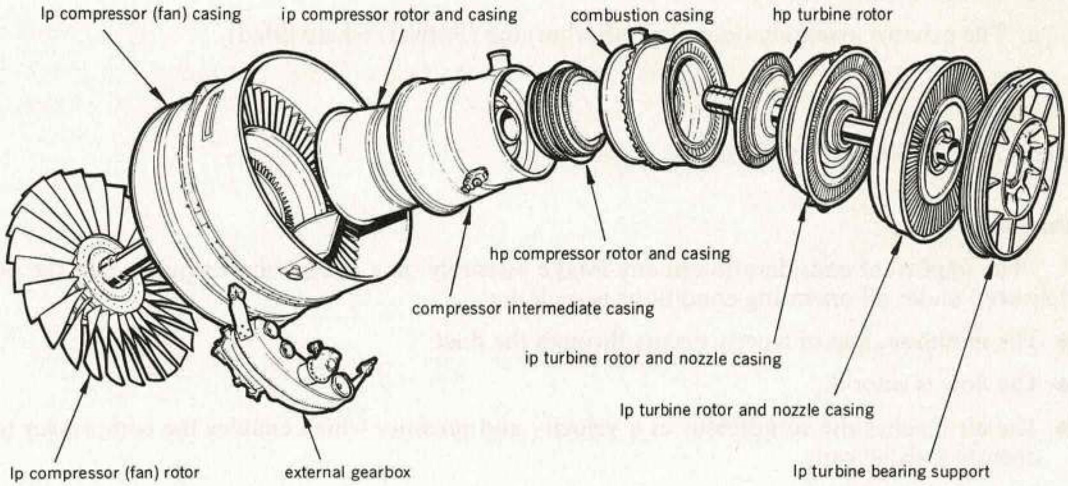
CHAPTER 2

TURBINE ENGINE CONSTRUCTION



Objectives

1. This Chapter has been written with the aim of helping you to satisfy the objectives in the relevant Skills and Knowledge Specifications (SAKS) for the trade in this subject area. When you have studied this Chapter, you should be able to:

a. Explain the purpose and the construction of each of the main assemblies of a gas turbine engine.

b. State the safety precautions to be observed when examining a compressor assembly and how to prevent metal filings entering the compressor.

c. Explain the reasons why the number of blades on a compressor, which can be dressed out, are limited at each stage of compression, and state where the reduction in the weight of blades is recorded.

d. State the safety precautions that must be performed or observed when examining turbine blades and exhaust units *in situ*.

e. List the signs of 'Foreign Object Damage' (FOD).

f. Explain the principles of reheat.

g. State the precautions to be observed when removing and fitting jet pipes.

Introduction

2. Now that we have discussed the principles of jet propulsion, we shall discuss the purpose and construction of the major assemblies of a gas turbine engine and the safety precautions and servicing procedures that must be observed to safeguard, not only very valuable equipment, but also the lives of the aircrew who depend upon your skills as a Propulsion Fitter. The cost of a gas turbine engine is very high—many thousands of pounds; *the cost of a life is incalculable.*

3. The main assemblies of a gas turbine engine are:

a. The air intake assembly (part airframe).

b. The compressor assembly.

c. The combustion chambers.

d. The turbine assembly.

e. The exhaust assembly (including afterburning (Reheat) where fitted).

THE AIR INTAKE ASSEMBLY

Purpose

4. The important consideration in any intake assembly on a gas turbine engine is that the air delivered under all operating conditions is such that:

- The minimum loss of energy occurs through the duct.
- The flow is smooth.
- The air reaches the compressor at a velocity and pressure which enables the compressor to operate satisfactorily.

Pitot Type Intake

5. The normal type of intake fitted to sub-sonic aircraft is a short pitot type circular intake which is illustrated at Fig 2.2.1. Most supersonic aircraft use an external/internal intake (*see* para 9).

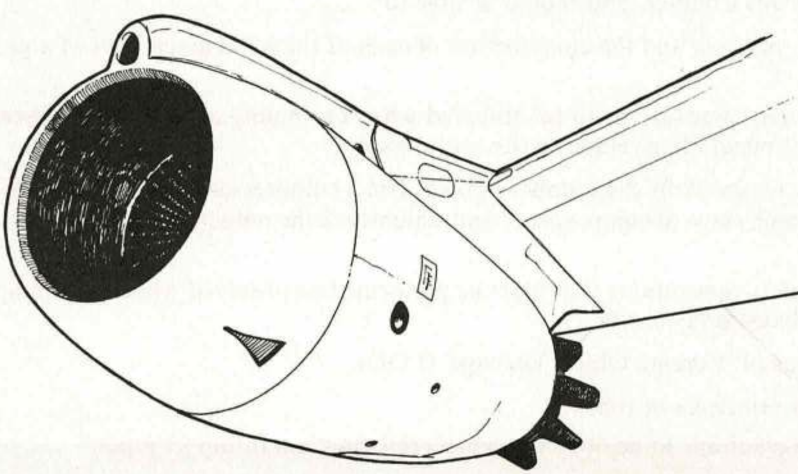


Fig 2.2.1 Pitot type intake

6. The pitot type of intake makes the fullest use of the ram effect on the air due to forward speed and it suffers the minimum loss of ram pressure during changes of aircraft attitude. However, as sonic speed is approached, the efficiency of this type of intake begins to fall due to

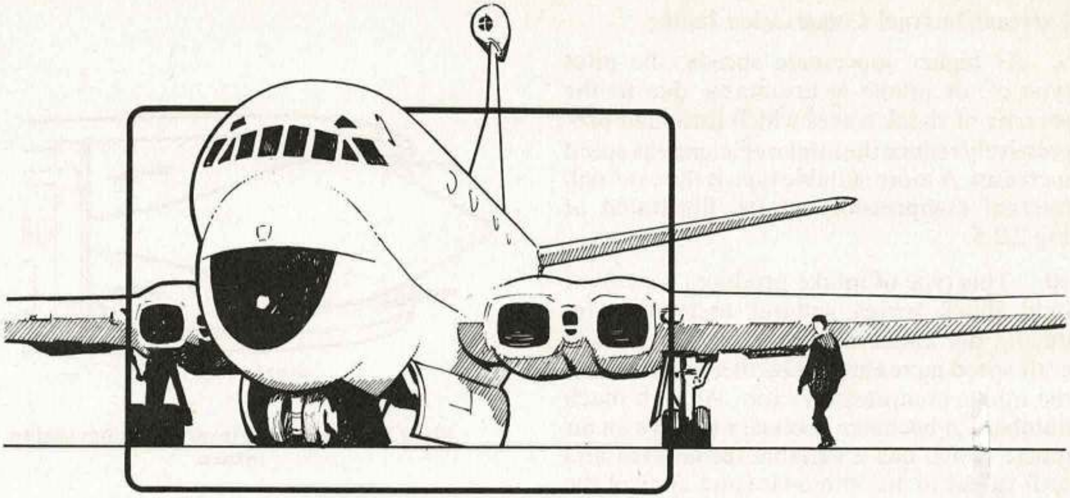


Fig 2.2.2 Wing leading edge intake

the formation of shock waves at the intake lip. The pitot type intake can be used for engines which are mounted in pods or in the wings, although the latter sometimes requires a departure from the circular cross section due to wing thickness, as illustrated at Fig 2.2.2.

Divided Type Intake

7. Single-engined aircraft sometimes use a pitot type intake, but as it generally involves the use of a long duct ahead of the compressor, a divided type of intake is often used which merges into the wing leading edge on each side of the fuselage, as illustrated at Fig 2.2.3.

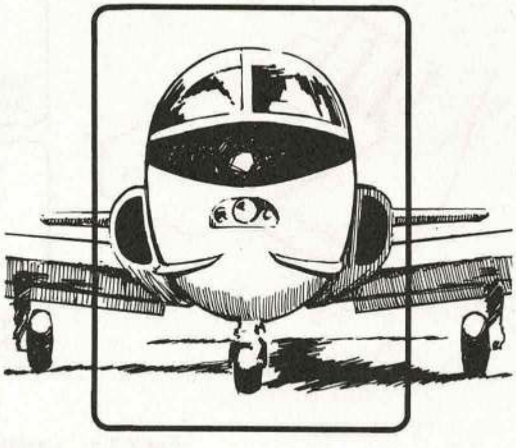


Fig 2.2.3 Divided type intake

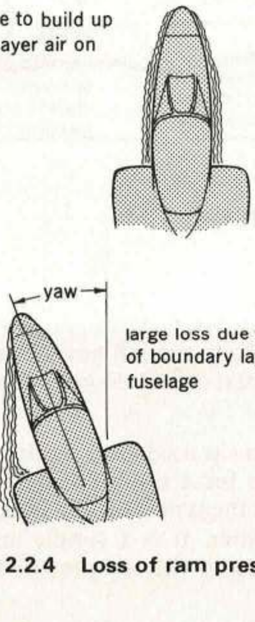


Fig 2.2.4 Loss of ram pressure

8. The disadvantage of the divided type of air intake is that when the aircraft yaws (turns), a loss of ram pressure occurs *on one side* of the intake, causing an uneven flow of air into the compressor. This loss of ram pressure on a divided air intake is illustrated at Fig 2.2.4.

External/Internal Compression Intake

9. At higher supersonic speeds, the pitot type of air intake is unsuitable due to the severity of shock waves which form and progressively reduce the intake efficiency as speed increases. A more suitable type is the external/internal compression intake, illustrated at Fig 2.2.5.

10. This type of intake produces a series of mild shock waves without excessively reducing the intake efficiency but, as the aircraft speed increases still further, so also does the intake compression ratio. At high mach numbers, it becomes necessary to have an air intake which has a variable throat area and spill valves to accommodate and control the changing volume of air. A variable throat area intake is illustrated at Fig 2.2.6.

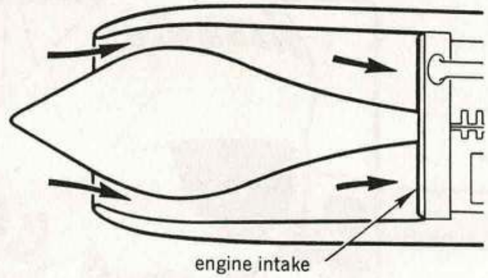


Fig 2.2.5 External/internal compression intake

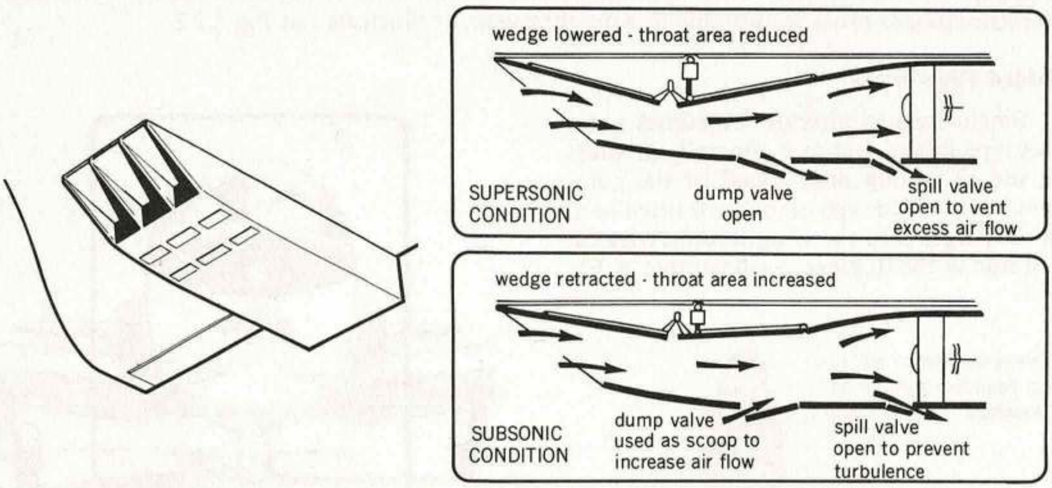


Fig 2.2.6 Variable throat area intake

Air Intake Casing

11. It can be seen from the foregoing that the design of the air intake has a considerable bearing upon the overall efficiency of the gas turbine engine; it also affects aircraft noise level. The engine air intake casings, as distinct from the airframe part of the intakes just described, are illustrated at Fig 2.2.7a, b and c.

12. The bifurcated intake (a) shown detached from the engine is used for a single entry impeller for a centrifugal flow compressor, and that shown at (b) is for a double entry impeller for a centrifugal flow compressor. The third intake shown at (c) is the type used for an axial flow type compressor and is the most common type we shall encounter. It is a simple annular intake casing of the full engine diameter connected by hollow struts to the compressor front bearing

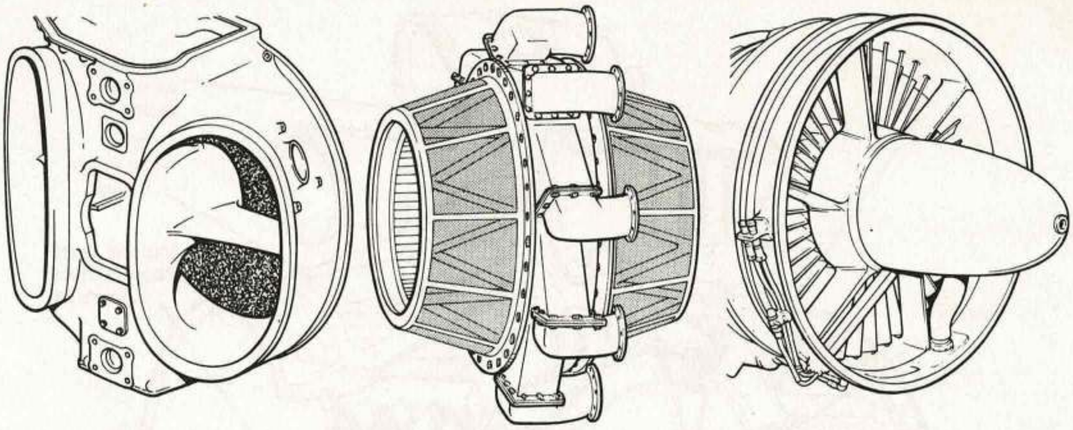


Fig 2.2.7 Air intake casings

housing. A starter fairing and nose cone are fitted to smooth the airflow over the starter motor. Provision for the mechanism for the variable intake guide vanes may also be made on the casing to automatically control the airflow requirements at various operating conditions.

Foreign Object Damage

13. You must constantly be aware of the serious consequences of Foreign Object Damage (FOD) to gas turbine engines. You will be reminded of these words many times in an effort to ensure that you fully understand the importance of preventing FOD. Any nut, bolt, rivet, split pin, piece of locking wire—even a pen from your pocket—left in the air intake to be ingested through the compressor can have disastrous result. So be aware of the problem; read Engineering Orders, Flight Safety Magazines and Posters. Make sure that:

- You carry out loose article checks.
- You use only the exact number of tools to do the job.
- Your workplace is clean.

THE COMPRESSOR ASSEMBLY

Types of Compressor

14. On the gas turbine engine, compression of the air, before expansion through the turbine, is effected by two types of compressor which are in common use—the centrifugal flow type and the axial flow type. Whichever type is fitted, the purpose of a compressor is to provide air at high pressure for all engine power requirements; in addition, the compressor supplies air for cooling, for the engine anti-icing system, for boundary layer control, and for aircraft services. These compressors are discussed in the following paragraphs.

Centrifugal Flow Compressor

15. The centrifugal compressor, illustrated at Fig 2.2.8, employs an impeller to accelerate the

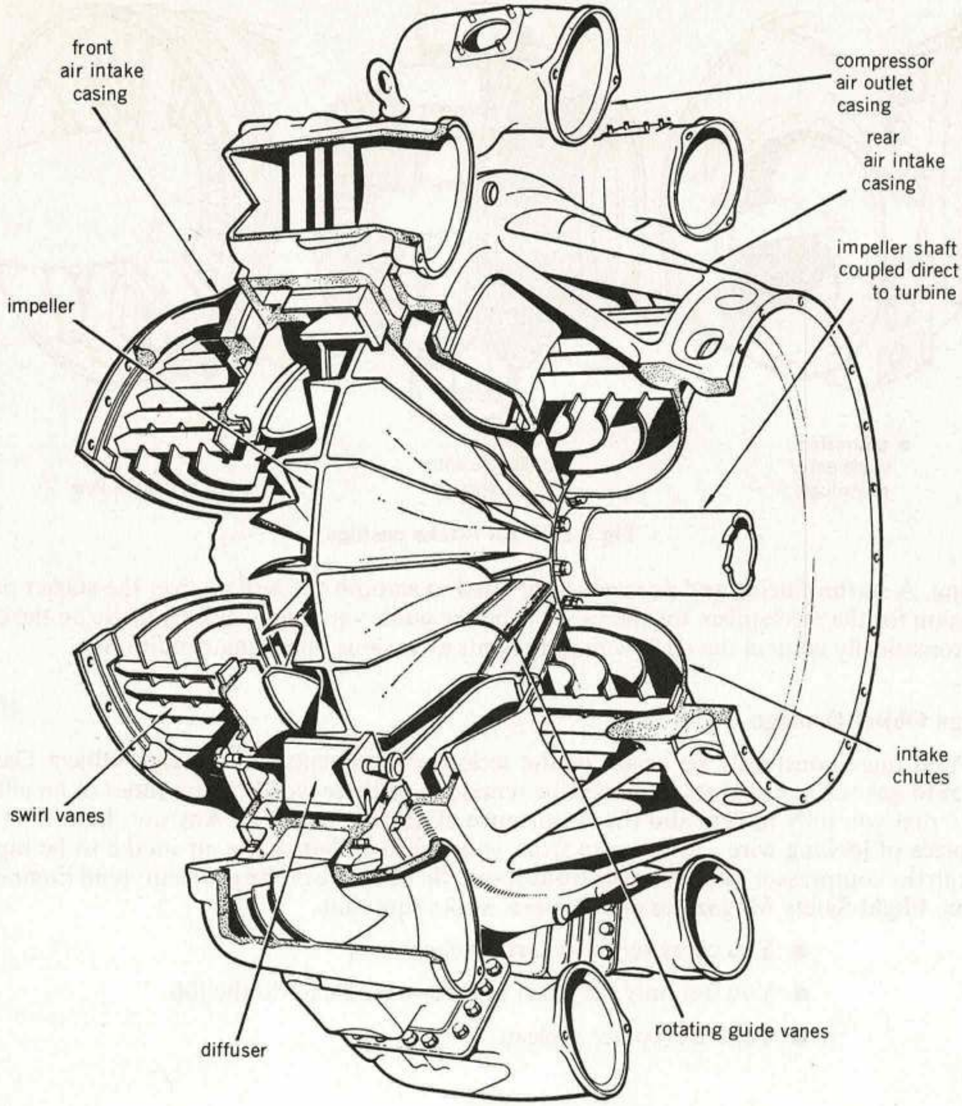


Fig 2.2.8 Centrifugal compressor

air, and a diffuser to convert the kinetic energy (velocity) of the air into pressure energy. The impeller is positioned inside a close fitting casing with the smallest possible clearance between fixed and moving parts, and with an air passage—the air intake—leading from atmosphere to the impeller eye. A ring of divergent vanes (the diffuser vanes) that surround the impeller tip, lead the compressed air into an annular space from which a number of outlet elbows lead, one to each combustion chamber.

16. **Impeller.** The impeller consists of a forged disc with integral radially disposed vanes on one or both sides of the disc, as illustrated at Fig 2.2.9. The vanes form divergent passages. The

single-sided impeller may also be shrouded to prevent efficiency losses due to scrubbing action of the air on the outer case. This is also illustrated at Fig 2.2.9.

17. The choice of impeller is determined by engine design requirements; but it is claimed that single entry ducting allows the air to be fed into the compressor at the best all round efficiency and also minimizes the chance of surging at altitudes, as it makes more efficient use of the ram effect than the double entry ducting. To deal with the same mass airflow as a double sided impeller, the single sided unit must be *of larger diameter*, and this necessitates a lower rotational speed for equivalent tip speeds. It follows, therefore, that the turbine must be of a larger diameter also to obtain the required turbine blade speed. This increases the overall diameter of a single-sided impeller type engine for a given thrust.

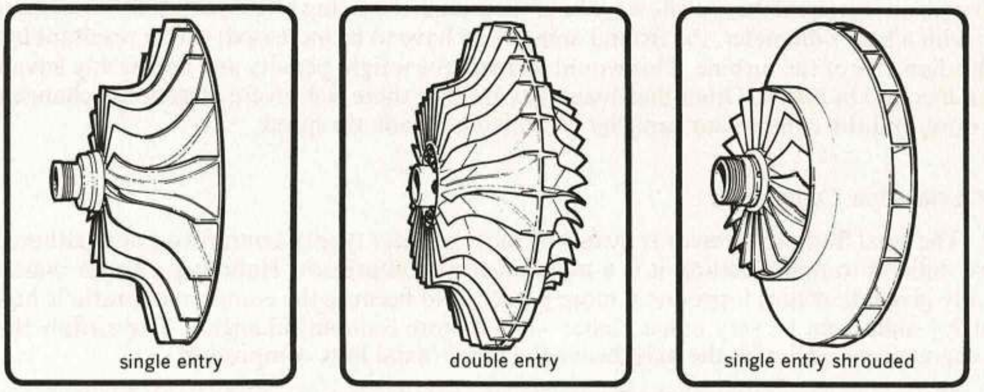


Fig 2.2.9 Types of impeller

18. **Operation.** The centrifugal impeller is rotated at high speed by the turbine, and centrifugal action causes the air between the impeller vanes to accelerate radially outwards until it is thrown off at the tip into the diffuser. The radial movement of the air across the impeller, from eye to tip, causes a drop in air pressure at the eye, and the faster the impeller is turning the lower the pressure at the eye becomes. The low pressure existing at the eye of the revolving impeller induces a continuous flow of air through the engine intake and into the eye of the impeller. The air, in turn, is accelerated across the impeller and passed into the diffuser. The kinetic energy in the air is then converted to pressure energy ready to enter the combustion chamber. The action of the diffuser is illustrated at Fig 2.2.10.

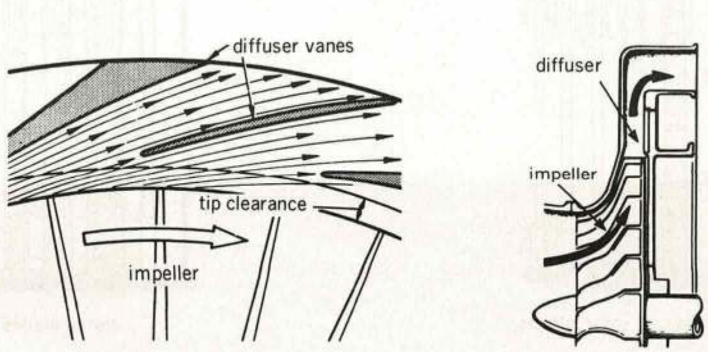


Fig 2.2.10 Action of a diffuser

19. **Advantages of a centrifugal flow compressor.** The centrifugal flow compressor has certain advantages, relative to the axial flow compressor; namely:

a. It is cheaper and easier to manufacture.

b. It is more robust and less subject to ingestion damage.

c. It is less subject to compressor stall (surge).

d. It is a simple compressor (based on a piston engine supercharger).

20. **Disadvantages of a centrifugal flow compressor.** Unfortunately, this compressor has disadvantages that have limited its further development. As stated earlier, with both the single sided and double sided impeller, the compression ratio was limited to about 4:1 (because they cannot deal with an increased mass airflow without their diameter being increased). It follows, therefore, that with a larger diameter, the frontal area would have to be increased, with a resultant increase in the diameter of the turbine. This would increase the weight penalty and negate any advantages of an increase in thrust. Other disadvantages are that there is a severe directional change to the gas flow, and the compressor capacity is limited by blade tip speed.

The Axial Flow Compressor

21. The axial flow compressor is by far the most popular type of compressor and, although it is more difficult to manufacture, it is a more efficient compressor. Handling a larger mass of air for any given diameter, it produces more power; and because the compression ratio is high—at least 9:1 and it can be very much higher—it is a more economical engine. The airflow through the engine is parallel with the axis, hence the name 'axial flow compressor'.

22. The compressor consists of a single or multi-rotor assembly which carries blades of aerofoil section; it is mounted in a casing which also houses the stator blades.

Single Spool Compressor

23. The compressor is a multi-stage unit, the amount of work done by each stage being quite small. Each stage of the compressor consists of one row of rotating blades (Fig 2.2.11a) followed by one row of stator blades (Fig 2.2.11b). The complete assembly consists of a series of rotor blades which fit between a corresponding series of stator blades and this is illustrated at Fig 2.2.12.

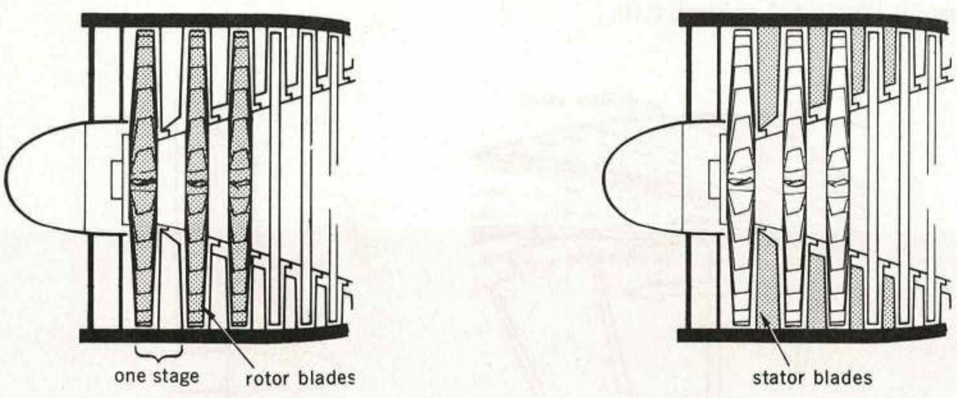


Fig 2.2.11 Stages of compression

24. From the front to the rear of the compressor, *ie* from the low to the high pressure end, there is a gradual reduction of the air annulus area between the rotor shaft and the stator casing (also illustrated at Fig 2.2.12). This is necessary to maintain the axial velocity of the air constant as the density increases throughout the length of the compressor. The convergence of the air annulus is achieved by the tapering of the casing or rotor.

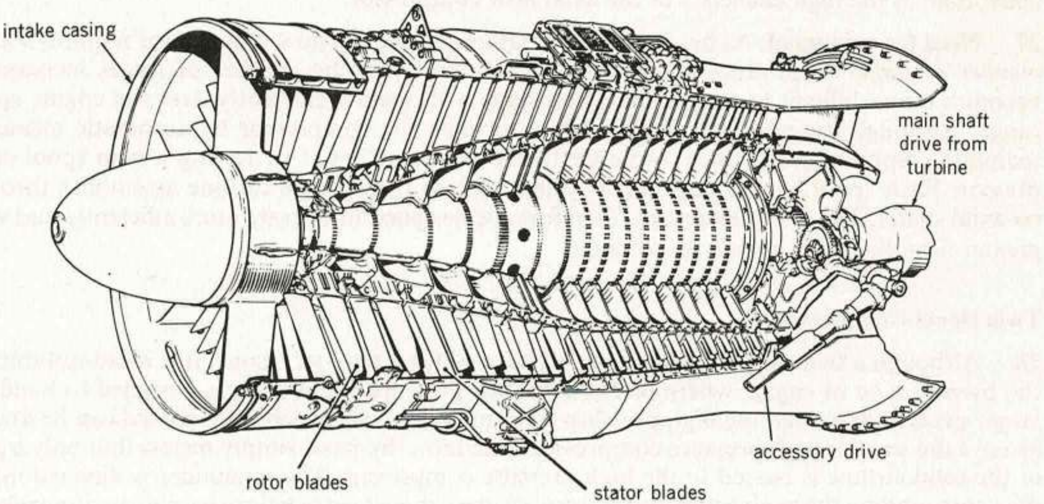


Fig 2.2.12 Compressor and annulus

25. **Operation.** The rotor is turned at high speed by the turbine so that the air is continuously induced between the guide vanes into the compressor, where it is accelerated by the rotating blades and swept rearwards into the adjacent rows of stator blades. The pressure rise in the airflow results from the diffusion process in the rotor blade passages and from a similar process in the stator blade passages. The stator blades also correct the deflection of air from the rotor blades and help to guide the air at the correct angle to the next stage. The last row of stator blades acts as 'air straighteners' to remove the swirl from the air so that it enters the combustion chambers at a fairly uniform velocity. The changes in pressure and velocity that occur in the airflow through the compressor are illustrated at Fig 2.2.13.

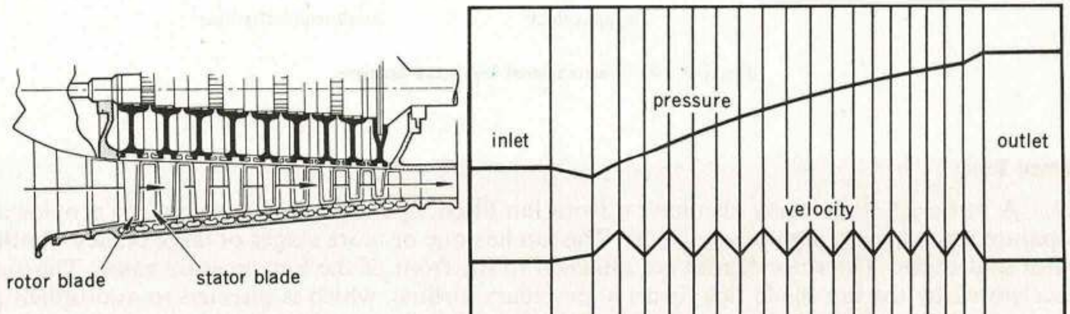


Fig 2.2.13 Changes in pressure and velocity

26. As stated at para 23, across each stage of compression, the ratio of the total pressure of the outgoing air to the inlet air is quite small. The reason for the small pressure increase through each stage is that the rate of diffusion and the deflection angle of the blades must be limited if losses due to air breakaway at the blades and subsequent blade stall are to be avoided. The small pressure rise through each stage, together with the smooth flow path of the air, does much to contribute to the high efficiency of the axial flow compressor.

27. **Need for twin spool.** As has been stated, although an axial flow compressor requires *a large number of stages* to produce a high compression ratio, as the number of stages increases it becomes more difficult to ensure that each stage will operate efficiently over the engine speed range. Although we can control the airflow through the compressor by automatic means to maintain compressor efficiency, more flexibility can be achieved by having a twin spool compressor. Each spool is an independent system, driven by separate turbine assemblies through co-axial shafts. The compressor can, therefore, be designed to operate more efficiently and with greater flexibility over a wide speed range.

Twin Spool Compressor

28. Although a twin spool compressor can be used for a pure jet engine, it is more suitable for the by-pass type of engine where the front or low pressure compressor is designed to handle a larger mass airflow than the high pressure section, and the air which is by-passed can be ducted around the smaller high pressure compressor. The term 'by-pass' simply means that only *a part* of the total airflow is passed to the high pressure compressor. The remainder is directed into a duct surrounding the engine and also mixes with the exhaust gases before passing to atmosphere. This gives a low velocity jet efflux with high propulsive efficiency. An example of a twin spool axial flow by-pass turbo-jet engine is illustrated at Fig 2.2.14.

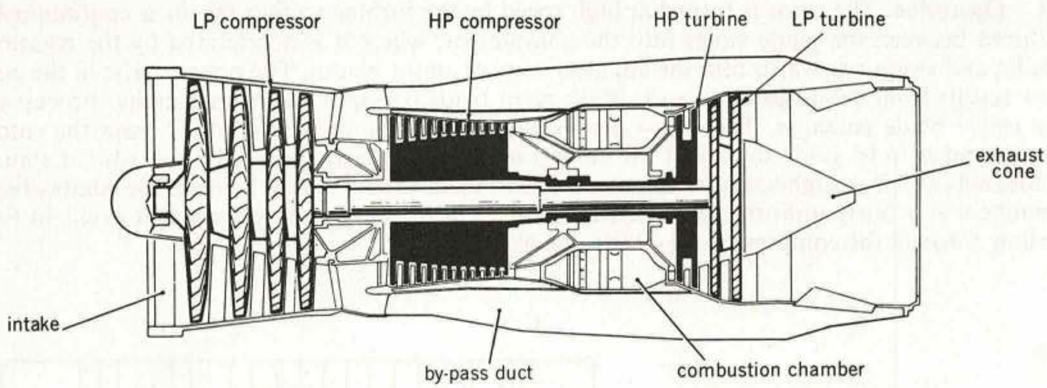


Fig 2.2.14 Twin spool by-pass engine

Front Fan

29. A turbo-jet engine may also have a front fan fitted, operating within a cowl, to provide a separate low velocity, high mass airflow. The fan has one or more stages of large blades—both rotor and stator. The rotor blades are attached to the front of the low pressure rotor. The air accelerated by the fan blade tips forms a secondary airflow, which is directed to atmosphere; the main airflow, from the inner portion of the fan blade, passes through the remainder of the compressor and into the combustion system. This improves the propulsion efficiency and lowers the specific fuel consumption due to the large mass flow and lower jet velocities.

Stall and Surge

30. This is a condition when the flow of air around the compressor blades on an axial flow compressor is subject to turbulence and the smooth airflow pattern through the compression stages is upset. A *stall* may affect only one stage or a group of stages; a compressor *surge* generally refers to a *complete flow breakdown* through the compressor.

31. Compressor blades are designed to produce a given pressure rise and velocity increase over the engine speed range. If something should disturb the pressure/velocity/rotational speed relationship, then the airflow across the blade profile will break away and create eddies until, eventually, the blade 'stalls'. This could occur if the airflow was reduced due to icing or flight manoeuvre, or if the fuel flow was too high. Damage due to ingestion could, of course, create a similar condition.

32. If the stall condition of a stage or group of stages continues until all stages are stalled, then the compressor will *surge*. The transition from a stall to a surge could be so rapid as to be unnoticed, whilst a stall may be so weak as to produce only a slight vibration, or poor acceleration or deceleration characteristics. At low engine speeds, or 'off design' speeds, a slight degree of blade stalling invariably occurs in the front stages of the compressor, even though a system of airflow control may be used. A more severe compressor stall is indicated by a rise in turbine gas temperature, vibration, or 'coughing' of the compressor. A surge is evident by a bang of varying severity from the engine and a rise in turbine gas temperature.

Multi-spool Engines

33. To increase the power and economy of an engine, the compression ratio of the compressor is increased to a higher value. This can be done by adding extra stages to a single spool compressor (but this adds to the stall and surge problems mentioned in the previous paragraphs), or by splitting the compressor into two or three spools of low and high pressure components. When extra spools are added the number of compressor stages in each spool is normally reduced, and extra turbine stages added to drive the spools at different speeds, through independent co-axial shafts.

Advantages of Axial Flow Compressors

34. The advantages to be gained over a centrifugal type compressor are:

a. Higher compression ratio.

b. Low specific fuel consumption.

c. Straight gas flow.

d. Smaller engine diameter.

e. Greater thrust.

f. Capacity for further development.

Disadvantages of Axial Flow Compressors

35. The disadvantages of the axial flow compressor are:

a. Complex and expensive to manufacture.

b. Critical to surge characteristics.

c. Slow to accelerate.

d. Will not readily accept 'ram'.

Servicing of Compressor

36. An awareness of FOD is essential (see para 13). Apart from periodic servicing, you may be called upon to repair blade damage. This may range from very minor repairs *in situ* to the first stage of compressor blades, to repairs to a greater depth by splitting the two halves of the compressor casing and removing the top half. *In all cases, reference should be made to the appropriate Engine Air Publication Volume 1 or Volume 6 or Part 16* as applicable, before any work is commenced. This will detail the extent of the repair allowed and the strict limitations imposed by the manufacturer. The *balance* of the compressor assembly is most critical after any major repairs are carried out. Damage to compressor blades causes vibration and you should be very observant during the engine run down period and listen for peculiar noises from the compressor.

37. **Balancing.** Because of the high rotational speeds, any out-of-balance in the main rotating assembly of a gas turbine engine is capable of producing vibration and stresses which increase as the *square* of the rotational speed. Very accurate balancing of the rotating assemblies is, therefore, necessary. The two main methods of locating out-of-balance forces are *static balancing* and *dynamic balancing*. With static balancing, it is possible to locate and correct unbalance in only one plane, *ie* centrally through the body of the rotor at 90° to the axis. However, because of the length of the compressor and turbine assemblies, unbalance may be present at any radial and axial position; this will produce uneven centrifugal forces when the assembly is rotating, which act on the bearings at the ends of the rotor. To counteract these forces, corrections are applied in two planes, usually at each end of the assembly.

38. Fig 2.2.15 shows that the rotor is in static balance because the weights at A and B are equal and equally disposed. However, when the part is rotating, each weight produces its own centrifugal force in opposition to the other with the tendency to turn the part end-over-end. This action is restricted by the bearings, with resultant stresses and vibration. It will be seen, therefore, that to bring the part to a state of dynamic balance, an equal amount of weight must be removed at A and B (or added at P and O). Thus, it may be said that a part is dynamically balanced when the couples set up by the centrifugal forces are equal. Out-of-balance is expressed in ounce-inches; thus one ounce of excess weight displaced two inches from the axis of a rotor, is two ounce-inches of unbalance.

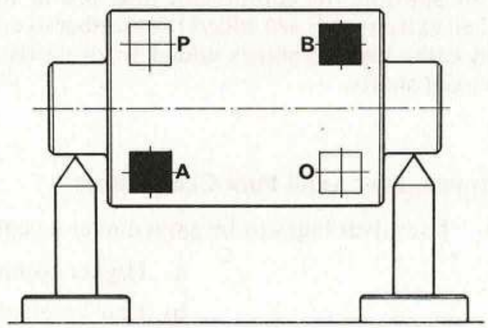


Fig 2.2.15 Unbalanced couples

39. Correction of unbalance may be achieved by one or a combination of the following basic methods:

- Redistribution of weight.
- Addition of weight.
- Removal of weight.

40. *Redistribution* of weight is possible for such assemblies as the compressor wheels, when

blades of different weight can be inter-changed; on some engines, clamped weights are provided for moving around the wheel. The *addition* of weight is probably the most common method used, certain parts of the assembly having provision for the fitting of screwed or riveted plugs, heavy wire or balancing plates. In some instances where blades are retained by pins, pins of different weight may be fitted. *Removing* weight by filing metal from specific positions or machining detachable plates is the third basic method.

41. **Types of damage to compressor blades.** Damage can be caused in many ways, such as metal damage due to ingestion of nuts, screws, locking wire, tools *etc*—stone damage, or damage by ice, slush, water or birds. Although there can be an excuse for ingestion by stones, ice, slush and water *etc* there is no excuse, apart from mechanical failure, for ingestion by nuts, screws *etc* and it is in this area that you must be absolutely vigilant.

42. If it is suspected that an engine has sustained compressor damage, it may well be that the first indications are damage to the inlet guide vanes. Using a strong spotlight, examine the stages of compressor blades as far back into the compressor as possible, rotating the compressor rotor slowly by hand. If there is compressor blade failure, the exhaust unit and turbine blades may show traces of metallic deposits; this condition may also show on the compressor bleed valve matrix (these are the exits where air is bled off from the compressor to promote airflow stability and overcome compressor stall at starting or low rev/min previously mentioned). If you find deposits of aluminium on the exhaust unit or turbine, the compressor assembly should be rejected; similarly, if the compressor blades are failing through insufficient clearance between the blade tips and the compressor casing. No repairs to the inlet guide vanes are normally allowed; these must be replaced if damaged.

43. Those blades which can be repaired (strictly in accordance with the repair manual) must be weighed both *before* and *after* any repair, and should be replaced *in their original position*. You will find the weight of each blade recorded in grammes on the aerofoil section of each blade. After completion of repairs of aluminium blades, air drying enamel should be applied. It may be that the weight of the diametrically opposed blade on the compressor may also have to be reduced to maintain compressor balance.

44. Finally, a further word of warning about loose articles or ingestion of foreign materials. If you are carrying out a minor repair to the first stage of the compressor (*ie* without removing the top half casing) a commonsense practice is to turn the affected blade to BDC before repair. This ensures that any metal filings during repair will drop into the bottom casing and will not contaminate other blades. A vacuum cleaner can then be used to remove the filings. If the compressor top half is removed, then it is common practice to slot an oil soaked rag between the compressor blades to prevent metal filings *etc* from entering the bottom half of the casing. Bits of blades, files or metal filings can cause further damage; so be very careful.

THE COMBUSTION CHAMBERS

The Combustion Chamber

45. The function of the combustion chamber 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 chamber must be constructed such that it is capable of maintaining stable and efficient combustion over a wide range of operating conditions.

Airflow

46. The airflow from the engine compressor enters the combustion chamber at a velocity that

is too high for combustion—like trying to strike a match in a galeforce wind. Therefore, the combustion chamber is shaped so that it acts as a diffuser to slow the airflow down and increase its pressure; even so, it is necessary to create a region of still lower axial velocity air to prevent the flame from blowing out. This region of low velocity airflow, suitable for combustion, is achieved by the design of the flame tube, which includes an air metering system for airflow along the length of the chamber. This airflow pattern is known as the primary, secondary and tertiary airflow. It is described as follows and illustrated at Fig 2.2.16.

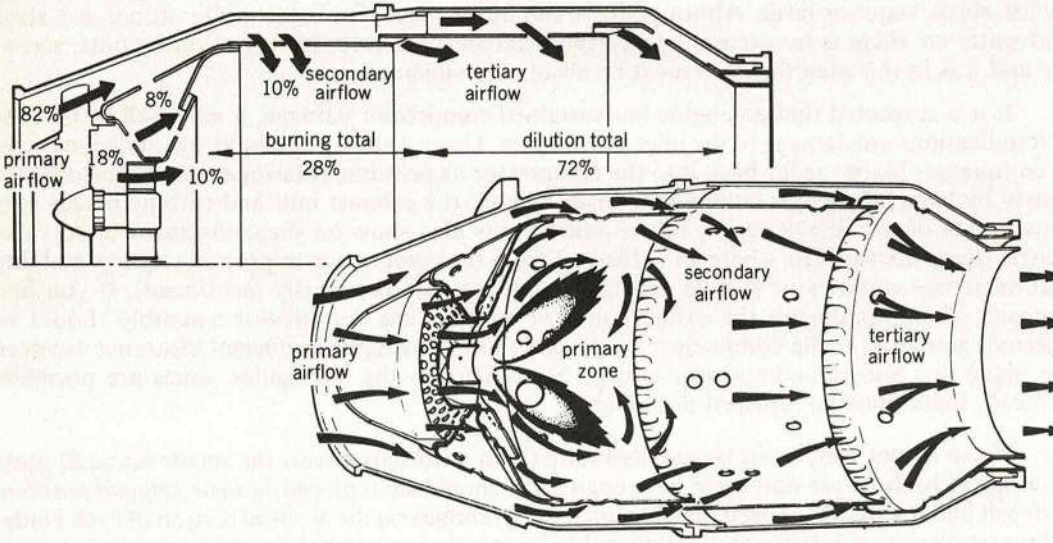


Fig 2.2.16 Airflow through combustion chamber

a. *Primary*—that part of the air mixed directly with fuel to effect combustion.

b. *Secondary*—that part of the airflow which is metered into the combustion zone to complete the combustion process.

c. *Tertiary*—the airflow which is metered into the flame tube towards the outlet end to dilute and reduce the temperature of the gases—also forms a boundary cooling airflow along the flame tube and takes no part in combustion.

47. Only a very small amount (about 18%) of the total airflow is allowed to enter the primary combustion zone. Some of the remaining air enters through holes further along the flame tube, to shape the flame and protect the tube from the heat of the flame. However, the design of the chamber is such that the bulk of the total airflow (60–75%) remains available to act as cooling air for both the combustion chamber and the turbine wheel.

48. The total airflow, accelerated by the heat of combustion, combines at the inlet to the turbine. It gives up some of its energy to drive the turbine wheel, and also provides a large amount of thrust for aircraft propulsion. The cooling effect of the airflow is such that the air casings remain relatively cool during all normal engine running conditions.

Types of Combustion Chamber

49. There are three main types of combustion chamber at present in use for gas turbine engines. These are the multiple chamber, the annular chamber and the tubo-annular chamber. We shall

discuss each briefly in turn.

a. *Multiple combustion chamber*. In this design a number of interconnected combustion chambers are arranged in a circle around the engine (Fig 2.2.17). 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 fuel igniters 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. To prevent unburned fuel from accumulating inside the engine fairings and becoming a fire hazard, each combustion chamber is provided with fuel drains to drain unburned fuel clear of the engine structure. (It is important to keep these fuel drains free from obstruction). The fuel drains are linked together to become a combustion chamber drain system. An illustration of the multiple combustion chamber design is illustrated at Fig 2.2.17.

b. *Annular combustion chamber*. The annular combustion chamber, illustrated at Fig 2.2.18, is a single chamber surrounding the engine. Annular inner and outer air casings form a tunnel around the spine of the engine, the outer casing becoming 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 igniter and airflow distribution to provide conditions suitable for combustion and cooling—similar to the airflow through a multiple combustion chamber. 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. The disadvantage, however, is that it is more difficult to obtain a satisfactory fuel spray pattern than with the individual combustion chambers.

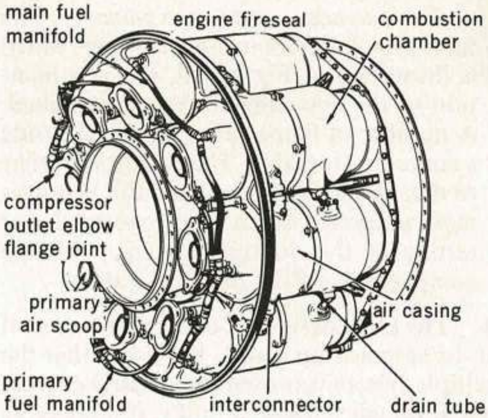


Fig 2.2.17 Multiple combustion chamber

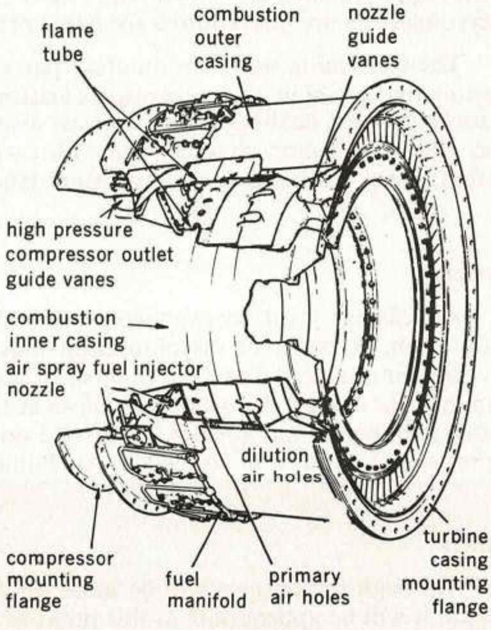


Fig 2.2.18 Annular combustion chamber

c. *Tubo-annular combustion chamber*. The tubo-annular combustion chamber, which is illustrated at Fig 2.2.19, is a combination of the two previous types described. A number of flame tubes are fitted inside a common air casing. The airflow is similar to that already described and this arrangement embodies the ease of overhaul and testing of the multiple system, with the compactness of the annular system.

50. The three designs of combustion system can be summed up simply by saying that the multiple system was used for all early engines and, although somewhat bulky, it was simple to dismantle for overhaul and repair because each chamber could be removed independently. The tubo-annular system has some of of the advantages of the early multiple chambers and is also more compact, with the added advantages of a smooth exterior and reduced weight. The further development of the annular combustion chamber provides a much more compact combustion system and, for the same power output, a much shorter one. This reduces the weight and cost of the engine. Furthermore the flame propagation is improved and the smaller air casing area reduces the amount of air needed for cooling purposes. These improvements, combined with better combustion, improve the efficiency of the engine. Interconnectors are not required for flame propagation.

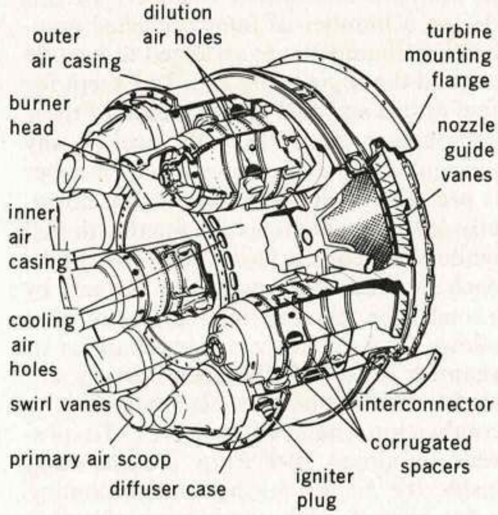


Fig 2.2.19 Tubo-annular combustion chamber

51. The containing walls and internal parts of the combustion chamber must be capable of resisting the very high gas temperatures existing in the primary zone. In practice, this is achieved by using the best heat-resisting materials available and by cooling the inner wall of the flame tube. 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.

Servicing

52. Air casings must be examined, particularly for gas leakage which is indicated by discolouration. A patch of discolouration may also indicate a burnt flame tube. At periodic servicing, or at a predetermined number of hours engine running, flame tubes are removed and examined for cracks, distortion and flaws at the welded seams. Repairs in this area are *strictly limited* and, before any repairs are carried out in workshops, reference should be made to the appropriate Volume 6 or equivalent Air Publication.

Burners

53. Although the burners will be more fully explained in the Chapter dealing with the Fuel System, it will be appropriate at this point to explain their purpose. The prime purpose of the burners is to deliver the fuel into the combustion chamber in a highly atomized state over the entire range of engine speed. Each burner has two orifices, primary and main. The primary produces fine atomization at the minimum flow required (engine starting, low power at high

altitude, or relighting in flight). When maximum flow is required, both the primary and main orifices come into operation.

54. The usual method of atomizing the fuel is to pass it through a swirl chamber, where tangentially disposed holes or slots impart swirl to the fuel by converting its pressure energy to kinetic energy. In this state the fuel passes through the discharge orifice where the swirl motion is removed as the fuel atomizes to form a cone shaped spray. The shape of the spray is an important indication of the degree of atomization. The rate of swirl and, therefore, the pressure of the fuel at the burner, are important factors in good atomization.

55. A pressurising valve may be employed to apportion the fuel to the manifolds. As the fuel flow and pressure increase, the pressurising valve moves to progressively admit fuel to the main manifold and the main orifices. This gives a combined flow down both manifolds. A duple type burner and pressurising valve are illustrated at Fig 2.2.20.

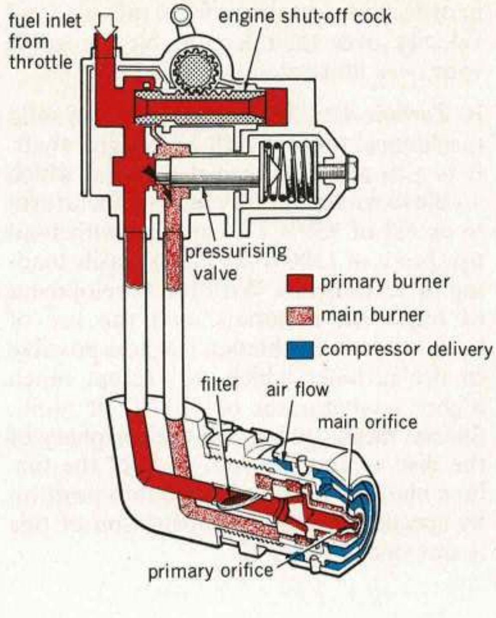


Fig 2.2.20 Duple burner and pressurising valve

THE TURBINE ASSEMBLY

Purpose

56. The purpose of the turbine is to extract sufficient energy from the gas stream to drive the compressor and the engine accessories. In a turbo-propeller combination, the turbine also provides shaft power for the propeller. To produce the necessary driving torque, there may be one or 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. The number of turbine stages depends upon:

- Whether the engine has a single turbine shaft or has co-axial shafts;
- The amount of power that the turbine pack has to produce;
- The largest turbine diameter that the design allows.

Construction

57. The basic components of a turbine assembly are the nozzle guide vanes, the turbine disc and the turbine blades. They are described briefly as follows:

a. *Nozzle guide vanes*. The aerofoil section vanes form a ring of convergent ducts which cause the gases to impinge on the turbine with a high angular velocity. Their function is two-fold; to present the gases at an acceptable angle to the turbine, and to increase gas velocity. They are made of heat resisting materials and are able to withstand temperatures in excess of 850°C. The nozzle guide vanes are twisted to provide a varying angle of attack in order to maintain uniform pressure and velocity over their length. Nozzle guide vanes are illustrated in Fig 2.2.21.

b. *Turbine disc*. The turbine disc is a solid mechanical forging with an integral shaft. It is also made of special material which is able to withstand very high temperatures in excess of 850°C; it can also withstand tip speeds of 1300 ft/sec and a tensile loading of 15 tons/in^2. With the development of improved materials, and the use of hollow air-cooled blades, it is now possible to use turbines which will accept much higher temperatures of 1200°C or more. Special meshings around the periphery of the disc receive the root ends of the turbine blades which are locked into position by special devices. An illustration of this is shown at Fig 2.2.22.

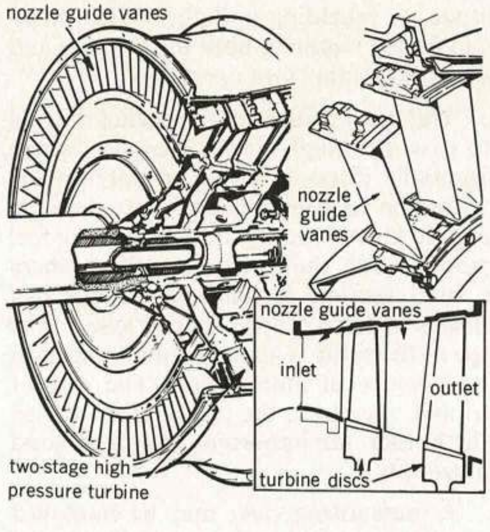


Fig 2.2.21 Turbine nozzle guide vanes

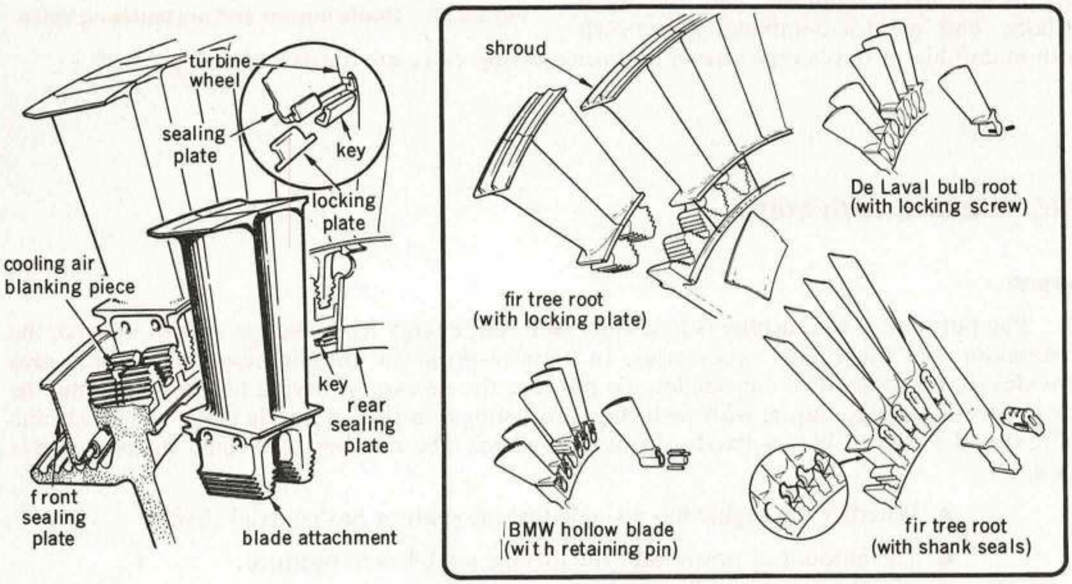


Fig 2.2.22 Turbine blade attachment to disc

c. *Turbine blades*. The turbine blades are twisted to give 'impulse' and 'reaction' sections. The sections are blended together, with the impulse section at the root (or inner end) of the blade, and the reaction section at the tip. This design is sometimes known as 'Vortex' blading. At the impulse section of the blade, a pressure drop, and a corresponding velocity increase, occurs in the convergent passages of the nozzle guide vanes. The resulting stream of high

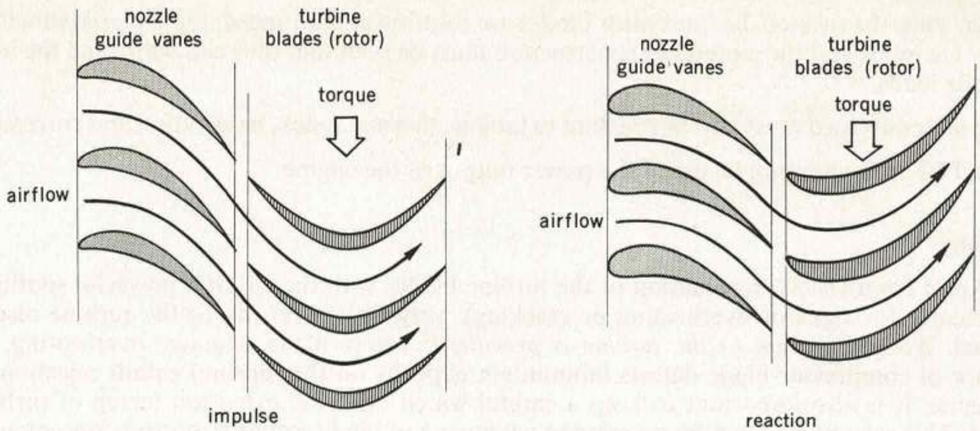


Fig 2.2.23 Impulse/reaction blading

velocity gas is directed at the rotor blades, causing the turbine to rotate (Fig 2.2.23). At the reaction section of the blade, the nozzle guide vane passages are constant in area and it is the rotor blades that have convergent passages in the direction of flow. The resulting acceleration of the gas through these passages provides a reaction force which drives the turbine (Fig 2.2.23).

58. **Turbine blade attachment.** In para 57b we mentioned that the turbine disc had special machinings around the periphery of the disc to receive the root ends of the turbine blades. The method of attachment is of considerable importance, since the stress on the disc around the fixings, or in the blade root, has an important bearing on the limiting rim speed. The blades are fixed to the turbine rim by various methods, the most common one being known as 'the fir tree method' (also illustrated at Fig 2.2.22). This type of fixing involves very accurate machining to ensure that the loading is shared by all serrations. The blade is free in the serrations (saw-like edge) when the turbine is stationary, and is stiffened in the root by centrifugal loading when the turbine is rotating.

59. **Turbine blade shroud.** To reduce the loss of efficiency due to gas leakage across the blade tips, a shroud is often fitted (Fig 2.2.22). This is formed by forging a small segment at the tip of each blade; when all the blades are fitted to the disc, the segments form a peripheral ring around the blade tips.

Turbine Entry Temperature (TET)

60. Among the obstacles in the way of using higher turbine entry temperatures have always been the effects of these temperatures on the nozzle guide vanes and the turbine blades, and the tensile force imparted to the turbine disc and blades by the high speed of rotation. It can be stated, therefore:

- The turbine entry temperature (TET) is high, and the materials used in the construction of the nozzle guide vanes and turbine blades must be such that they can withstand the high temperature.

- Also, since the turbine disc and rotor blades are rotating at high speed, the material of which they are made and the method of construction must be such that they can withstand the high tensile loads.
- The materials used must also be resistant to fatigue, thermal shock, oxidization and corrosion.
- The TET is the limiting factor of the power output of the engine.

Servicing

61. Apart from visual examination of the turbine blades with the aid of a powerful spotlight (particularly for signs of overheating or cracking), very little servicing to the turbine disc is required. *No rectification to the turbine is permitted;* severe blade damage, overheating, or evidence of compressor blade defects (aluminium deposits on the turbine) entails rejection of the engine. It is also important to keep a careful watch on blade extension (creep of turbine blades). This may be detected by waisting (a narrowing of blade section), mottling (discolouration), cracks, or an increase in blade length. The latter is checked by a feeler gauge between the blade tip and the shroud ring).

THE EXHAUST ASSEMBLY

Purpose of an Exhaust System

62. The purpose of a basic exhaust system is to collect the hot gases when they leave the turbine unit and pass the gases to atmosphere at such a velocity as to provide the resultant thrust. On some sophisticated exhaust assemblies, however, provision is made for after-burning (reheat), thrust reversal (already dealt with in Chapter 1) and noise suppression equipment. It should be remembered, however, that in the turbo-jet engine, the velocity and pressure of the exhaust gases create thrust; but in the turbo-propeller engine, only a small amount of thrust is contributed by the exhaust gases, as most of the energy has been absorbed by the turbine stages for driving the propeller. The design of the exhaust system exerts a considerable influence on the performance of the engine. The areas of the jet pipe and propelling nozzle affect the TET, the mass airflow and the velocity and pressure of the exhaust jet.

The Basic System

63. The exhaust unit, which is bolted into the turbine casing, consists of an outer pipe that is cylindrical or conical in shape, and an inner cone secured inside the pipe by aerofoil-shaped support struts; the complete unit forms a divergent duct, giving an increase in pressure and a decrease in the speed of the exhaust gases (Fig 2.2.24 refers). The outlet duct is annular in shape to match the outlet from the turbine blades, with the volume available to the gas flow increasing to the rear.

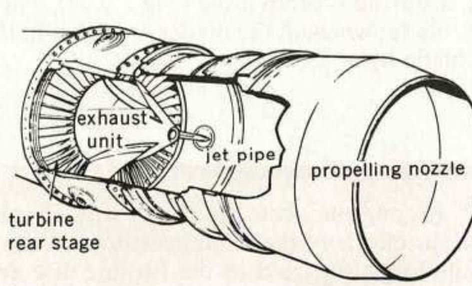


Fig 2.2.24 Exhaust system and jet pipe

64. The exhaust cone is fitted so that it shields the rear face of the turbine disc from the hot gases, and the streamlined support struts straighten out the 'whirl' in the gas flow before the

gases pass into the extension known as the jet pipe (also illustrated at Fig 2.2.24). The outlet from the jet pipe is reduced in diameter to act as a propelling nozzle. This reduction in diameter, because it is a convergent duct, increases the speed of the exhaust gases (velocity) and causes a decrease in pressure.

65. A short exhaust system is more efficient because there are less frictional losses and more energy available for propulsive thrust. However, to clear the aircraft structure, an additional length of exhaust pipe may be needed—this varies in length depending on where the engine is situated. The complete exhaust system is usually lagged with heat-resisting material (called an insulating blanket) to protect the aircraft structure from the effects of the hot gases and to reduce fire risks. Another method of protecting the aircraft structure is achieved by ducting air around the jet pipe.

66. Due to the wide variations of temperature to which the exhaust system is subjected, it must be mounted on trunnion blocks and have its sections joined together in such a manner as to make allowances for a great deal of expansion and contraction.

Servicing

67. Apart from an examination of the exhaust unit and jet pipe for cracks and signs of buckling, the two other most important points to remember are an examination for signs of overheating and of gas leakage. Normally, if you find buckling, the jet pipe is removed for further examination. The joints between the exhaust unit and the jet pipe must be carefully sealed to prevent gas leakage. The acceptance standards for cracks on an exhaust unit, or for buckling on the jet pipe, are laid down in the appropriate AP.

68. Jet pipes must be very carefully handled and the proper stand must always be used. When fitting jet pipes, they must always be centralized to ensure adequate clearance from the aircraft structure. Special clearance checks are also carried out when fitting the exhaust unit, and the jet pipe to the exhaust unit. It cannot be overstressed how important this is because of the danger of gas leakage.

Reheat or Afterburning Jet Pipes

69. Although the subject of reheat will be dealt with in a later Chapter, it will be appropriate at this point to consider a reheat jet pipe as an extension of the subject matter in the previous paragraphs.

70. Afterburning or reheat is a method of augmenting the basic thrust of an engine to improve the take-off, climb and combat performance of an aircraft. An increase in thrust could be achieved by a more powerful engine, but this would mean an increase in weight and frontal area, coupled with a higher specific fuel consumption. An improvement is achieved by fitting an

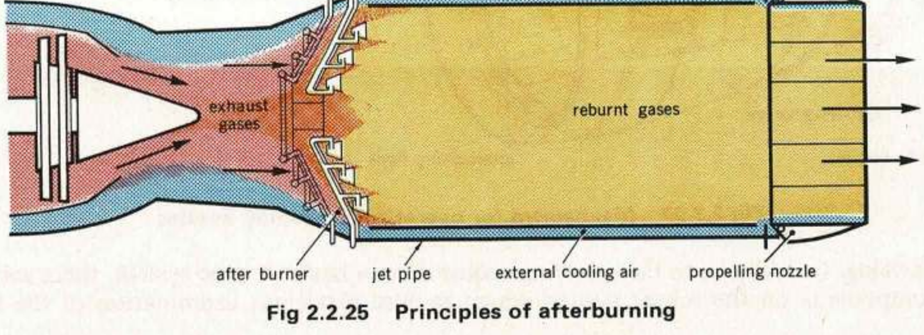


Fig 2.2.25 Principles of afterburning

afterburning jet pipe, where an atomized fuel spray is fed into the jet pipe through a number of burners, and combustion is initiated by an igniter plug. The unburned oxygen in the exhaust gas is utilized to support combustion. An example of the principles of afterburning is illustrated at Fig 2.2.25.

71. **Construction of afterburning jet pipe.** The afterburning jet pipe (illustrated at Fig 2.2.26) is longer than a normal jet pipe and is fitted with either a two position or a variable-area propelling nozzle. It is made from a heat-resisting alloy steel and requires heavier insulation than the normal jet pipe. Insulation is of a double skin construction, and provision is also made to accommodate expansion and contraction to prevent gas leaks at the jet pipe joints. On some aircraft an intermediate jet pipe is fitted between the exhaust unit and the reheat jet pipe.

72. **System components.** Fuel is supplied by a centrifugal flow or gear type pump which is switched on automatically when afterburning is selected. The propelling nozzles are operated by a motor and inching mechanism or by pneumatically operated rams (Fig 2.2.27 refers). The burner system consists of one or more circular fuel manifolds supported by struts inside the jet pipe. Fuel is supplied to the manifolds by feed pipes in the support struts and sprayed into the flame area from holes in the downstream edge of the manifolds.

73. An anti-howl liner (Fig 2.2.28) is fitted in a robust jet pipe. The liner, which is corrugated and perforated, prevents combustion instability from creating excessive noise and vibration which would cause rapid deterioration of the afterburning equipment.

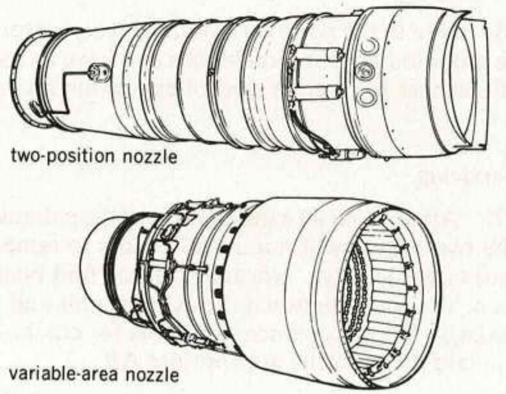


Fig 2.2.26 Afterburning jet pipe

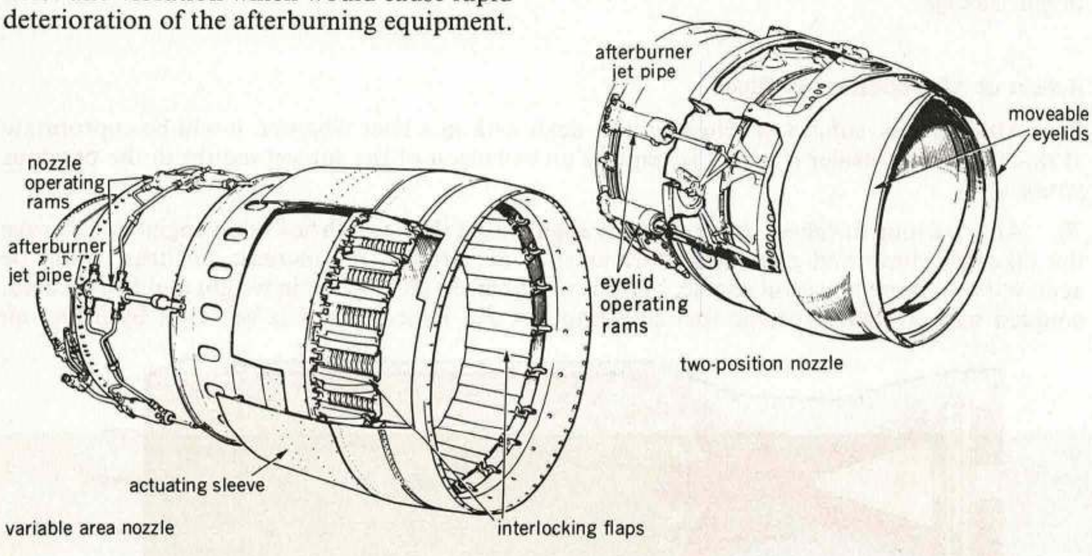


Fig 2.2.27 Mechanism for operating propelling nozzles

74. **Servicing.** In addition to the servicing required on a basic jet pipe system, there are many more components on the reheat system which require servicing: examination of the burner

assembly, fuel pipes, fuel control unit, the air motor, control linkages and the nozzle assembly. A simplified reheat control system is illustrated at Fig 2.2.29.

75. Before any repair or adjustments are carried out on the reheat equipment, reference should always be made to the appropriate Volume 1 and Volume 6 (or equivalent) AP.

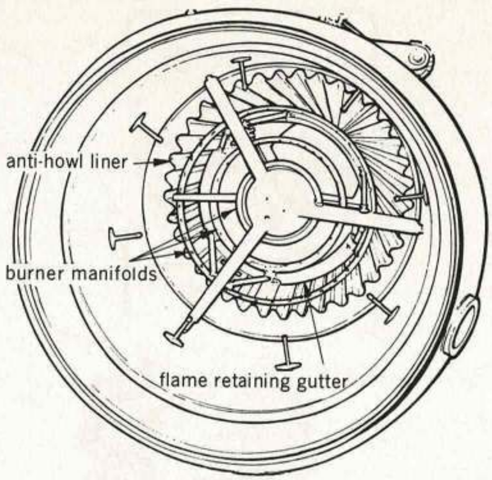


Fig 2.2.28 An anti-howl liner

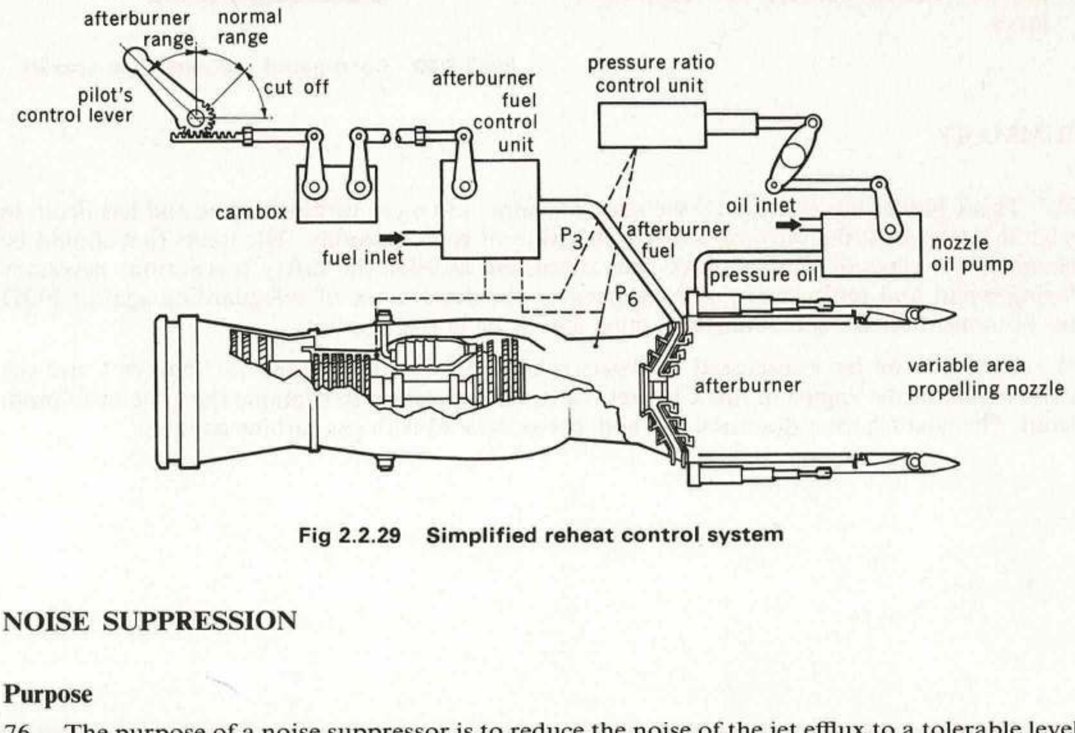


Fig 2.2.29 Simplified reheat control system

NOISE SUPPRESSION

Purpose

76. The purpose of a noise suppressor is to reduce the noise of the jet efflux to a tolerable level. The noise results mainly from the turbulence produced when the exhaust gases link with the atmosphere and it increases in proportion to the speed of the exhaust jet.

Construction of Noise Suppressor

77. The noise suppressor forms the exhaust system propelling nozzle and is a separate assembly bolted to the jet pipe. The nozzle area can be adjusted for calibration. The suppressor is a fabricated welded structure and is manufactured from heat resistant alloys.

Types of Suppressor

78. There are two types of suppressor — corrugated nozzle and lobe-type nozzle. Both types become more effective as the aircraft speed increases, when more air becomes available to link with the jet efflux.

a. *Corrugated nozzle*. In the corrugated nozzle, illustrated at Fig 2.2.30, atmospheric air flows down the outside corrugations and into the exhaust jet to promote rapid mixing of the air and jet efflux.

b. *Lobe-type nozzle*. In the lobe-type suppressor nozzle, also illustrated at Fig 2.2.30, the exhaust gases are divided to flow through the lobes and a small central nozzle. This forms a number of separate exhaust jets which again mix rapidly with the air passing between the suppressor lobes.

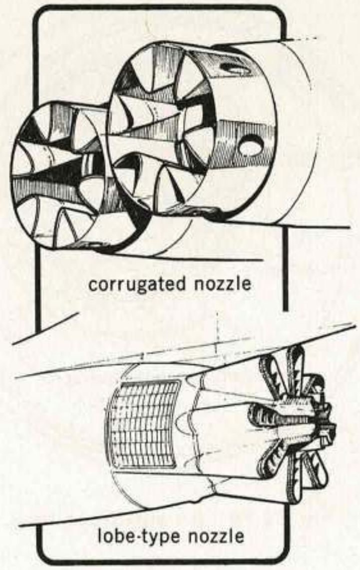


Fig 2.2.30 Corrugated and lobe-type nozzles

SUMMARY

79. This Chapter has considered the main assemblies in a gas turbine engine and has dealt, in general terms, with the purpose and construction of each assembly. The items that should be examined for signs of damage have been discussed, as have the safety precautions necessary during repair and replacement of components. The importance of safeguarding against FOD has been mentioned—something that must always be borne in mind.

80. Now that we have discussed the basic principles of jet propulsion in Chapter 1 and the construction of the engine in this Chapter, we are in a position to examine the systems in more detail. The next Chapter discusses fuel systems associated with gas turbine engines.

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