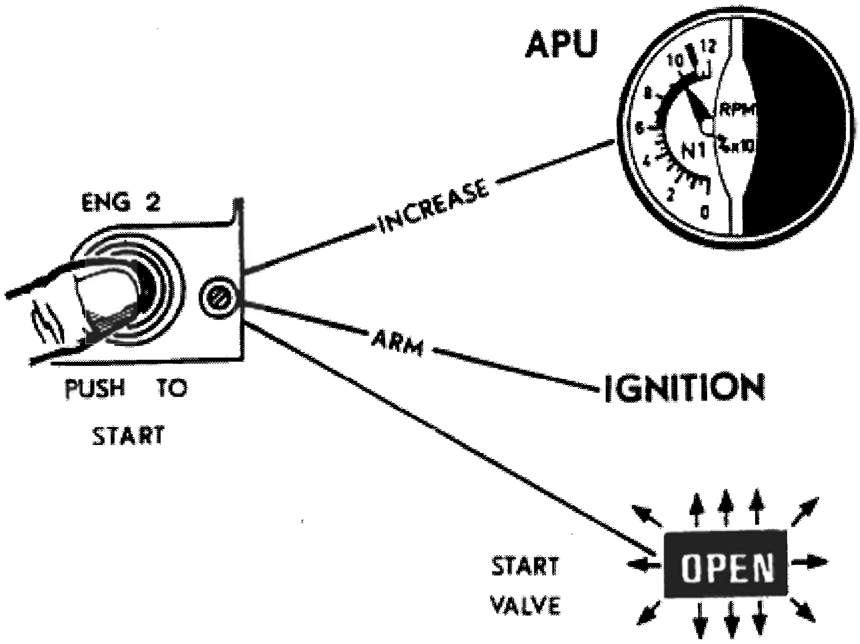

Figure 13.17: When the Start Button is pressed, the APU goes to 100%

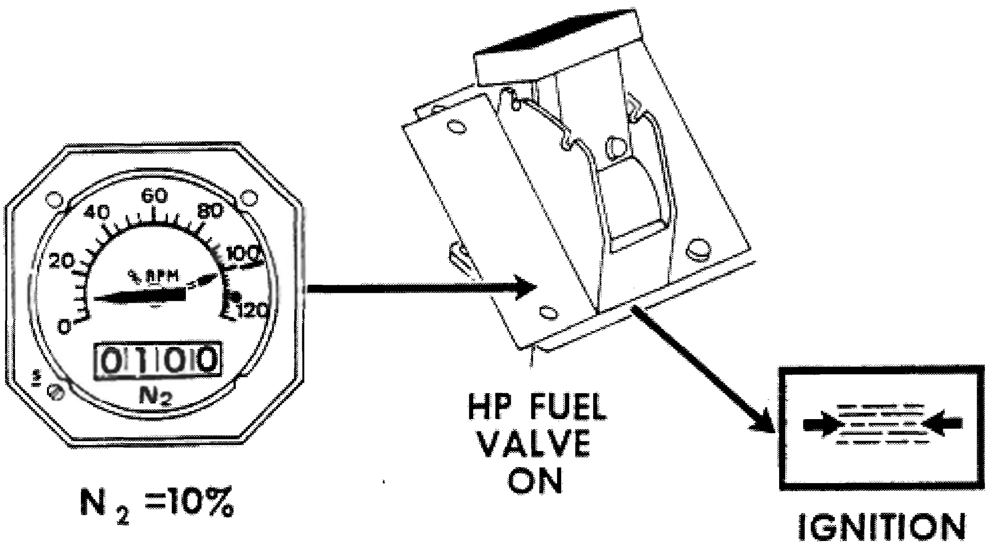

Figure 13.18: At 10% N2 the HP fuel valve is opened

When engine N_2 reaches 10% the HP Fuel Shut-off Valve must be opened.

This supplies fuel to the engine and energises the ignition exciters. The engine should light up and EGT should increase.

When N_2 reaches 45% the engine will be self-sustaining so the ignition is switched off, the push-to-start button pops out and the APU demand goes back to normal.

Engine rpm should now increase to Ground Idle, which is approximately 65% N_2 and 24% N_1.

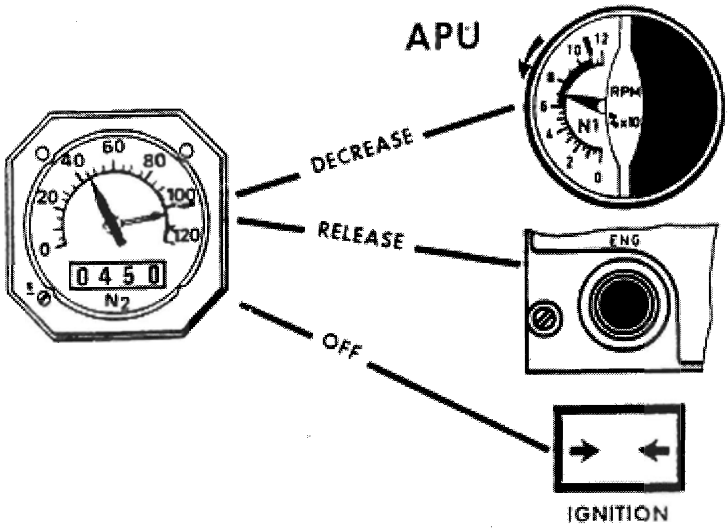

Figure 13.19: At 45% the start sequence is cancelled

Engine Start Fault Terminology

Here are some common phrases, often seen in technical log reports

Hung Start	Engine lights up and reaches self sustaining speed, but then the rpm is slow or fails to reach IDLE rpm, TGT on or near limit. Likely cause is the FCU.
Wet Start	Excess fuel causing failure to light up. If start occurs, high TGT and TORCHING.
Hot Start	Maximum start TGT exceeded - likely cause, low starter supplies electrical and/or air.
Abortive Start	Engine does not light up within specified period. No increase in TGT. No increase in speed above motoring rpm - likely causes, no fuel or no ignition.

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Ignition Systems

Overview

The purpose of the ignition system is to provide a means of initiating or sustaining combustion within the engine, an identical system is fitted to each engine. The system requirements are :-

Satisfactory engine starting
Relight at altitude when necessary
Continuous operation during critical flight conditions

High Energy (HE) ignition is used for starting all jet engines and a dual system is always fitted. Each system has an igniter unit connected to its own igniter plug, the two plugs being situated in different positions in the combustion chamber (usually at the 4 and 8 o'clock positions).

Ignition units are rated in "joules". A high value output (e.g. 12 joules) is necessary to ensure that the engine will "relight" at high altitudes and is sometimes necessary for starting (especially with engines fitted with a vaporising tube type nozzle). However, in certain flight conditions, such as icing or take-off in heavy rain or snow, it may be necessary to have the ignition system operating **continuous** to give an automatic relight should a "flame-out" occur. For this condition, a low output (e.g. 3 to 6 joules) would be used because it results in a longer life of both the igniter system and the plug. See diagram overleaf showing a typical large aircraft ignition system.

Use of Ignition

Many systems incorporate two circuits within the same casing - one a low energy **continuous duty** circuit, the other a high energy **intermittent duty** circuit. Both plugs may be fired from the intermittent duty circuits, but there is a second circuit which fires just one plug on a lower energy output.

Continuous duty - is used for periods of flying in icing conditions or during heavy rain or snow. The cockpit switches would be positioned to the **left** or **right** positions to protect against flame-out. The energy output of this system is not sufficient to cause "light-up" in the air or on the ground, but will merely help to sustain ignition in bad flying conditions.

Intermittent duty - is used for initial "light-up" on the ground or to "re-light" should a flame-out occur at altitude. If the switch is placed in the "START" position, the intermittent duty circuit is activated **and** the starter system is activated. In this position the "VALVE OPEN" light will illuminate to show that the starter motor is being fed with supply air. If the switch were placed in the "FLT START" position, the intermittent duty circuit is activated, but since the engine will be windmilling, it does not require a starter motor, and hence this system remains off.

With the older types of intermittent system, the intermittent duty circuits have a time limit on their operation. A typical time limit would be two minutes ON, with a three to twenty minutes OFF for cooling.

A Typical DC Ignition Unit

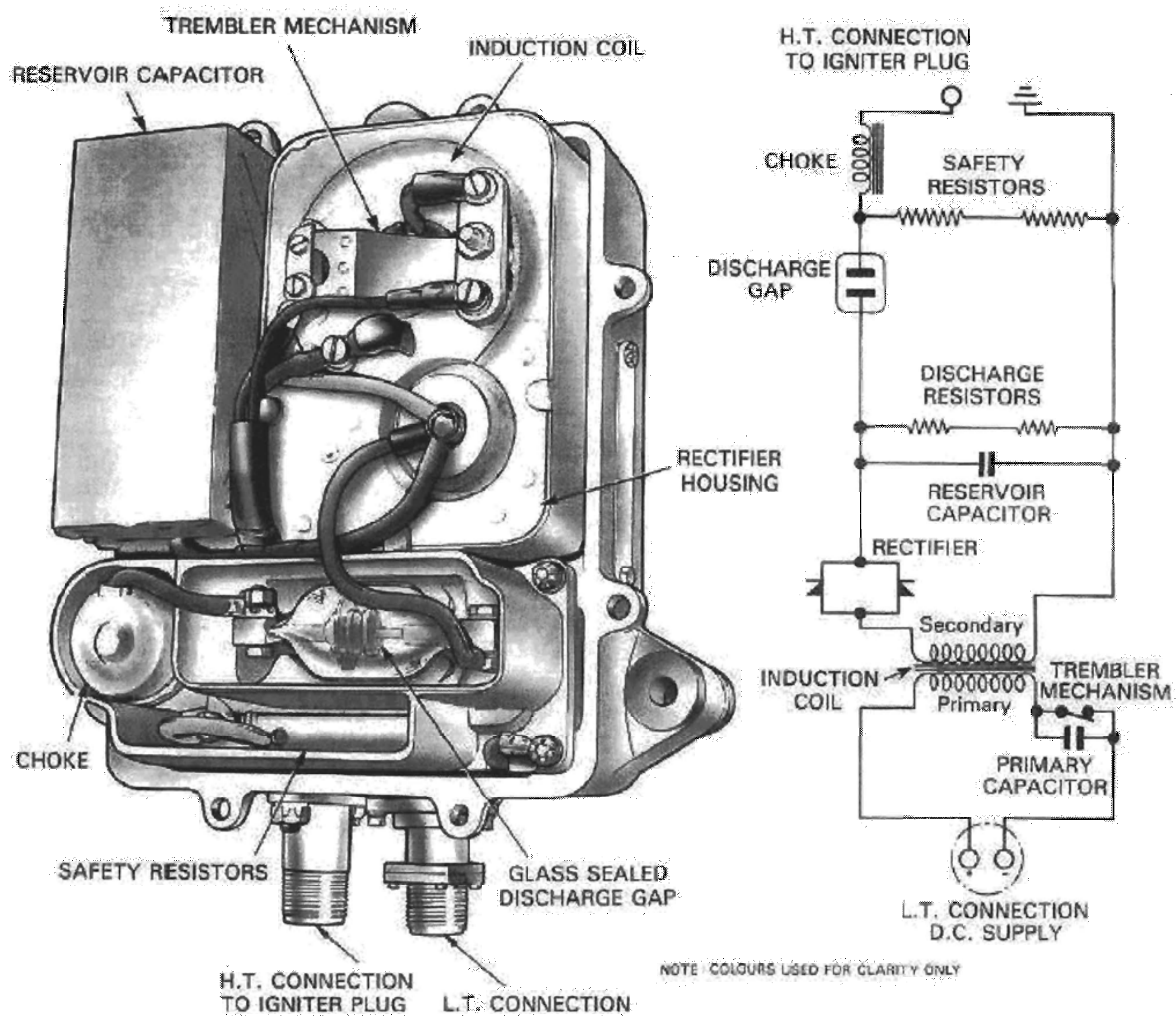


Figure 13.20: Trembler type DC Ignition Unit and Circuit

Above is a typical DC trembler switch operated unit. Its operation is as follows;

The **trembler mechanism** is simply a switch which vibrates and hence opens and closes about 200 times a second, thereby pulsating DC current flows through the primary coil. This trembler sometimes works off the natural vibrations of the aircraft, but usually is a mechanism containing a "normally closed switch, which is opened as soon as current flows through it, by a solenoid (similar to an electric bell).

As the contacts open and close rapidly, there would be a tendency for a spark to ark across the points. This is reduced by the **primary capacitor** which provides a path of least resistance for the current to flow.

The secondary coil of the **induction coil** contains many more windings than the primary coil, so a large current is induced in the coil. The electrons flowing from the secondary coil begin to build up on the left hand side of the **reservoir capacitor**. The **rectifier** stops these electrons flowing the opposite way round the circuit to the right hand side of the reservoir capacitor.

After about half a second of repeated cycles, there will be enough charge in the reservoir capacitor to jump the **discharge gap.** All the charge in the reservoir capacitor will jump the gap at once and so the igniter plug receives a large amount of current at once, which it conveys to the earth circuit. The **choke** is fitted to extend the duration of the discharge slightly, especially if there is more current than is required by the igniter plug at any one time. The cycle is repeated about twice a second.

The **discharge resistors** are fitted to ensure that any stored energy in the capacitor is dissipated within one minute of the system being switched off. The **safety resistor** provides an alternative path for the discharge current if the igniter plug is disconnected but the system is still switched on.

More modern circuits have the trembler mechanism replaced by a transistorised "chopper circuit" which simply generates a pulsating DC supply.

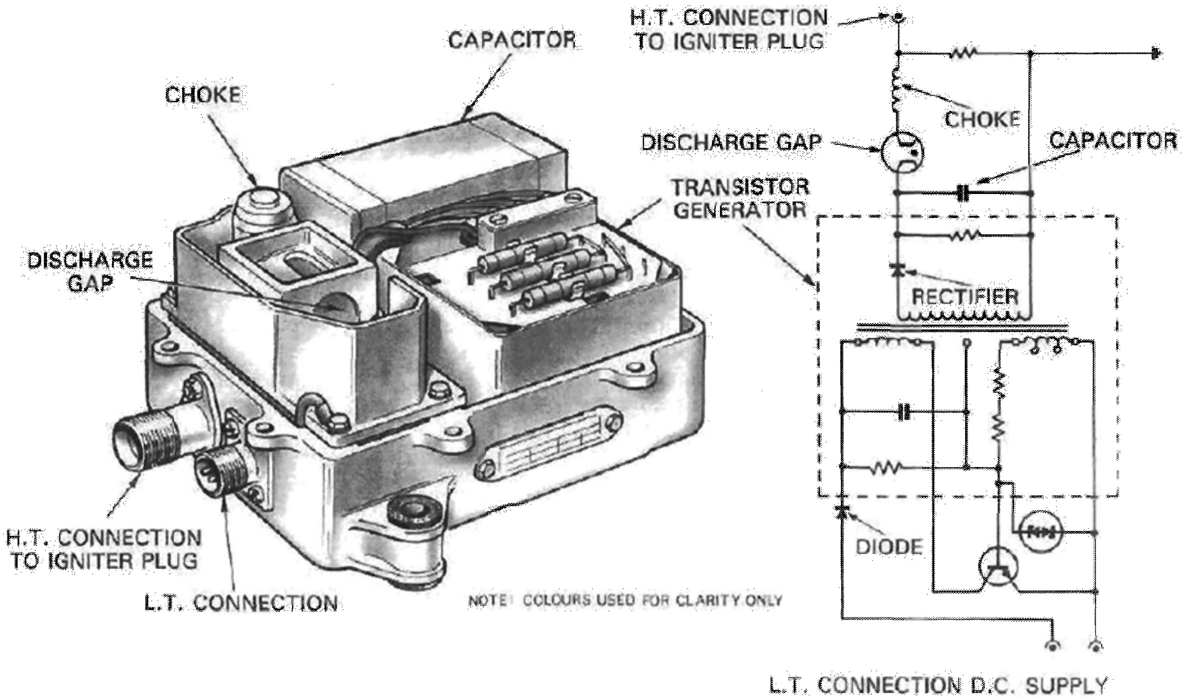


Figure 13.21: A Typical DC Transistorized Unit

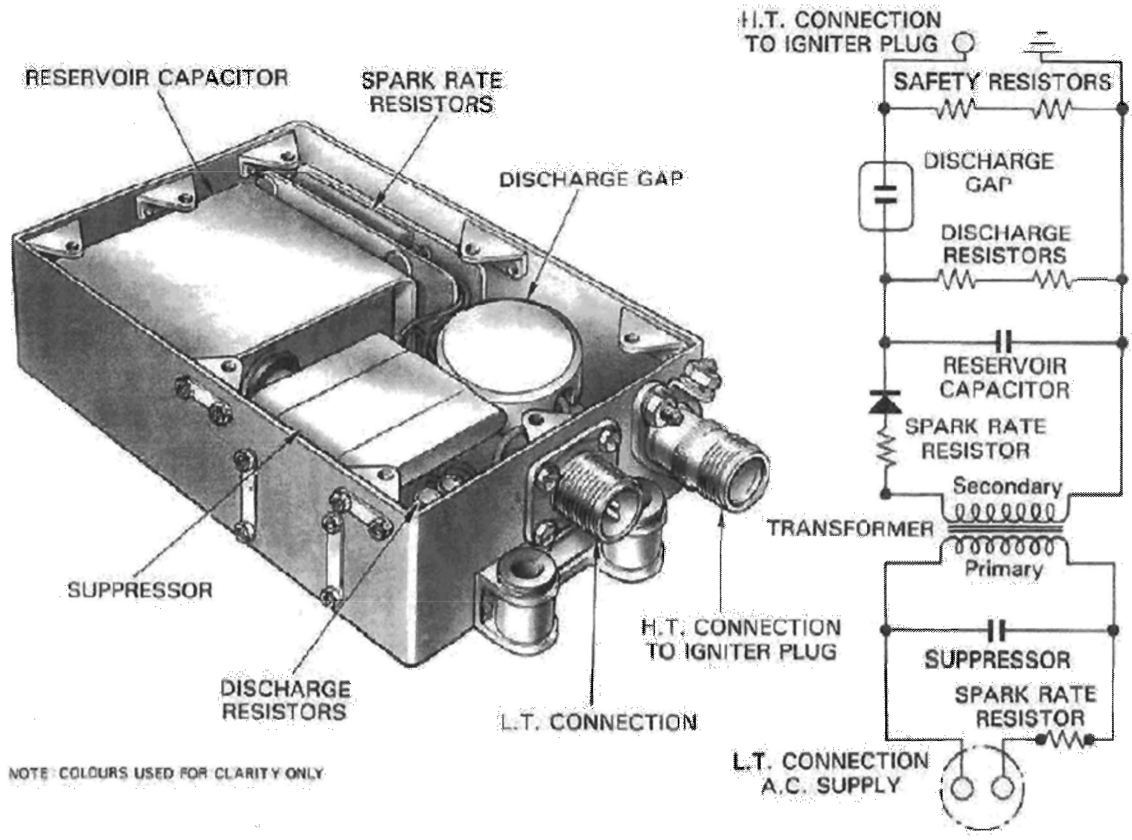


Figure 13.22: A Typical AC Ignition Unit

The operation of an AC circuit is identical to a DC circuit except that the trembler switch mechanism (or transistorised chopper circuit) is replaced with 115 V AC supply.

AC Versus DC Input Systems

The AC Input system has the following advantages over the DC systems:-

The DC input system relies upon the aircraft battery for operation, whereas the AC input system relies upon some auxiliary power such as the APU or a Ground Power Unit. Therefore, an aircraft fitted with a DC input system is self sufficient as far as starting is concerned.

The AC input system is said to have a better "extreme climate" reliability than the DC input system.

The operational cycle of a typical intermittent duty cycle, the AC system is 10 minutes on, 20 minutes off (for cooling). A DC system heats up more rapidly, and a typical operational cycle of a system with the same Joule rating as the AC system mentioned above might be 2 minutes on, 3 to 20 minutes off.

The DC system remains in popular use, especially when no auxiliary power unit is installed and a battery input voltage is all that is available for starting.

Igniter Plugs

Spark Igniters

Constrained or Constricted Air Gap Type

Constrained Air Gap Igniter Plugs for Gas Turbine Engines differ considerably from spark plugs for reciprocating engines. The gap at the igniter plug tip is much wider and the electrode is designed to withstand a much higher intensity spark. The igniter plug is also less susceptible to fouling because the **high energy** spark removes carbon and other deposits every time the plug fires. The construction material is also different because the igniter plug is made of very high quality, **nickel-chromium alloy** for its corrosion resistance and low coefficient of heat expansion. The threads in many cases are also silver plated to prevent seizing. For this reason, it is many times more expensive than an automobile spark plug.

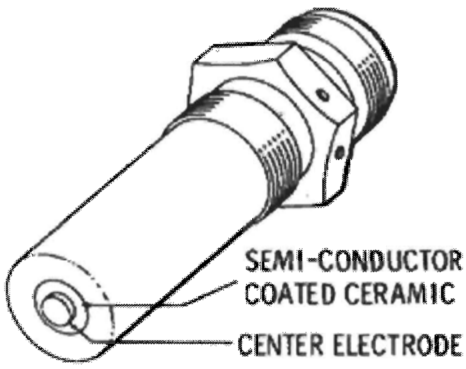


Figure 13.23: Air Gap Type igniter

Many varieties of igniter plugs are available, but usually only one will suit the needs of a particular engine. The igniter plug tip must protrude properly into the combustion chamber and on some fully ducted fan engines, the plug must be long enough to mount on the outer case, pass through the fan duct, and penetrate the combustion chamber.

Igniters for High and Low Energy systems are not interchangeable, and care should be taken to ensure that the manufacturers recommended plug is fitted.

Cooling - The shell at the hot end of the igniter is generally air cooled to keep it 500^0F to 600^0F cooler than the surrounding gas temperature.

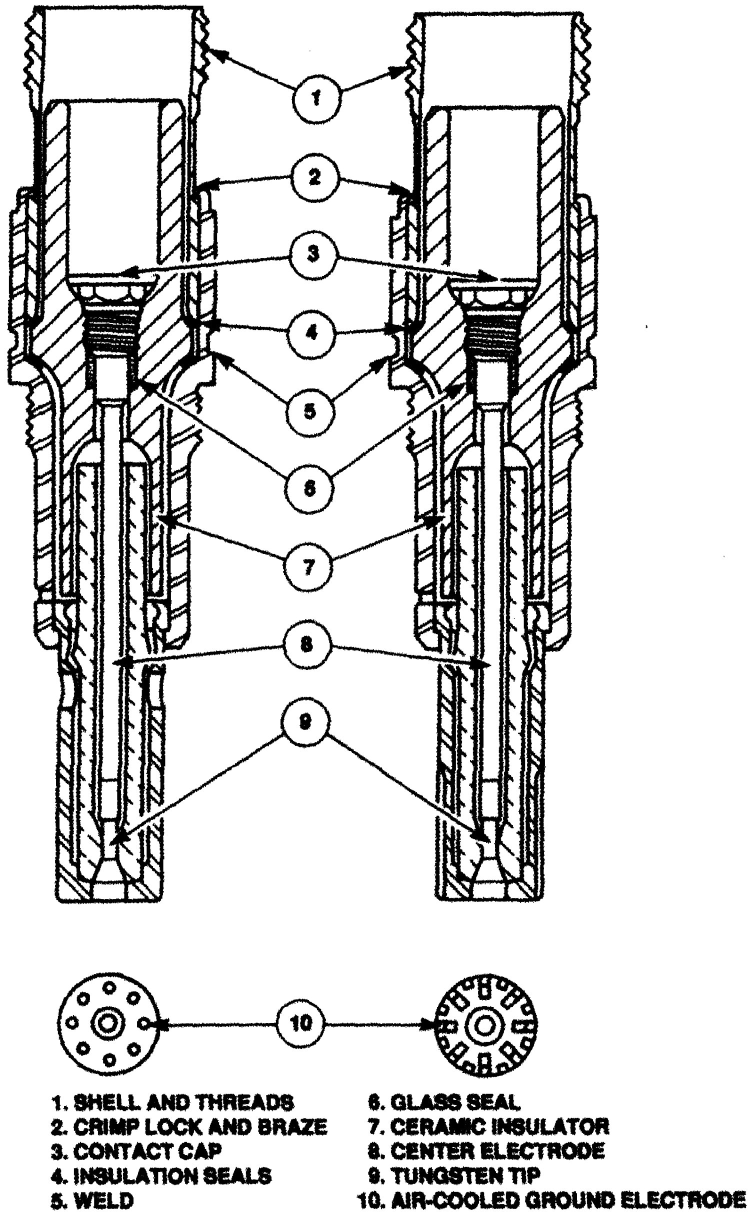


Figure 13.24: High Energy Constrained Gap Igniter

Surface Discharge Igniter Plug

The surface discharge igniter plug has the end of the insulator formed by the semi-conductor pellet which permits an electrical leakage from the central high tension electrode to the body. This ionises the surface of the pellet to provide a low resistance path for the energy stored in the capacitor. The discharge takes the form of a high energy flashover from the electrode to the body and only requires a potential difference of approximately 2000 volts for operation.

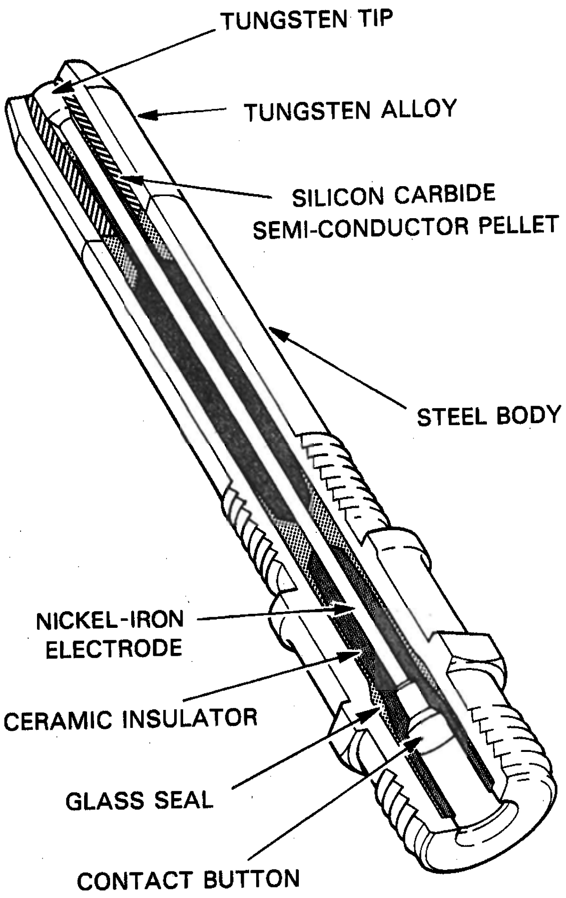
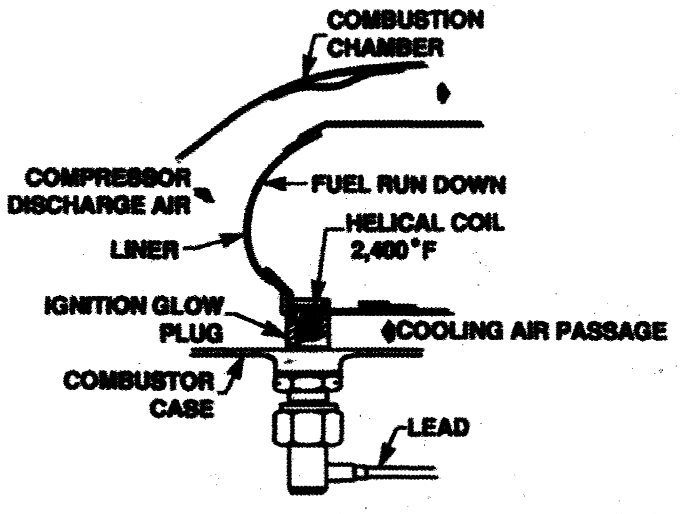


Figure 13.25: Surface Discharge Igniter Plug

Glow Plugs

Some smaller engines are fitted with a glow plug type igniter rather than a spark igniter. This glow plug is a resistance coil of a very high heat value and is particularly effective for extremely low temperature starting.

The glow plug is supplied with 28VDC at approximately 10 amps to heat the coil to a yellow hot condition. The coil is very similar in appearance to an automobile cigarette lighter. Air directed up through the coil mixes with fuel sprayed from the main fuel nozzle. This is designed to occur when the main nozzle is not completely atomizing its discharge at low flow conditions during start-up. The influence of the airflow on the fuel acts as to create a "hot streak" or blow torch type ignition.



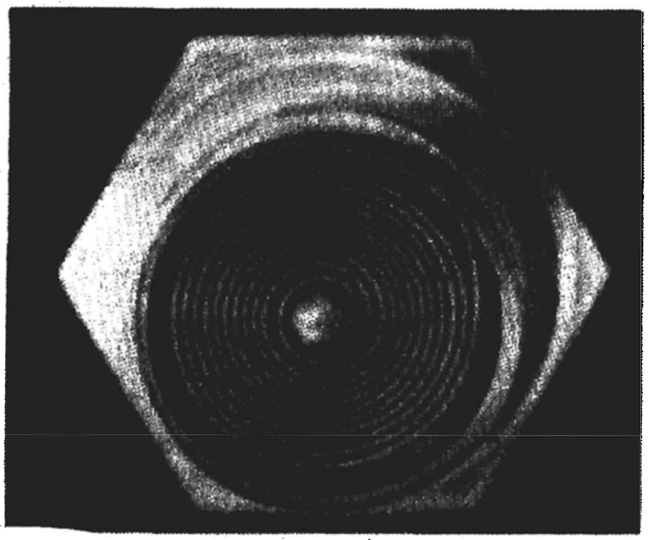


Figure 13.26: Glow Plug

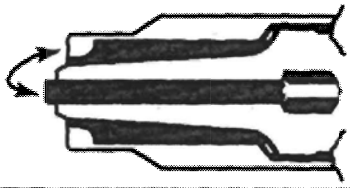
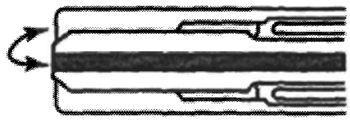
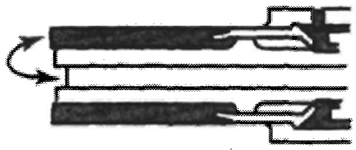
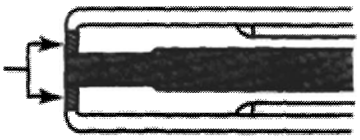
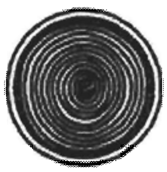
GAP DESCRIPTION	TYPICAL FIRING END CONFIGURATION	CLEAN FIRING END
HIGH VOLTAGE AIR SURFACE GAP		YES
HIGH VOLTAGE SURFACE GAP		YES
HIGH VOLTAGE RECESSED SURFACE GAP		YES
LOW VOLTAGE SHUNTED SURFACE GAP (SELF IONIZING)	SEMI-CONDUCTOR 	Only clean if manufacturer allows
LOW VOLTAGE GLOW COIL ELEMENT		YES

Figure 13.27: Ignition Plug Firing End Summary

Cleaning, Inspection and Testing

Cleaning

High energy constrained gap type plugs are usually cleaned using a solvent and soft non-metallic brush. Never use abrasive grit blasting, as this will damage the ceramic insulator. Low energy surface discharge plugs are usually only cleaned on their outer surface, as the semi-conductor material in the tip is easily damaged, this is regardless of carbon build up.
Glow plugs can be cleaned if carbon build up is seen across the coil with a solvent to loosen the carbon deposit then a soft non metallic brush can be used to remove particles

Inspection

Inspection of igniter plugs consists of visual inspection and, for the high voltage type, a gap check using a gap wear gauge. The AMM will define the amount of permissible wear and carbon build up.

Testing

A Functional check of igniters is carried out in situ by isolating the fuel and starter circuit and selecting the igniters on. Standing outside the jet pipe a distinct crack can be heard. The spark rate (normally 60- 100 sparks per minute) can also be checked. Glow plugs are tested by connecting the plug to the power lead and observing the plug end turn bright yellow within 15-20 seconds.

Fitment and Removal

The depth at which an igniter plug is fitted to a combustor is critical. Too deep and the plug will be burnt, not deep enough and the spark will not ignite the fuel. To ensure the correct depth the combustor is normally depth gauged from the boss on the engine outer casing into the combustor liner. Spacers or gaskets are then fitted to the igniter plug to reflect the depth gauge measurement. The depth gauge is a 'special to type' combustor tool. Refer to the applicable AMM for details.

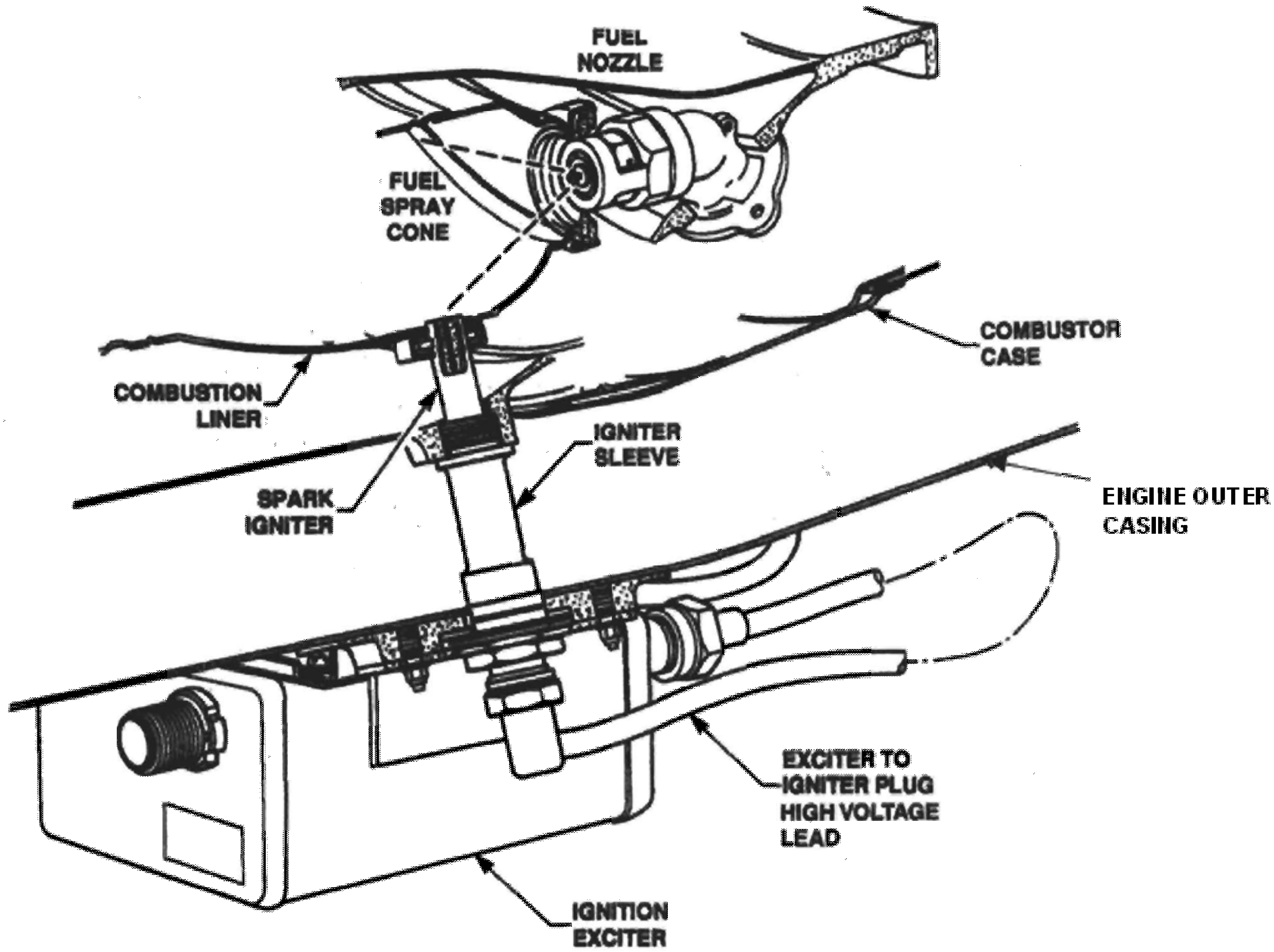


Figure 13.28: Igniter plug in situ

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Handling of Ignition Units and Igniter Plugs

- Ensure that the ignition switch is turned off before performing any maintenance on the system.
- To remove an igniter plug, disconnect the HE ignition unit input lead and **wait for the prescribed amount of time** (usually 1 minute) to allow any residual charge to dissipate through the safety resistors. Then disconnect the igniter lead and ground the centre electrode to the engine to discharge any current stored in the plug, the igniter plug is now safe to remove.
- Ensure proper disposal of unserviceable igniter plugs. If they are the type that contain aluminium oxide and beryllium oxide, a toxic insulating material, the usual method is to place plugs in a sealed container and bury them at a designated disposal sight.
- Exercise great caution in handling sealed ignition units. Some contain radioactive material (caesium-barium 137) on the air gap points. This material is used to calibrate the discharge point to a pre-set voltage.
- If an igniter plug is dropped it should be discarded since internal damage can occur that may not be detectable by testing or examination.
- Always use a new gasket where the plug is reinstalled. The gasket is essential in providing a good conductive current path to ground.

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An Ignition System Example

Boeing 757 Starter System

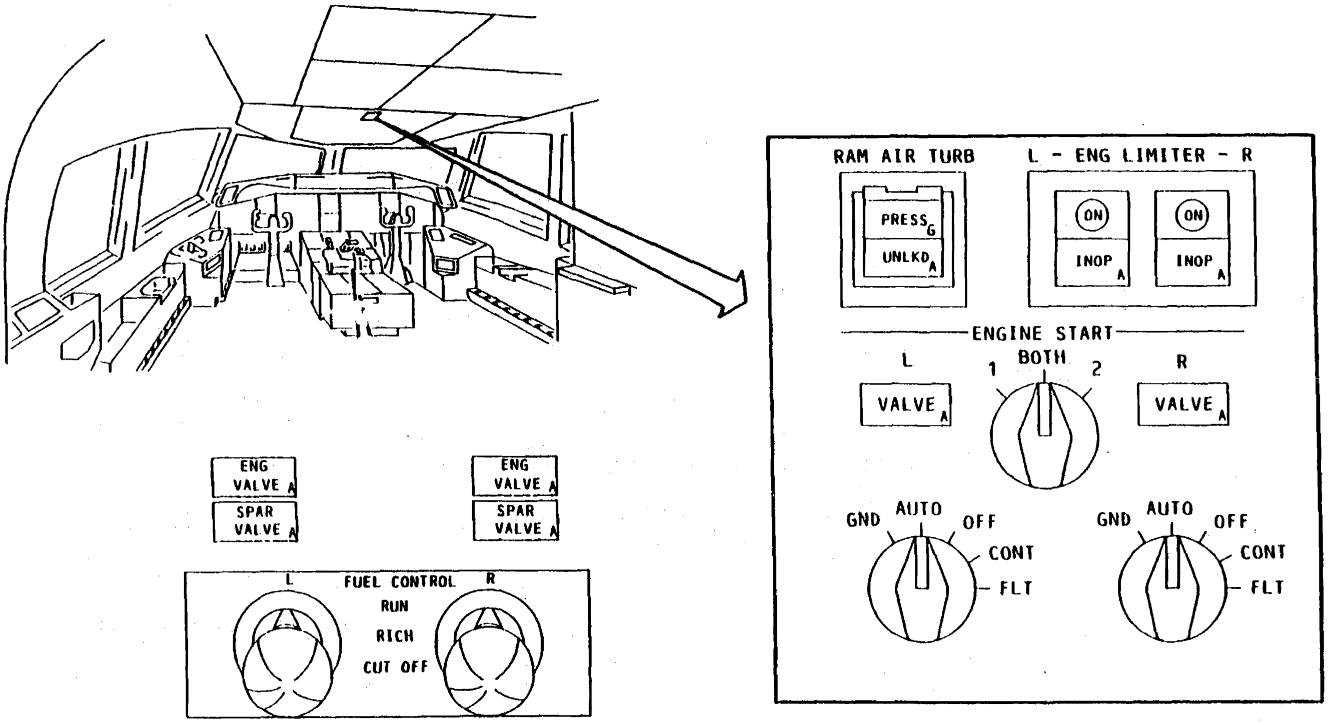

Figure 13.29: Boeing 757 Start Panel

The ignition system initiates or sustains combustion of the fuel air mixture in the annular combustion chamber.

Ignition is available when the engine start switch in the overhead panel (P5) is placed in GND, AUTO, CONT, or FLT position and the fuel control switch in the centre console (P10) is placed in RUN or RICH

Each engine has two independent high ((10-joule) and low (4 joule) energy ignition units, each feeding one igniter plug. High energy output is used for starting and relighting and low energy for continuous ignition.

A single rotary ignition select switch, with three positions 1-BOTH-2 enables either or both ignition UNITS to be selected.

Control Sequence
115 volts AC is provided by the respective Left or Right AC buses to power igniters No. 1 on the left and right engines white the standby bus normally powers igniters No. 2. The power sense relay automatically selects standby power for igniter No. 1 in case main bus power is not available.

The fire switch must be in normal and the fuel control switch (P10) must be in the RUN or RICH position.

Normal Sequence
The ignition select switch selects the ignition system to be used.

When the engine start switch is selected to the GND position it energizes the starter solenoid and a holding coil which maintains the GND position until N3 reaches 47%. Above 47%, N3 the engine start switch springs to AUTO.

With the switch in the AUTO position ignition is provided when the Flaps are not up, when the engine anti-ice is on or when a signal is received from the Transient Pressure Unit (TPU)

FLT provides ignition for in-flight starts and CONT ignition is used during turbulent conditions or takeoffs and landings, if AUTO is not selected.

High Energy Ignition Units Control
Whether the output of either 10- or 4-joules is applied, is determined by the position of the engine start switch or whether or not a signal is received the transient pressure unit.

Normal power sources for the ignition units are the 115 volt ac buses. Interruption of power from the normal bus sources causes automatic switching to the standby bus.

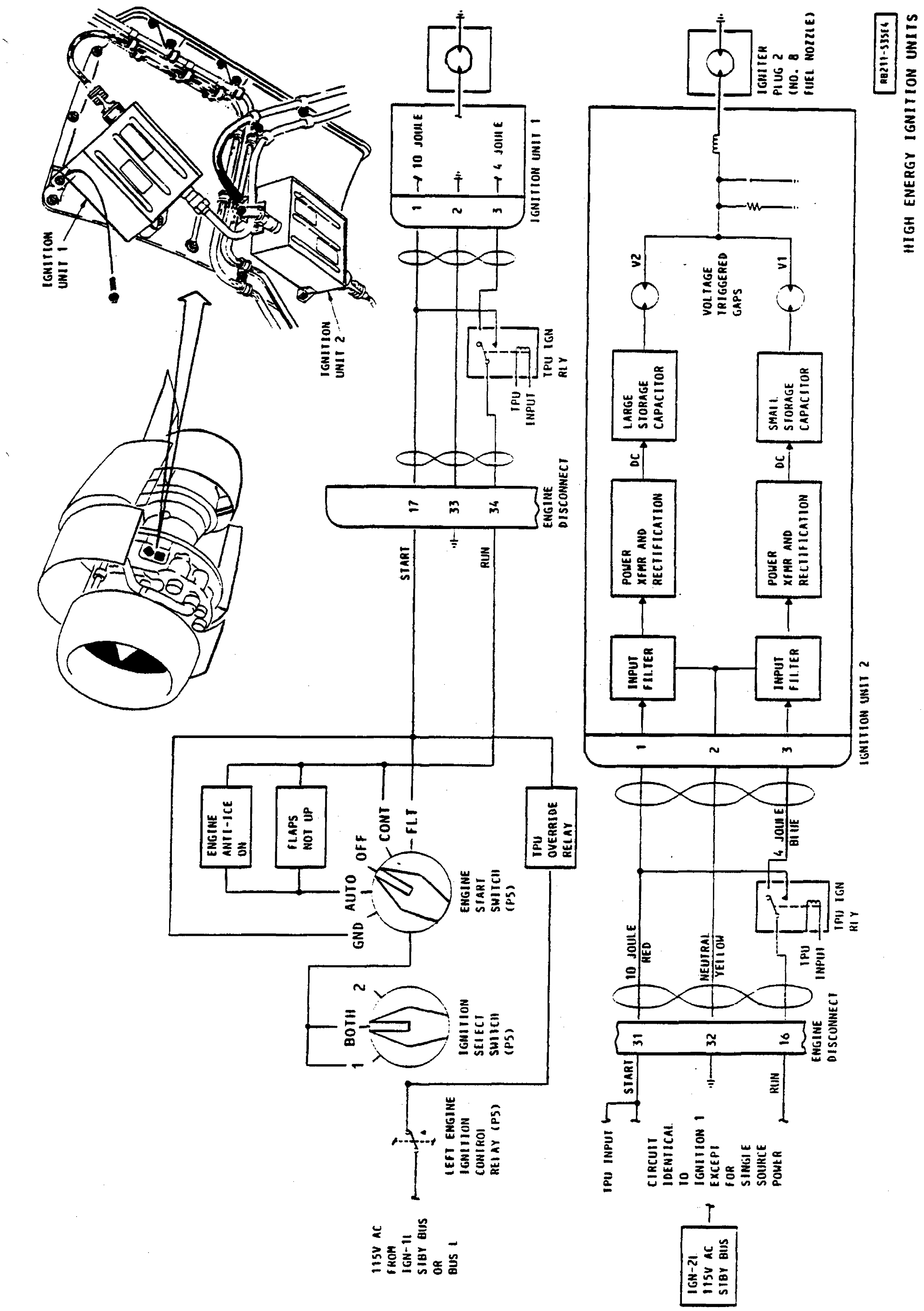

Figure 13.30: HEIU Electrical Circuit

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