Coventry University

203AAE - Aircraft System

Engine Task: Aide Memoire

Introduction

A propulsion unit provides a means of propelling an aircraft forward enabling the wings to produce lift.

Gas turbine propulsion

A gas turbine engine is capable of producing more power than a piston engine of similar mass, and without the restrictions imposed by a propeller is able to propel an aircraft higher and faster.

Newton's laws of motion

To enable an understanding of how a gas turbine engine produces thrust it is necessary to understand Newton's Laws of Motion.

Newton's first law states: "A body will remain at rest or will continue in uniform motion in a straight line unless acted upon by a force".

Application – A propulsion unit can provide the force necessary to move an aircraft from rest. Once moving, drag becomes a force preventing the uniform motion of the aircraft. The propulsion unit can overcome this force.

Newton's second law states: "When a body is acted upon by an external force, the rate of change of momentum is proportional to the force and takes place in the direction of the force".

Application -The engine will take a MASS of air and ACCELERATE it.

Newton's third law states: "For every action there is an opposite and equal reaction".

Application -The action of accelerating a mass of air and discharging it rearwards will produce a reaction within the propulsion unit and propel the aircraft forward. This internal force is known as **thrust**.

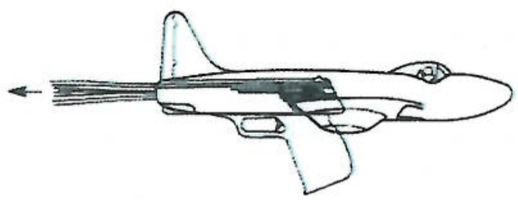

Fig 1 - Thrust

Engine thrust

The thrust obtained is proportional to the MASS OF AIR passing through the engine and to the VELOCITY INCREASE of the mass airflow. Thus the same amount of thrust can be obtained by:

Subjecting a large mass of air to a small acceleration.

Subjecting a small mass of air to a large acceleration.

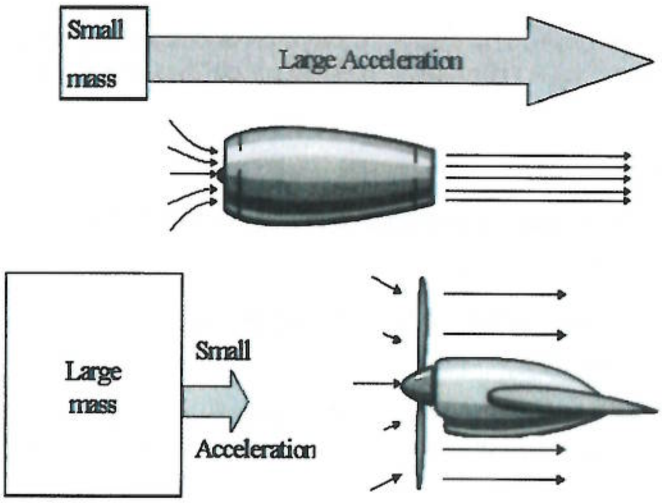

Figure 2 – Mass / Acceleration

Types of gas turbine engine

Gas turbine engines are considered to be of two types:

Torque producing

These engines provide the turning force or 'TORQUE' necessary to turn a propeller or rotor.

Thrust producing

Thrust forces are produced within the engine as a reaction to the acceleration of the air from its velocity at the engine inlet to the final velocity achieved at the engine outlet.

NB: Thrust (or jet reaction) is an internal phenomenon and is ***not*** *as sometimes assumed the result of the jet efflux impinging on the atmosphere.*

Selection of a particular type of gas turbine engine will depend on two main factors – (1) the specialised use and (2) the cruising speed of the aircraft.

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For aircraft designed to operate at sea level speeds below 600kph it is more effective to absorb the power developed in the gas turbine engine by gearing it to a propeller instead of using pure thrust. At higher speeds propeller efficiency decreases. Turbojets are most efficient at speeds of 1200kph and above. To fill the gap between turboprop and pure turbojet systems the bypass (turbofan) engine was developed.

There are four main types of engine used in aircraft today:

- **Turboprop engines** (torque producing)
- **Turboshaft engines** (torque producing)
- **Turbojet engines** (thrust producing)
- **Turbofan engines** (thrust producing)

Turboprop engines

The turboprop will have a gas generator section similar to the turbojet except the turbine section is designed to absorb more energy from the gas stream than the turbojet. This excess energy is designed to drive a propeller, which is mounted, on the inlet section driven via a reduction gearbox.

The propeller can be directly driven by the turbine which also drives the compressor and is termed a *directly coupled* turbo-prop engine, or, the propeller can be driven by a separate turbine, that does not drive the compressor and is then termed a *free turbine* turbo-prop engine (figure 3).

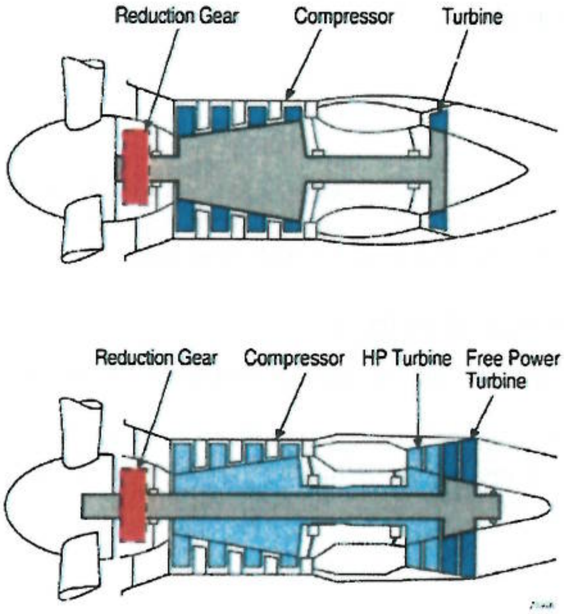


Figure 3 - Turboprop

Turboshaft engines

A gas turbine engine that delivers power through a shaft to operate something other than a propeller is referred to as a turboshaft. The turboshaft has many applications, one of which is to power rotary-wing aircraft.

The turbo shaft has a gas generator section that extracts approx. two thirds of the gas energy to drive the compressor and ancillaries, leaving approx. one-third to drive a power turbine.

The power turbine drives the helicopter rotor via an aircraft transmission (reduction gearbox). The power output shaft or drive can be of the forward drive or the rearward drive configuration.

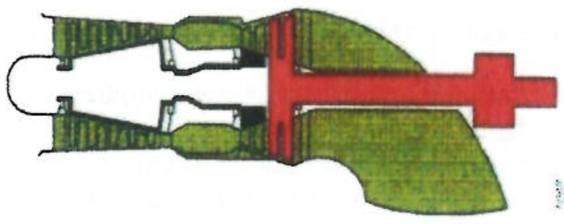


Figure 4 - Turboshaft

Smaller turbo-shafts can be used as engine starters, auxiliary power units (APUs), electrical power sources etc for aircraft services. Other non-aviation applications include power generators, ship engines and tank engines.

Turbojet engines

The turbo jet engine gets its propulsive power from reaction to the flow of hot gases.

The turbojet (figure 5) consists of a compressor, combustion section and a turbine. (together termed the gas generator). In order to function correctly the gas turbine engine requires two further sections.

The air is presented to the gas generator smoothly and uniformly by an air intake. The air exiting the gas generator is discharged into the exhaust system, which accelerates the air at high velocity to atmosphere.

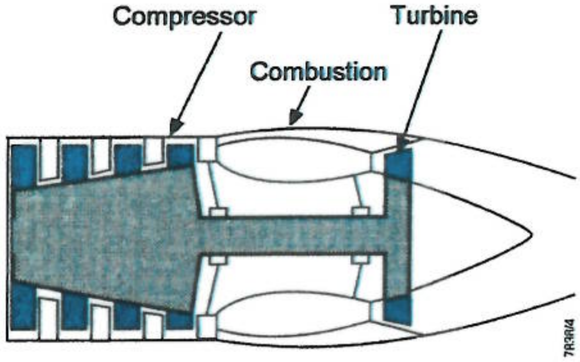


Figure 5 - Turbojet

Turbofan engines

The turbofan powers the majority of modern aircraft. It can offer the power of a turbojet but can generate this power more efficiently over a larger aircraft speed range depending on the design.

The turbofan (figure 6) will pass all the air through a first compressor where a selected percentage of the air is ducted through a second compressor, the combustion chamber and the turbine (termed the core engine).

The remaining air is diverted around the core engine where it is ducted direct to atmosphere or rejoins the mainstream rearwards of the turbine and mixed before accelerating through the exhaust nozzle.

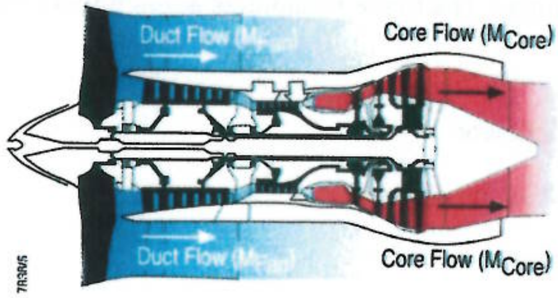


Figure 6 - Turbofan

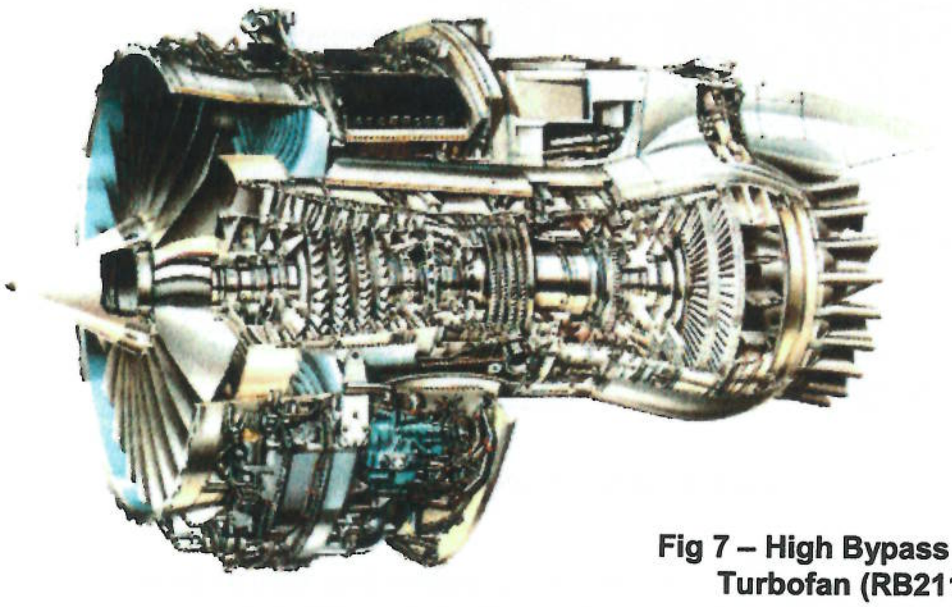


Fig 7 – High Bypass Ratio Turbofan (RB211)

Engine construction

To ensure the engine cycle works to its full potential each section has been designed to ensure the air possesses the correct energy content before passing to the next section. Thus each section has a definite role to play to ensure every other section and the engine as a whole works efficiently. The major sections of a gas turbine engine are:

Inlet

Compressor

Combustion chamber

Turbine

Exhaust

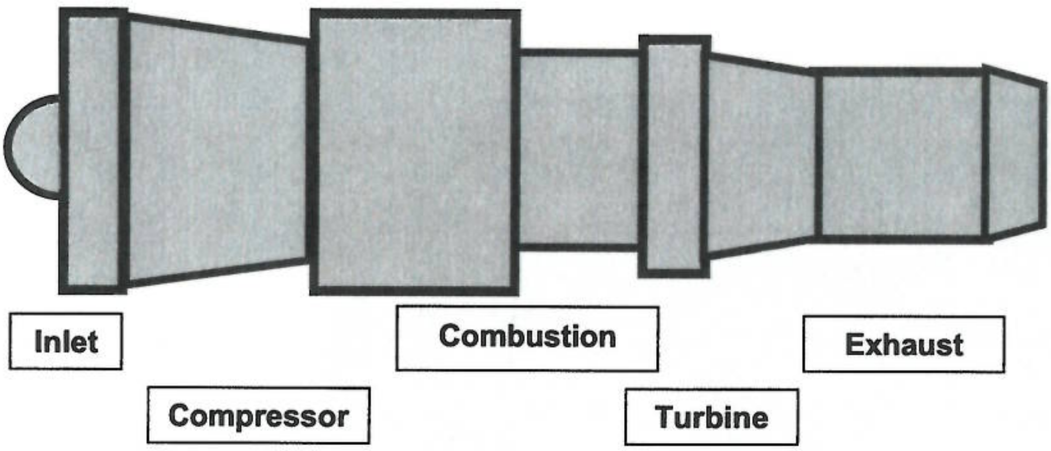


Figure 8 – Engine sections

Each engine section will convert energy from one form to another depending on the energy content required for that particular section. Although changing the energy content is quite simple in principle, it involves complex processes outside the scope of this course. It is however, worthwhile to have a basic understanding of the processes for each energy conversion and how this is achieved.

Air will act in a predictable manner when flowing through a duct and the physical properties of the air will change. Each engine section will convert energy from one form to another by altering the shape of the duct the air is flowing through, changing the properties of the air accordingly.

Intake casing/inlet fairing

The compressor intake casing is a ring shaped single piece lightweight structure made of aluminium alloy or steel, usually cast and then machined.

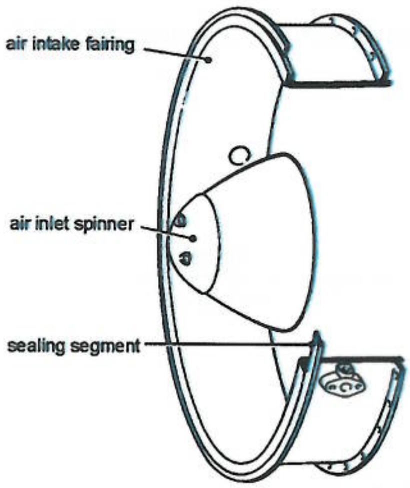


Figure 9 - Air inlet fairing

On some engines the compressor casing directly abuts the airframe air intake, however, on other engines there is a separate engine intake casing. The intake casing makes an airtight joint between the aircraft intake and the compressor and is normally flange bolted to the front face of the compressor casing. The casing can house inspection ports and temperature and pressure probes for systems control and may also provide mountings for system components.

If an engine incorporates Inlet Guide Vanes, or has a compressor front bearing, the intake casing will form a central housing supported by either the vanes themselves or aerodynamic struts. The struts or vanes may be of hollow cross section to accommodate oil or air passages to transfer system fluids for lubrication, cooling, anti icing etc. In this case the spinner will be fixed, and mounted on the bearing front support.

Some engines, especially high by-pass engines require some form of noise suppression due to the LP fan blades producing low intensity tones as the airflow from the fan passes over downstream vanes. This suppression is in the form of stainless steel /aluminium honeycomb acoustic linings.

Compressor

The purpose of the compressor section of the engine is to compress the ingested air, prior to it being fed into the combustion system. The secondary purpose of the compressor section is to supply engine bleed air to cool the hot internal sections of the engine. The bleed air is also used for such things as:

Cabin pressurisation

Air conditioning

Anti icing

Gun heating

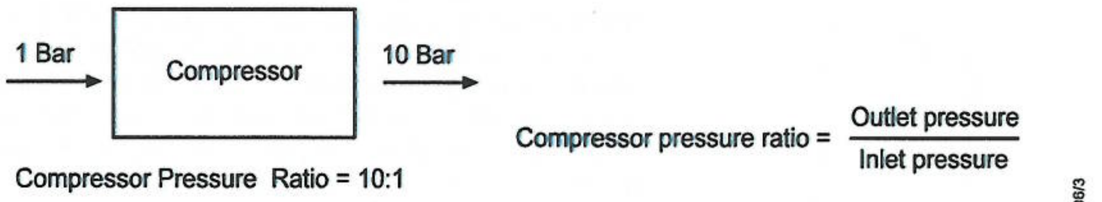
Fuel tank pressurisation

For maximum efficiency to be realized, a compressor must satisfy a number of requirements:

- High Pressure Ratio
- High Mass Flow.
- Stable Operation under all Conditions.

Compressor pressure ratio

This is defined as the ratio of the total pressure at compressor outlet to that at the compressor inlet.



Pressure ratio

High mass flow

The air mass flow through the compressor is dependent on the following:

The revolutions per minute (rpm) of the compressor

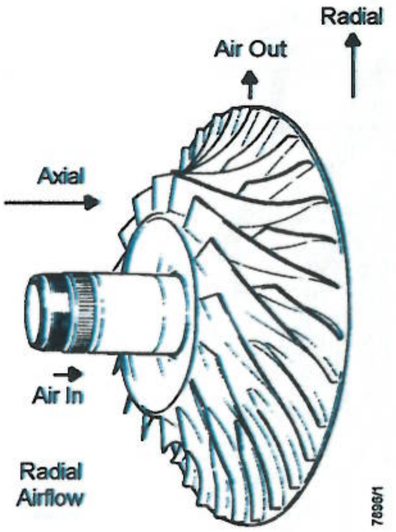
The diameter of the compressor

The air density at the compressor inlet

The pressure ratio across the compressor

Compressor types

The compressor section compresses the ingested air prior to its delivery into the combustion system. There are two configurations of compressor – centrifugal and axial flow.



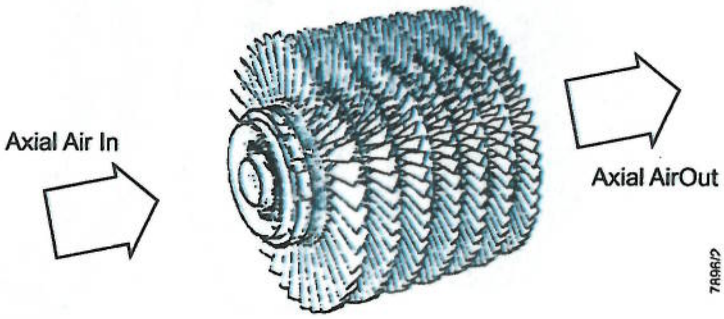


Figure 10 - Centrifugal **Figure 11 - Axial flow**

In the centrifugal compressor the airflow is radial, with the flow of air from the centre of the compressor outwards. This type of compressor was used extensively in the early days of gas turbines, the technology being based upon piston engine superchargers. In the axial compressor the flow of air is maintained parallel to the compressor shaft.

Although superseded by the axial flow compressor for mainstream military and commercial engines the centrifugal compressor remains in widespread use for installations where a compact and robust engine is required. Typical applications are as power plants for small executive jet aircraft and missiles and as 'gas generators' for engine air starter systems. Centrifugal compressors generally need to operate at much higher rpm than axial compressors.

Either type, or a combination of both, may be used in gas turbines and each has its advantages and disadvantages. Axial / centrifugal compressor combinations are used extensively in turbo-shaft and turboprop engines, while axial flow compressors are used in turbofan and turbojet engines.

Centrifugal compressor

Introduction

In its simplest form the centrifugal compressor consists of three main elements - the impeller, diffuser and the compressor manifold.

Impeller. The impeller consists of a forged disc with radially disposed vanes forming divergent passages. To ease the air from axial flow in the intake duct on to the rotating impeller, the guide vanes in the centre (eye) of the impeller are curved in the direction of rotation.

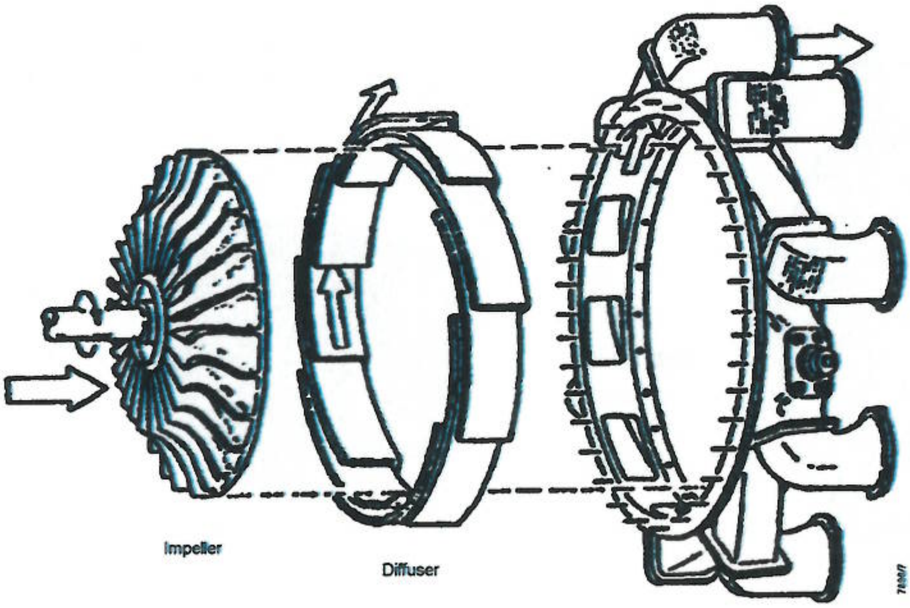


Figure 12 - Centrifugal construction

The impeller rotates at high rpm therefore the material chosen must be capable of withstanding considerable stresses. Modern materials, used in impeller construction, have enabled significant improvements to the pressure ratios that can be achieved with centrifugal compressors.

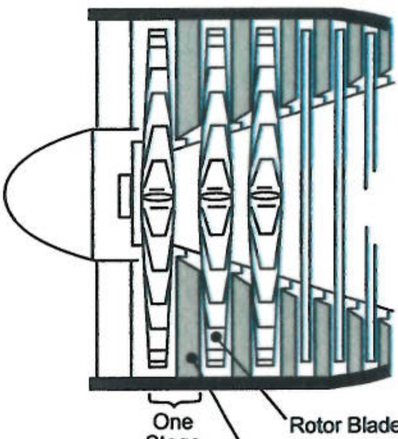
Diffuser. The diffuser (static) may be formed integral with the compressor casing or be bolted to it. In each instance, it consists of a number of vanes formed tangentially to the impeller.

Compressor Manifold. As well as providing a close fitting housing containing the impeller, and support for the diffuser, the compressor casing also forms the compressor intake and the delivery manifold to the combustion chambers.

Axial flw compressor

Introduction

The axial flow compressor converts kinetic energy into static pressure energy using rows of rotating blades (rotors), which impart kinetic energy to the air and alternate rows of stationary vanes (stators), which convert the kinetic energy to pressure energy.



In the axial flow compressor many stages of moving and stationary aerofoil shaped blades and vanes are needed. These are positioned alternately so that each row of rotor blades is followed by a row of stator vanes. A row of rotor blades and a row of stator vanes form a compressor stage. The axial flow compressor consists of an outer compressor casing that provides location for the stator vanes, and a rotor shaft assembly that provides location for the rotor blades.

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Figure 13 - Axial construction

The rotor shaft and the compressor casing form an annular air passage, that gradually reduces in cross sectional area from the low pressure air inlet to the high pressure air outlet. Consequently the size of rotors and stators also reduces from inlet to outlet. The rotor shaft is connected to and driven by the turbine. The rotating assembly comprising the compressor and turbine is referred to as a spool.

Combination compressor

To take advantage of the beneficial properties of both the centrifugal and the axial flow compressor, and to eliminate some of their disadvantages, both axial flow and centrifugal compressors may be combined into one unit.

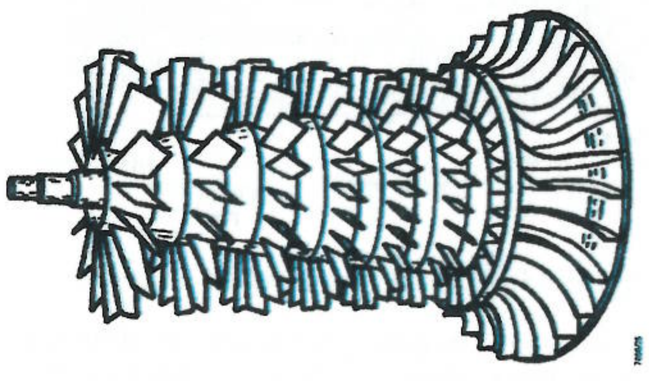

Figure 14 - Combination compressor

This application is currently used in many small gas turbine engines. This type of compressor produces high mass airflow for a small frontal area in the axial stages. The centrifugal stage gives a high final pressure rise. This gives better overall compression ratios over a wider range of rpm and operating conditions.

Combustion system

Introduction

The purpose of the combustion system is to effect the mixing and burning of air and fuel in order to heat and accelerate the gas flow rearwards in a steady stream at uniform temperature without raising the pressure.

The combustion system must be constructed such that it is capable of maintaining stable and efficient combustion over a wide range of operating conditions. The combustion system is required to release the chemical energy of the fuel in the smallest possible space, and with the minimum of pressure loss.

Principles of operation

The airflow from the compressor enters the combustion chamber at a velocity that is too high for combustion. Additionally, the total air delivered by the compressor results in air/fuel ratios far in excess of the 15:1 ratio actually needed for complete combustion. Therefore, for stable and complete combustion, the air from the compressor must be reduced in velocity and metered, progressively, through the combustion chamber.

The Figure below shows a typical basic combustion chamber comprising an outer casing and an inner combustion liner or flame tube.

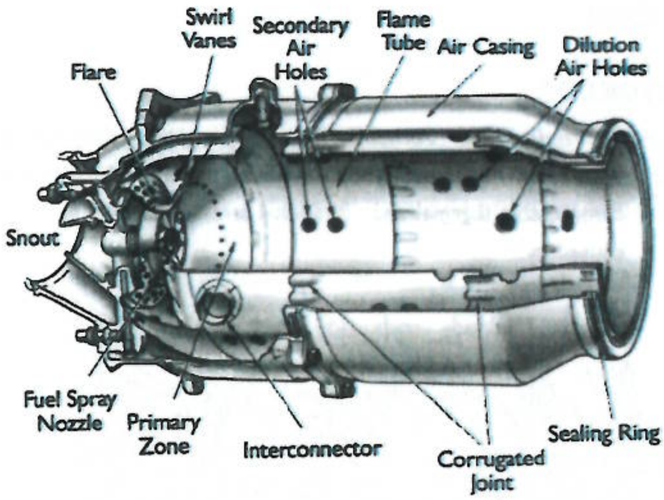

Figure 15 - Typical combustion chamber

The inlet to the combustion chamber is shaped so that it acts as a diffuser to slow the airflow and increase its pressure. Even so, it is necessary to reduce the axial velocity of the air further to prevent the flame from being blown out.

Types of combustion systems

There are four types of layout used for combustion systems:

Multiple chamber
Turbo-annular or cannular chamber
Annular chamber
Reverse flow annular chamber

Each system, although differing in construction, is designed to meet the same fundamental combustion system requirements. In each case similar methods are utilized for controlling the airflow.

Multiple combustion chamber system

In this design a number of inter-connected combustion chambers are arranged in a circle around the engine. Except for fuel drains and fuel igniters, each of these combustion chambers is identical on any particular mark of engine.

Each chamber is provided with a fuel burner, but normally only two chambers are fitted with igniter plugs to light the flame. Because of this, each chamber is connected to the next by a small tube called an 'interconnector' that allows the flame to pass from chamber to chamber until all the fuel burners are alight. Interconnectors also balance the combustion chamber pressures.

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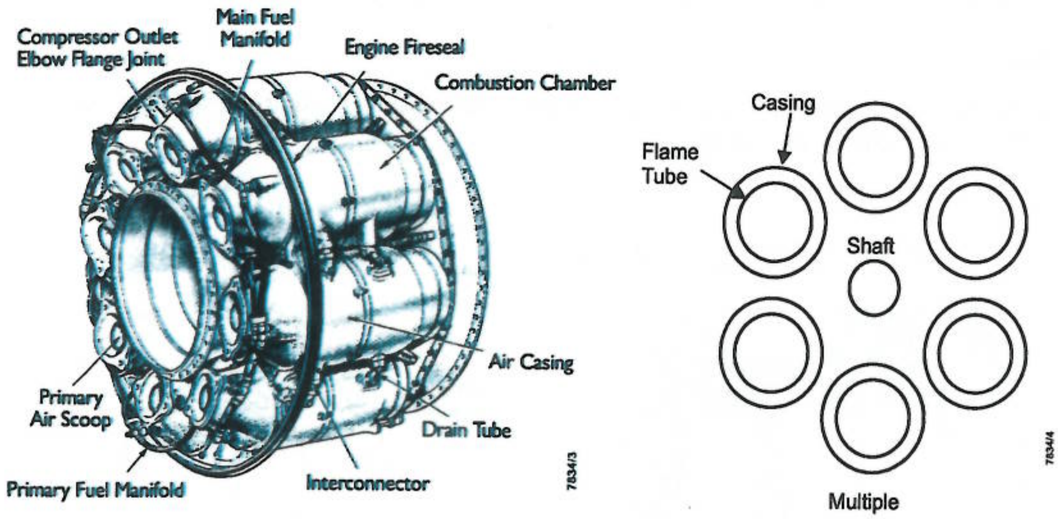

Figure 16 - Multiple chamber combustion system

Tubo-annular (cannular) system

The natural development from the individual can layout of the multiple chamber. A number of flame tubes are fitted inside an annular air casing.

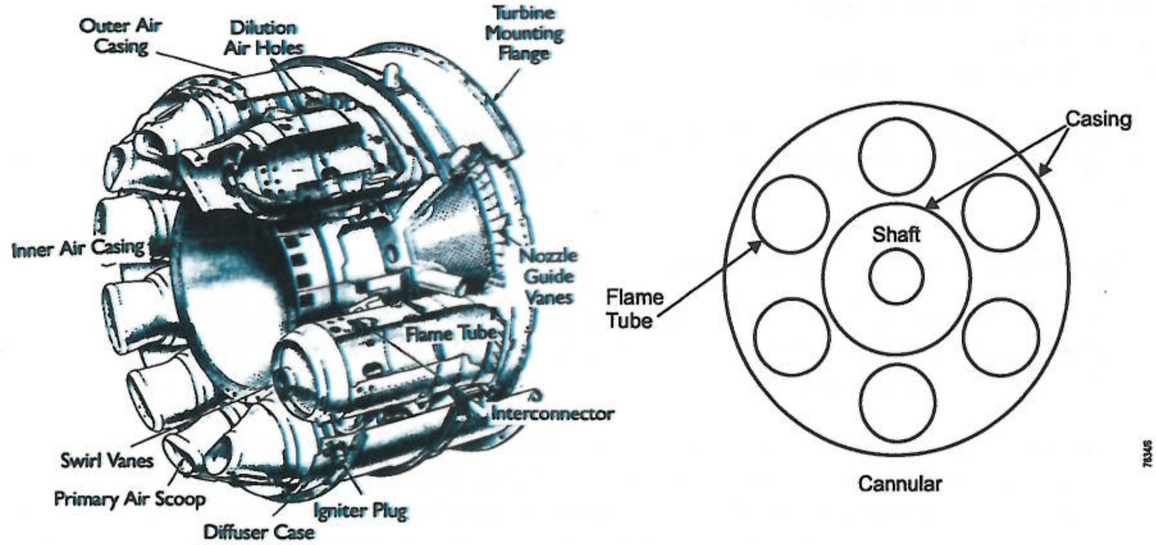

Figure 17 – Cannular combustion system

The airflow is similar to that described for the multiple combustion chamber system. Interconnector tubes are used to connect the flame tubes for flame propagation and pressure balance, provision is made in 2 of the flame tubes for igniter plugs.

Annular system

This type of combustion chamber consists of a single, completely annular, flame tube, which is contained within inner and outer casings.

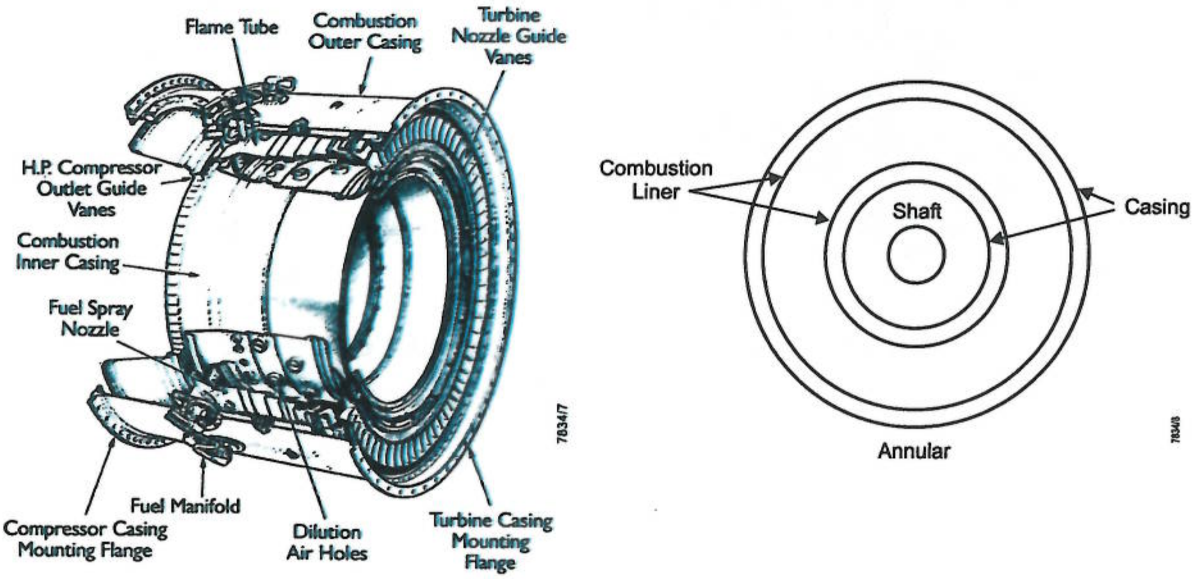

Figure 18 - Annular combustion chamber

Annular inner and outer air casings form a tunnel around the core of the engine, the outer casing becomes part of the engine exterior. Into the space between inner and outer air casings is fitted a completely annular flame tube with suitable fittings and drillings for fuel burners, fuel igniters and airflow distribution to provide conditions suitable for combustion and cooling. The annular chamber has the advantage of using the limited space available for combustion between the compressor and the turbine without increasing the engine diameter.

Reverse flow annular system

The reverse flow annular combustion system is normally used in smaller, low mass flow gas turbine engines. The reverse flow combustor operates in exactly the same way as the through flow types mentioned earlier.

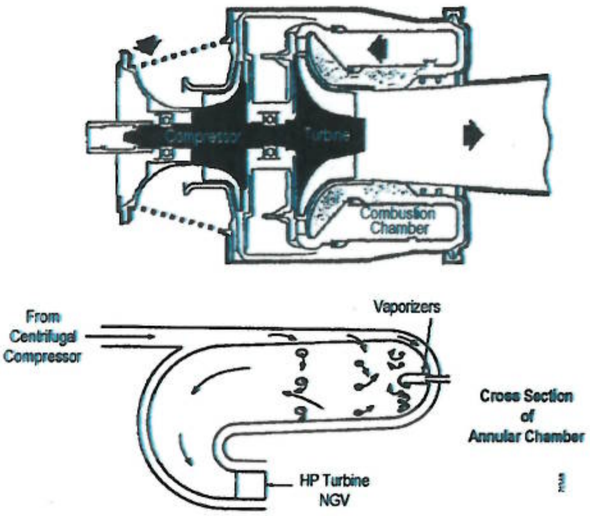

Figure 19 – Reverse flow combustion system

It only differs in the flow of air through the combustor. Instead of air entering the combustor from the front, it flows over the flame tube and enters from the rear, with the combustion gas flow being opposite in direction to the normal airflow through the engine. After combustion takes place, the gases flow into a deflector, which turns them 180°, to exit the engine in the normal direction.

This reverse flow arrangement provides for shorter engine length and weight reduction and also allows for preheating of the compressor discharge air. These two factors make up for the loss of efficiency, which occurs when the gases make the turns during combustion.

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Turbine

Introduction

The high temperature, high pressure gases leaving the combustion system contain a large amount of energy, some of which needs to be extracted as efficiently as possible to drive the compressor and engine driven accessories. This task is carried out by the blades of the turbine. The remaining energy in the gas stream is then available for expansion through a propelling nozzle (turbo-jet or turbo fan), or to drive an additional turbine and output shaft (turbo-prop or turbo-shaft).

The turbine, like the axial flow compressor, consists fixed blades known as nozzle guide vanes (NGV), and rotor blades. A turbine stage comprises one set of NGV's followed by one set of rotor blades.

In a turbo propeller or turbo shaft engine, the turbine also provides shaft power for the propeller or rotor. As these engine types need to extract nearly all of the gas stream energy to produce the necessary driving torque, there may be several turbine stages, with each stage consisting of a ring of nozzle guide vanes (turbine stators) and a row of blades fixed to a turbine wheel.

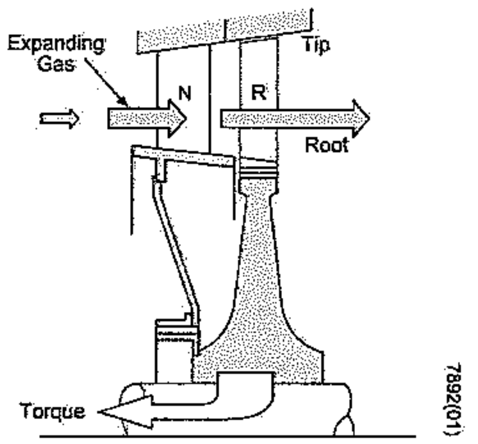

Figure 20 – Turbine stage

Exhaust system

Introduction

Aero gas turbine engines have an exhaust system, which passes the turbine discharge gases to atmosphere at a velocity and in the required direction, to provide the resultant thrust.

The velocity and pressure of the exhaust gases create the thrust in the turbojet engine.

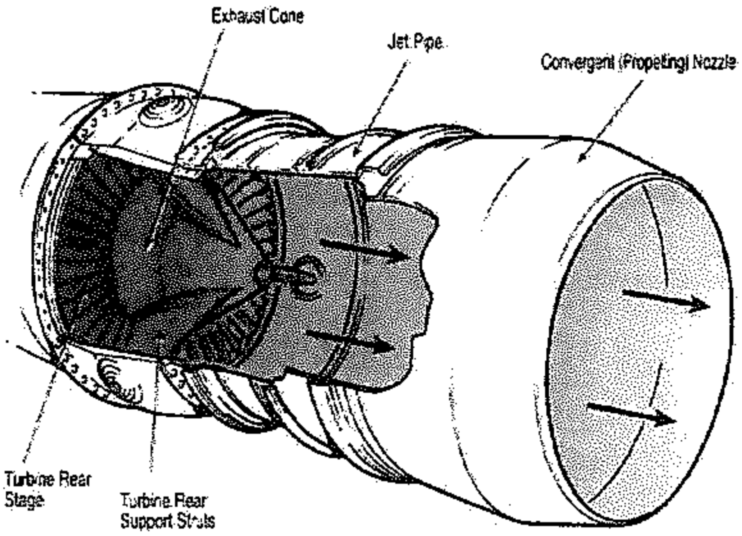

Figure 21 – Exhaust section

In the turbo-propeller engine the exhaust gases contribute only a small amount of thrust, because the turbine for driving the propeller has absorbed most of the energy.

Exhaust unit

The exhaust gases leave the turbine at very high speed, and then slow down considerably on entering the larger cross-section of the jet pipe. It is common to hold the exhaust gas velocity to about Mach 0.5. The exhaust unit, owing to the shape of the exhaust cone, creates a divergent duct, which decelerates the gas flow thus reducing pressure losses. Its other purpose is to protect the rear face of the turbine disc from over heating. The cone is held in place by struts attached to the exhaust unit walls, which also act as straightening vanes to remove any swirl present in the gas flow.

Jet pipe

The jet pipe is used to convey the exhaust gases from the exhaust unit to the propelling nozzle.

Propelling nozzle

The propelling nozzle can be a fixed nozzle or a variable area nozzle. Variable area is required for engines with afterburner. Future designs will allow the direction of the jet efflux to be controlled to improve manoeuvrability.

Drives, gearboxes and accessories

Accessory drive

Accessory units provide the power for aircraft hydraulic, pneumatic and electrical systems in addition to providing various pumps and control systems for efficient engine operation. The accessory drive is a gearbox driven by shafts. There are a variety of gearboxes in use depending on engine design, the most common are:

- Internal gearbox
- External gearbox
- Auxiliary gearbox
- Intermediate gearbox
- Reduction gearbox

For the purpose of this document we will concentrate on the internal and external gearboxes only.

The drive for the accessory units, is typically taken from a rotating engine shaft via an internal gearbox, to an external gearbox, which provides a mount for the accessories and distributes appropriate geared drives to each accessory unit. A starter may also be fitted to provide an input torque to the engine.

Internal Gearbox.

The drive for the external gearbox is taken from a compressor shaft via an internal gearbox. The location of the internal gearbox within the core of an engine is dictated by the difficulties of bringing a drive shaft radially outwards and the space available within the engine core. On a two or three spool engine the drive is normally taken from the HP shaft. Occasionally a drive is taken from both the HP and LP shafts to drive separate high and low speed gearboxes.

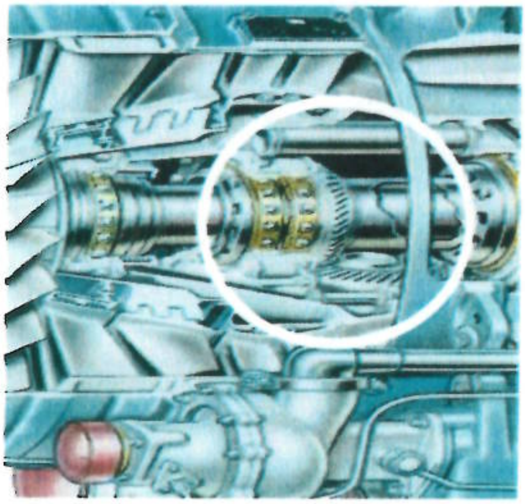

Figure 22 – Internal gearbox

External Gearbox.

The engine external gearbox drives the engine accessories. Typical components driven by the gearbox are:

- Oil pump
- LP fuel pump
- HP fuel pump
- Reheat pump
- Tachometer
- Electrical generator
- Fuel flow governor
- Hydraulic pumps
- Centrifugal breather

As well as containing the drives for the accessories, it also provides the drive from the starter and provides a mounting face for each accessory unit. The gearbox can also be used to mount other accessories e.g. Fuel Control Unit (FCU), coolers and filters.

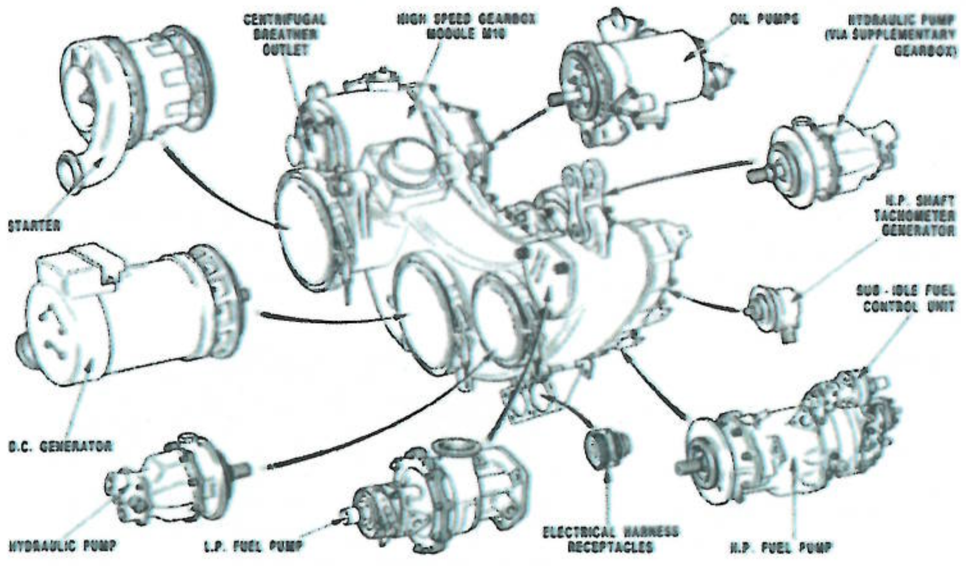

Figure 23 – External gearbox and accessories

Safety precautions

- If you have to enter an intake, make sure that someone knows you are in there.
- Either have a safetyman or place a large warning placard in the cockpit to ensure that no one operates engine start or ignition controls.
- Some intakes incorporate sections that move under the influence of electric or hydraulic power. If you have to enter an intake where moving parts are involved, make sure that they are 'SAFE'.
- When working in intakes, always wear overalls and never carry any more tools than you need for the job.
- Remove all possible loose articles such as pens, money from pockets and check shoes for debris in treads before entering intake.
- Whenever possible, exit from an intake backwards, checking for loose articles as you go.
- When you are satisfied that the intake is clear, fit blanks and covers.

Ground running danger zones

- When an installed aero engine is run on the ground, specified areas to the front and to the rear of the aircraft are classified as DANGER ZONES. These areas are to be kept clear of all personnel for the duration of the runs.
- Whilst running, a gas turbine engine consumes large quantities of air, which creates a considerable hazard in front of the aircraft as it is sucked into the engine intake. The depression created by the intake airflow is sufficient to physically suck an adult into the intake.
- Prior to ground running an aircraft, you must ensure:
- The site is free from loose stones, metallic objects and debris.
- A thorough examination of the engine(s) and engine intake(s) for foreign objects and debris is carried out.
- That all access panels and engine cowlings are securely fitted to the aircraft.
- Intake debris guards are examined for loose fittings, particularly locating pins and any similar type of attachment used to secure the guards to the aircraft. A broken 'pip-pin' retaining wire or chain will cause the pin to become a loose article hazard. Ingestion into a gas turbine engine could cause serious damage to the engine.
- All ground equipment to be used during the run is suitably restrained against movement.
- Tools required for the run are secured against movement.

- All articles of clothing are secured on the body and all loose Items are removed from clothing pockets.