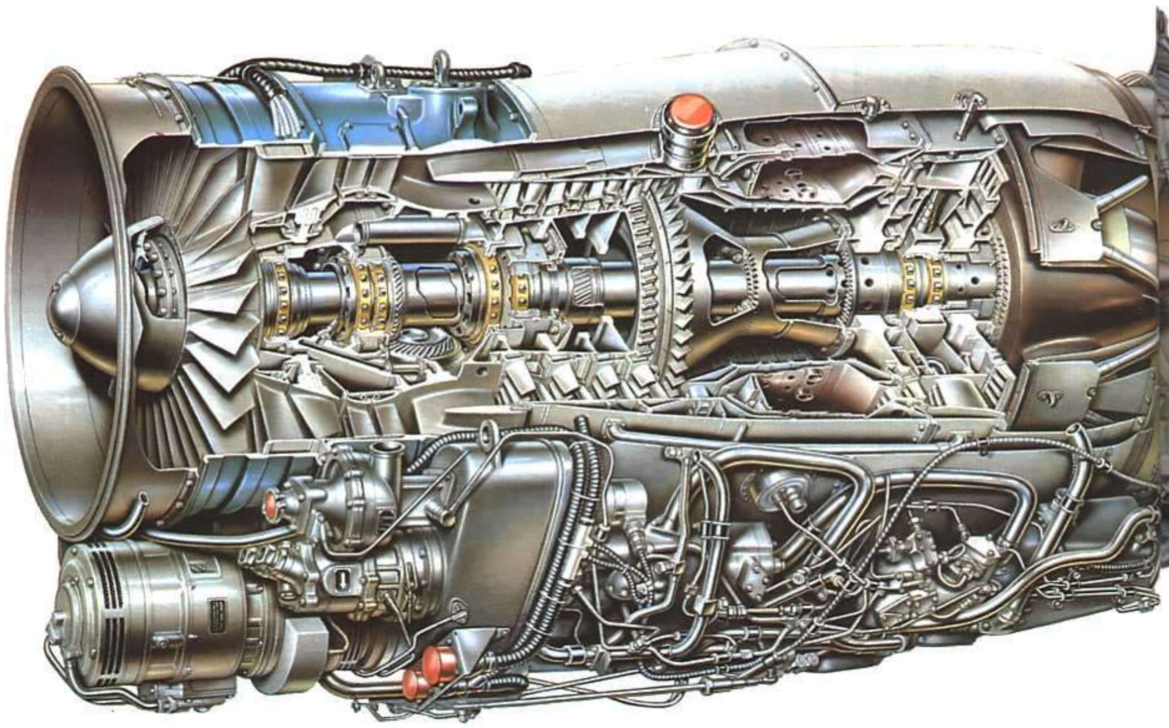
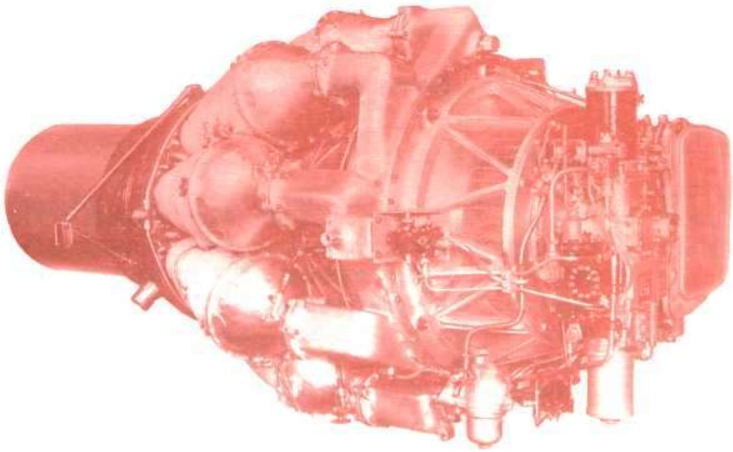
Rolls-Royce Turbomeca Adour Mk102

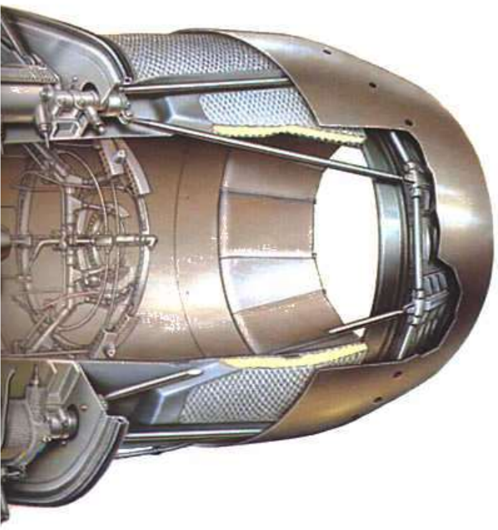




Work commenced in January 1945 on a 0.855 scale Nene, reduced to fit the engine nacelle of a Gloster Meteor. Known as the Derwent V the engine passed a 100 hr test at 2600 lb thrust in June 1945 and in September went into production with a service rating of 3500 lb. Two world speed records were set by Meteor IV's powered by special Derwent V's in November 1945 and September 1946.

Rolls-Royce RB37 Derwent V

5: Turbines



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INTRODUCTION

1. The turbine has the task of providing the power to drive the compressor and accessories and, in the case of engines which do not make use solely of a jet for propulsion, of providing shaft power for a propeller or rotor. It does this by extracting energy from the hot gases released from the combustion system and expanding them to a lower pressure and temperature. High stresses are involved in this process, and for efficient operation, the turbine blade tips may rotate at speeds over 1,500 feet per second, The continuous flow of gas to which the turbine is exposed may have an entry temperature between 850 and 1,700 deg. C. and may reach a velocity of over 2,500 feet per second in parts of the turbine.

2. To produce the driving torque, the turbine may consist of several stages each employing one row of stationary nozzle guide vanes and one row of moving blades (fig. 5-1). The number of stages depends upon the relationship between the power required

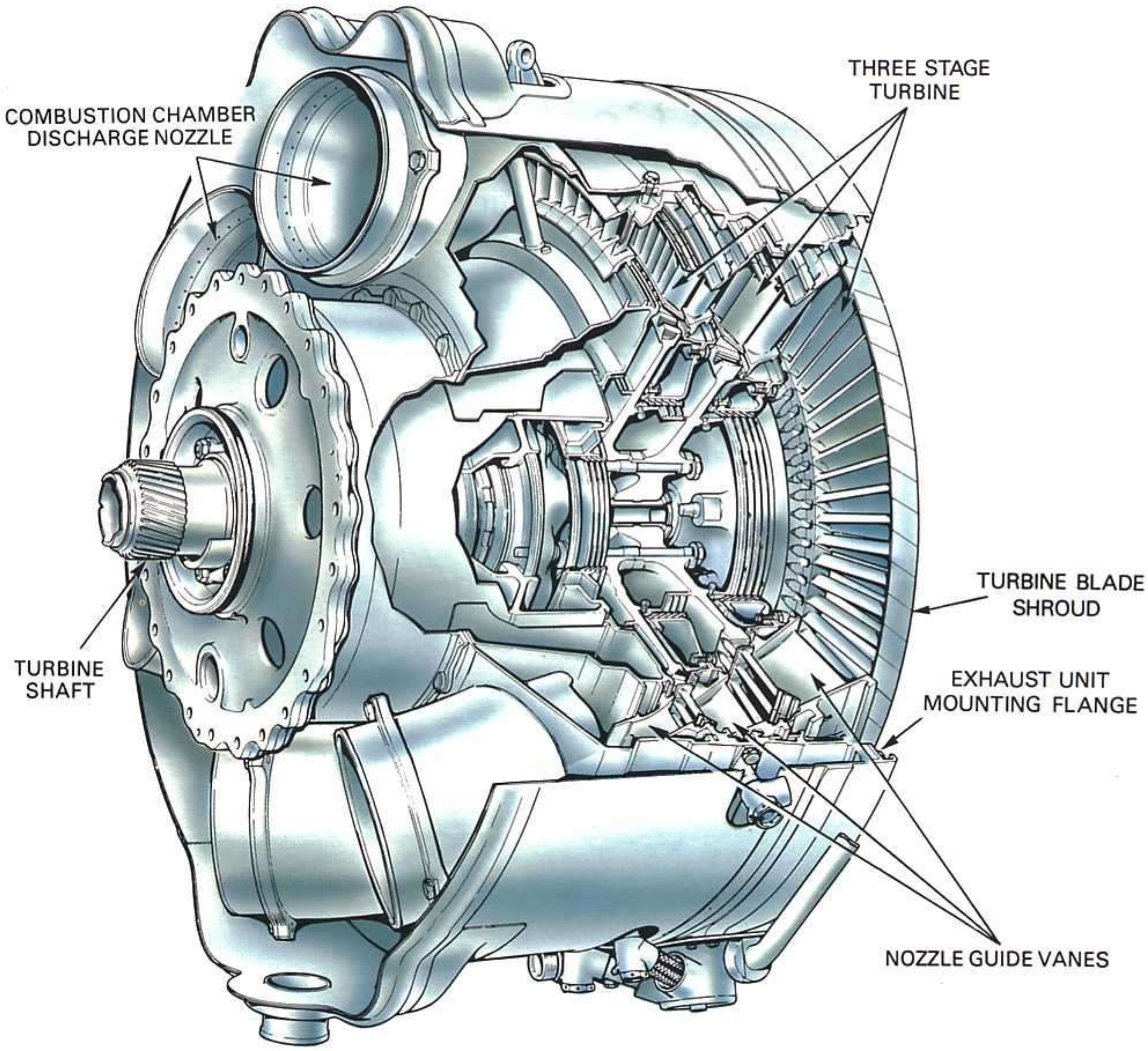


Fig. 5-1 A triple-stage turbine with single shaft system.

from the gas flow, the rotational speed at which it must be produced and the diameter of turbine permitted.

3. The number of shafts, and therefore turbines, varies with the type of engine; high compression ratio engines usually have two shafts, driving high and low pressure compressors (fig, 5-2). On high by-pass ratio fan engines that feature an intermediate pressure system, another turbine may be interposed between the high and low pressure turbines, thus forming a triple-spool system (fig, 5-3). On some engines, driving torque is derived from a free-power turbine (fig. 5-4). This method allows the turbine to run at its optimum speed because it is mechanically independent of other turbine and compressor shafts.

4. The mean blade speed of a turbine has considerable effect on the maximum efficiency possible for a given stage output. For a given output the gas velocities, deflections, and hence losses, are reduced in proportion to the square of higher mean blade speeds. Stress in the turbine disc increases as the square of the speed, therefore to maintain the same stress level at higher speed the sectional thickness, hence the weight, must be increased disproportionately. For this reason, the final design is a compromise between efficiency and weight. Engines operating at higher turbine inlet temperatures are thermally more efficient and have an improved power to weight ratio. By-pass engines have a better propulsive efficiency and thus can have a smaller turbine for a given thrust.

5. The design of the nozzle guide vane and turbine blade passages is based broadly on aerodynamic considerations, and to obtain optimum efficiency, compatible with compressor and combustion design, the nozzle guide vanes and turbine blades are of a

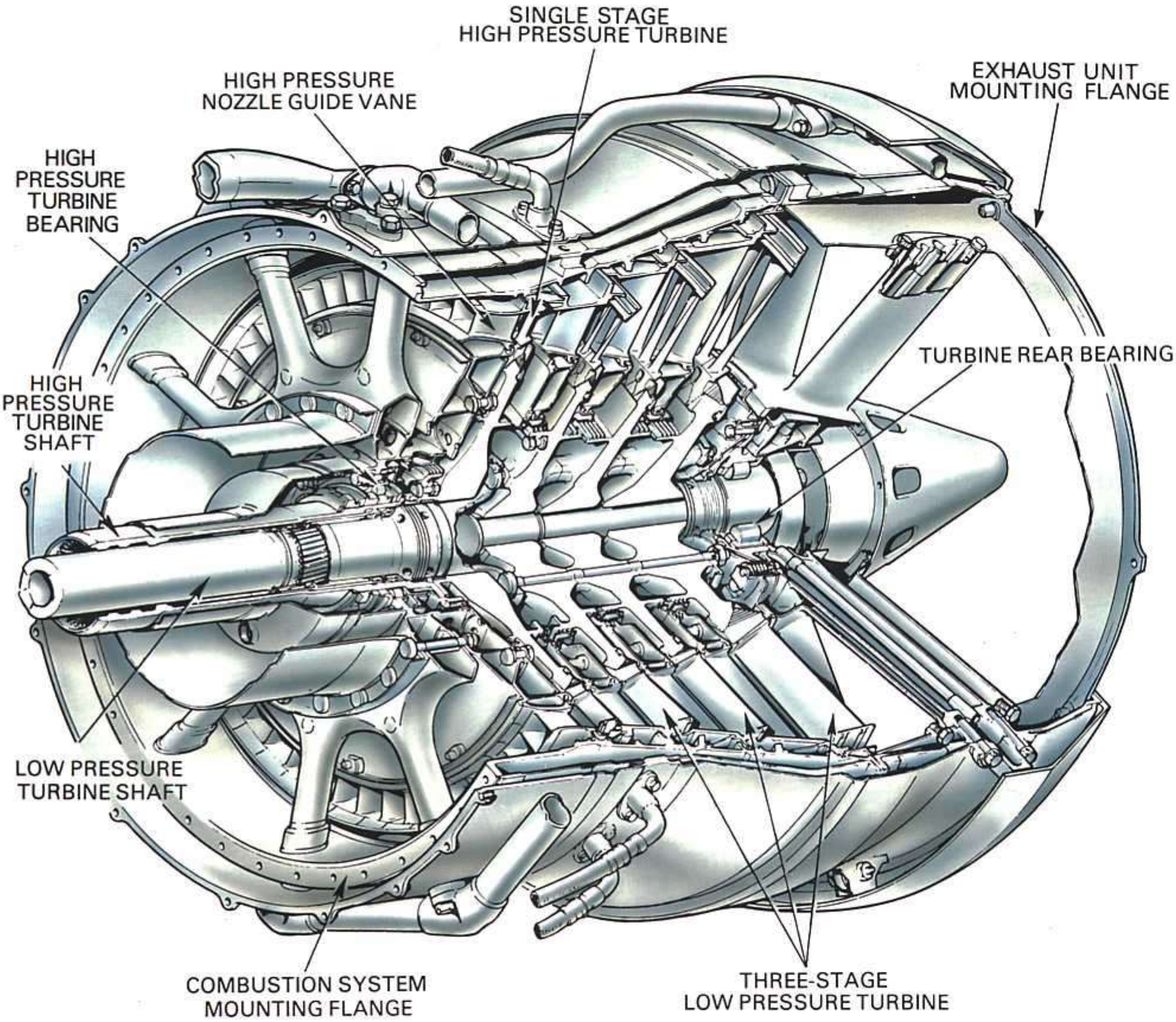


Fig. 5-2 A twin turbine and shaft arrangement.

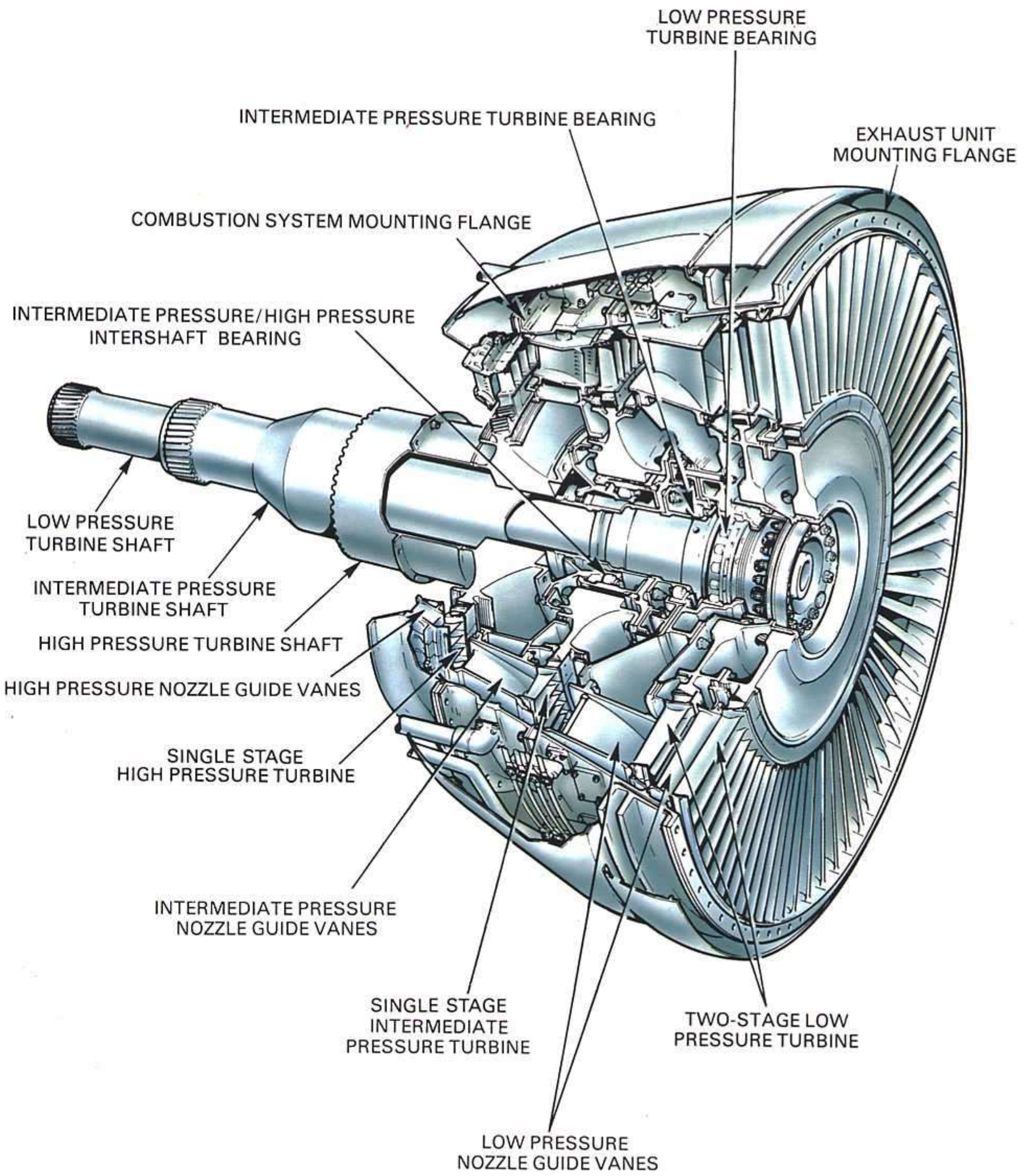


Fig. 5-3 A triple turbine and shaft arrangement.

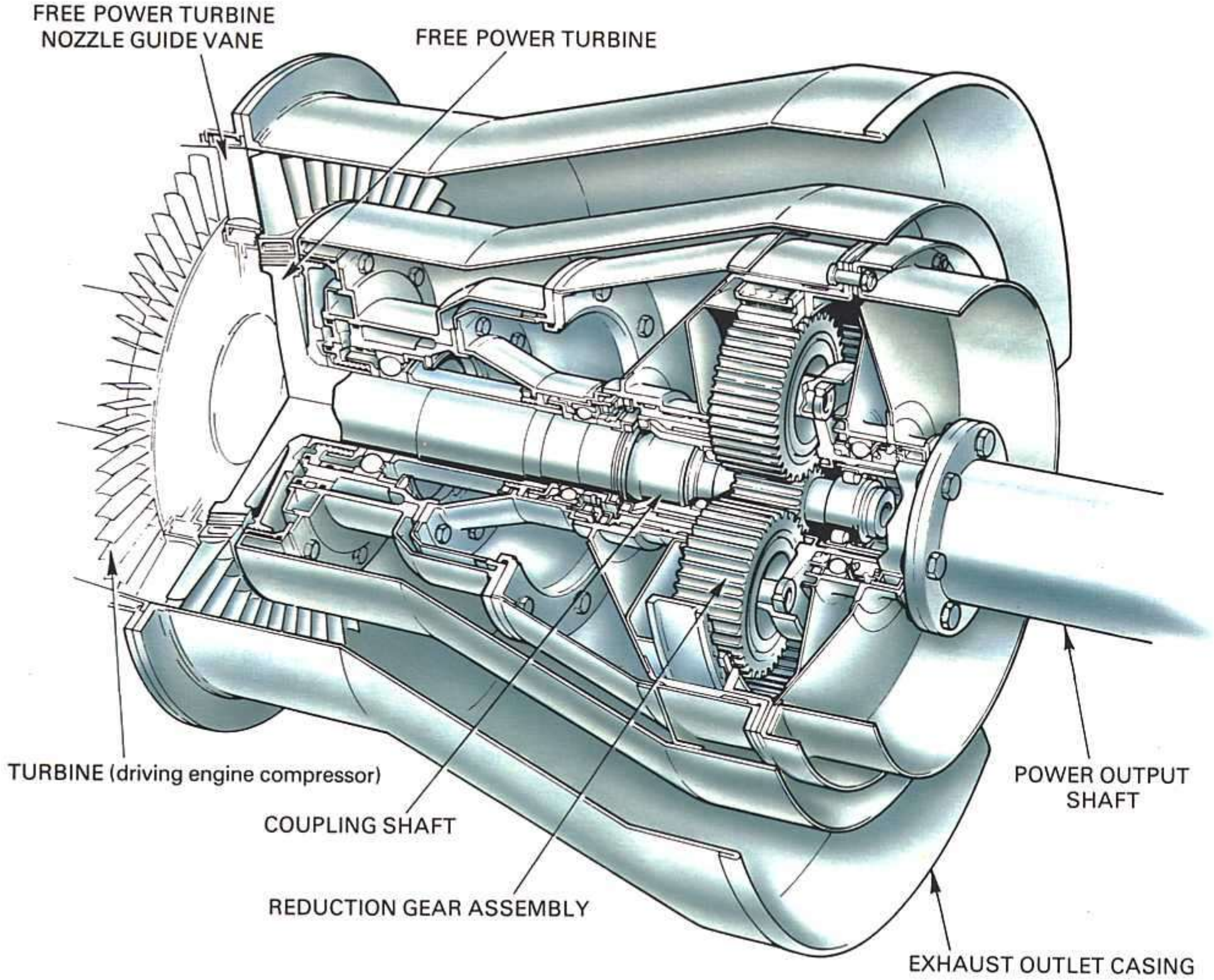


Fig. 5-4 A typical free power turbine.

basic aerofoil shape. There are three types of turbine; impulse, reaction and a combination of the two known as impulse-reaction. In the impulse type the total pressure drop across each stage occurs in the fixed nozzle guide vanes which, because of their convergent shape, increase the gas velocity whilst reducing the pressure. The gas is directed onto the turbine blades which experience an impulse force caused by the impact of the gas on the blades. In the reaction type the fixed nozzle guide vanes are designed to alter the gas flow direction without changing the pressure. The converging blade passages experience a reaction force resulting from the expansion and acceleration of the gas. Normally gas turbine engines do not use pure impulse or pure reaction turbine blades but the impulse-reaction combination (fig. 5-5). The proportion of each principle incorporated in the design of a turbine is largely dependent on the type of engine in which the turbine is to operate, but in general it is about 50 per cent impulse and 50 per cent reaction. Impulse-type turbines are used for cartridge and air starters (Part 11).

ENERGY TRANSFER FROM GAS FLOW TO TURBINE

6. From the description contained in para. 1, it will be seen that the turbine depends for its operation on the transfer of energy between the combustion

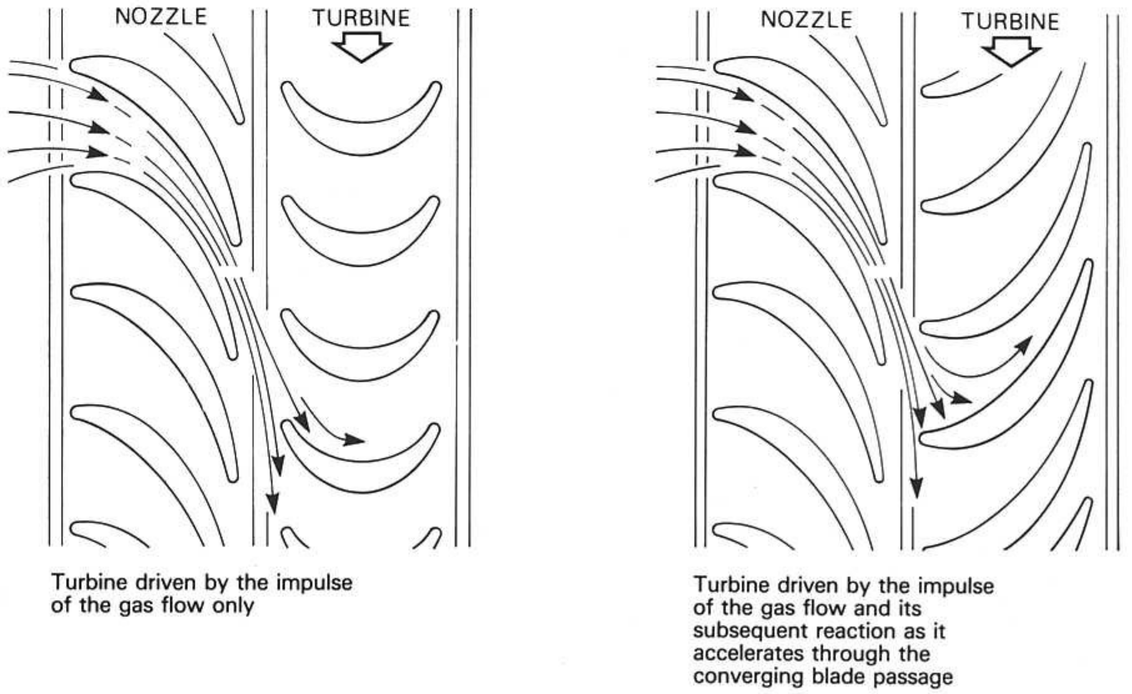


Fig. 5-5 Comparison between a pure Impulse turbine and an impulse/reaction turbine.

gases and the turbine. This transfer is never 100 per cent because of thermodynamic and mechanical losses, (para. 11).

7.when the gas is expanded by the combustion process (Part 4), it forces its way into the discharge nozzles of the turbine where, because of their convergent shape, it is accelerated to about the speed of sound which, at the gas temperature, is about 2,500 feet per second. At the same time the gas flow is given a 'spin' or 'whirl' in the direction of rotation of the turbine blades by the nozzle guide vanes. On impact with the blades and during the subsequent reaction through the blades, energy is absorbed, causing the turbine to rotate at high speed and so provide the power for driving the turbine shaft and compressor.

8. The torque or turning power applied to the turbine is governed by the rate of gas flow and the energy change of the gas between the inlet and the outlet of the turbine blades, The design of the turbine is such that the whirl will be removed from the gas stream so that the flow at exit from the turbine will be substantially 'straightened out' to give an axial flow into the exhaust system (Part 6). Excessive residual whirl reduces the efficiency of the exhaust system and also tends to produce jet pipe vibration which has a detrimental effect on the exhaust cone supports and struts.

9. It will be seen that the nozzle guide vanes and blades of the turbine are 'twisted', the blades having a stagger angle that is greater at the tip than at the root (fig. 5-6). The reason for the twist is to make the gas flow from the combustion system 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. This results in certain changes in velocity, pressure and temperature occurring through the turbine, as shown diagrammatically in fig. 5-7.

10. The 'degree of reaction' varies from root to tip, being least at the root and highest at the tip, with the mean section having the chosen value of about 50 per cent.

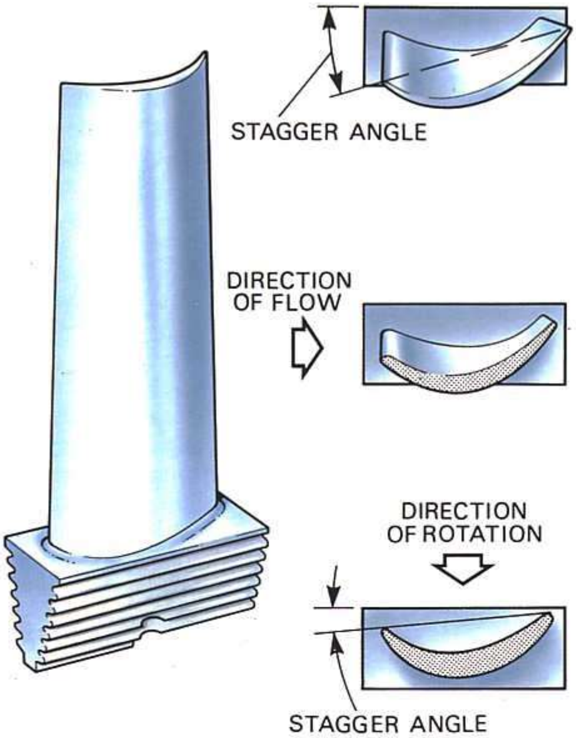


Fig. 5-6 **A typical turbine blade showing twisted contour.**

11. The losses which prevent the turbine from being 100 per cent efficient are due to a number of reasons. A typical uncooled three-stage turbine would suffer a 3.5 per cent loss because of aerodynamic losses in the turbine blades. A further 4.5 per cent loss would be incurred by aerodynamic losses in the nozzle guide vanes, gas leakage over the turbine blade tips and exhaust system losses; these losses are of approximately equal proportions. The total losses result in an overall efficiency of approximately 92 per cent.

CONSTRUCTION

12. The basic components of the turbine are the combustion discharge nozzles, the nozzle guide vanes, the turbine discs and the turbine blades. The rotating assembly is carried on bearings mounted in the turbine casing and the turbine shaft may be common to the compressor shaft or connected to it by a self-aligning coupling.

Nozzle guide vanes

13. The nozzle guide vanes are of an aerofoil shape with the passage between adjacent vanes forming a convergent duct. The vanes are located (fig. 5-8) in the turbine casing in a manner that allows for expansion.

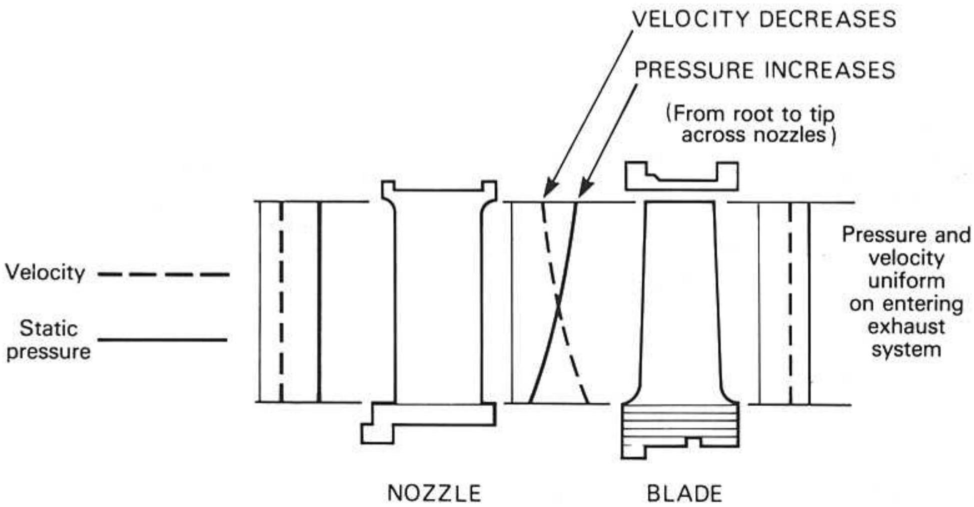
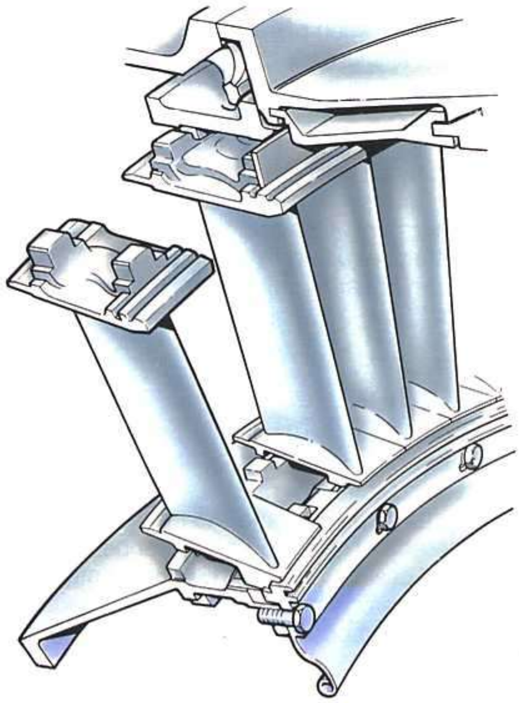


Fig. 5-7 **Gas flow pattern through nozzle and blade.**



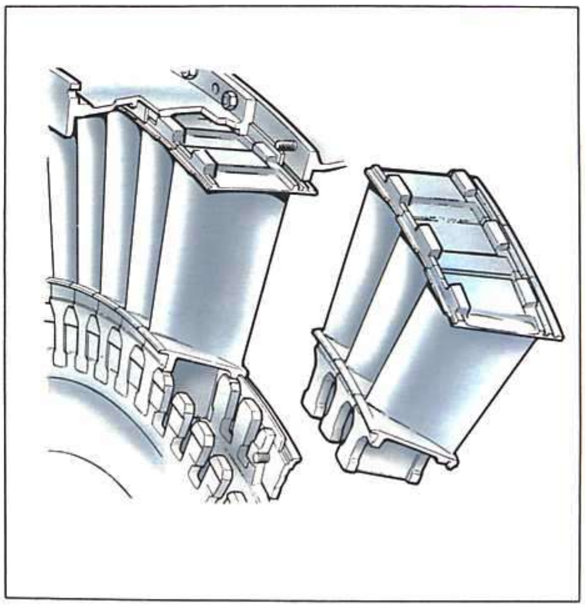


Fig. 5-8 Typical nozzle guide vanes showing their shape and location.

14. The nozzle guide vanes are usually of hollow form and may be cooled by passing compressor delivery air through them to reduce the effects of high thermal stresses and gas loads. For details of turbine cooling, reference should be made to Part 9.

15. Turbine discs are usually manufactured from a machined forging with an integral shaft or with a flange onto which the shaft may be bolted. The disc also has, around its perimeter, provision for the attachment of the turbine blades.

16. To limit the effect of heat conduction from the turbine blades to the disc a flow of cooling air is passed across both sides of each disc (Part 9).

Turbine blades

17. The turbine blades are of an aerofoil shape, designed to provide passages between adjacent blades that give a steady acceleration of the flow up to the 'throat', where the area is smallest and the velocity reaches that required at exit to produce the required degree of reaction (para. 5).

18. The actual area of each blade cross-section is fixed by the permitted stress in the material used and by the size of any holes which may be required for cooling purposes (Part 9). High efficiency demands thin trailing edges to the sections, but a compromise has to be made so as to prevent the blades cracking due to the temperature changes during engine operation.

19. The method of attaching the blades to the turbine disc is of considerable importance, since the stress in the disc around the fixing or in the blade root has an important bearing on the limiting rim speed. The blades on the early Whittle engine were attached by the de Laval bulb root fixing, but this design was soon superseded by the 'fir-tree' fixing that is now used in the majority of gas turbine engines. This type of fixing involves very accurate machining to ensure that the loading is shared by all

the serrations. The blade is free in the serrations when the turbine is stationary and is stiffened in the root by centrifugal loading when the turbine is rotating. Various methods of blade attachment are shown in fig. 5-9; however, the B.M.W. hollow blade and the de Laval bulb root types are not now generally used on gas turbine engines.

20. A gap exists between the blade tips and casing, which varies in size due to the different rates of expansion and contraction. To reduce the loss of efficiency through gas leakage across the blade tips, a shroud is often fitted as shown in fig. 5-1. This is made up by a small segment at the tip of each blade which forms a peripheral ring around the blade tips. An abradable lining in the casing may also be used to reduce gas leakage as discussed in Part 9. Active Clearance Control (A.C.C.) is a more effective method of maintaining minimum tip clearance throughout the flight cycle. Air from the compressor is used to cool the turbine casing and when used with shroudless turbine blades, enables higher temperatures and speeds to be used.

Contra-rotating turbine

21. Fig. 5-10 shows a twelve stage contra-rotating free power turbine driving a contra-rotating rear fan. This design has only one row of static nozzle guide vanes. The remaining nozzle guide vanes are, in effect, turbine blades attached to a rotating casing which revolves in the opposite direction to a rotating drum. Since all but one aerofoil row extracts energy from the gas stream, contra-rotating turbines are capable of operating at much higher stage loadings than conventional turbines, making them attractive for direct drive applications.

Dual alloy discs

22. Very high stresses are imposed on the blade root fixing of high work rate turbines, which make conventional methods of blade attachment impractical. A dual alloy disc, or 'blisk' as shown in fig. 5-11, has a ring of cast turbine blades bonded to the disc. This type of turbine is suitable for small high power helicopter engines.

COMPRESSOR-TURBINE MATCHING

23. The flow characteristics of the turbine must be very carefully matched with those of the compressor to obtain the maximum efficiency and performance of the engine. If, for example, the nozzle guide vanes allowed too low a maximum flow, then a back pressure would build up causing the compressor to surge (Part 3); too high a flow would cause the compressor to choke. In either condition a loss of efficiency would very rapidly occur.

MATERIALS

24. 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 turbine blades, The high speed of rotation which imparts tensile stress to the turbine disc and blades is also a limiting factor.

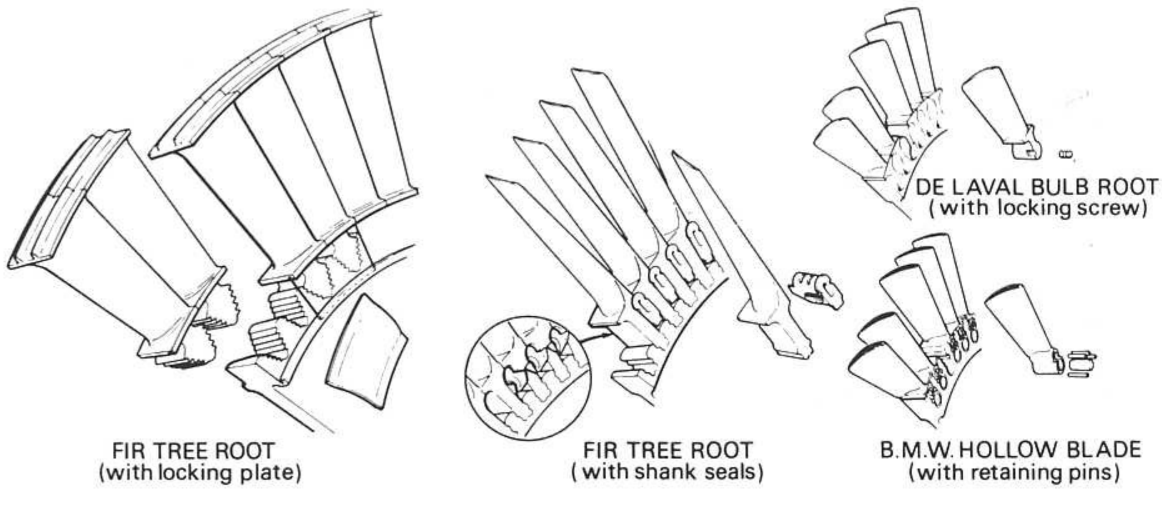


Fig. 5-9 Various methods of attaching blades to turbine discs.

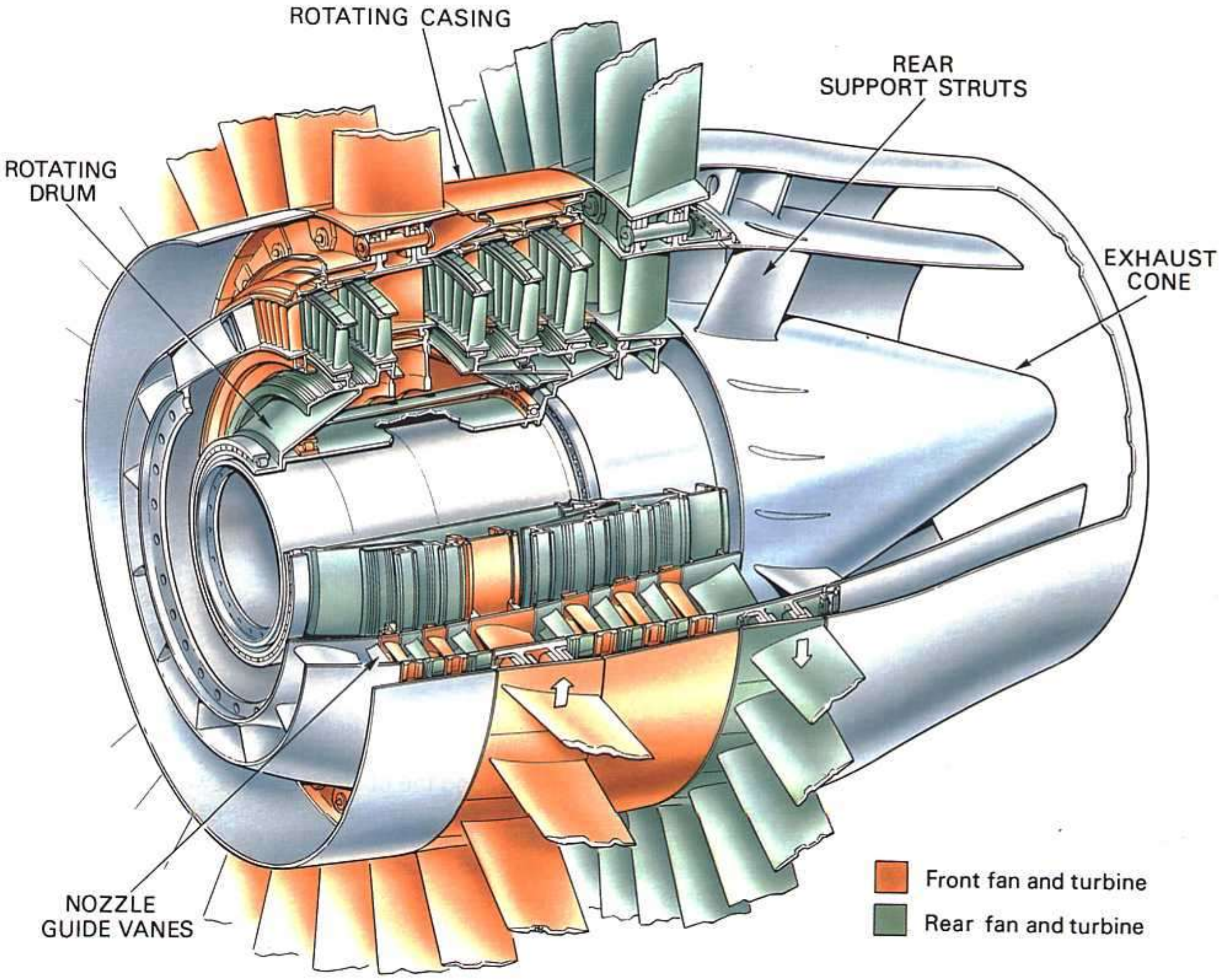


Fig. 5-10 Free power contra-rotating turbine.

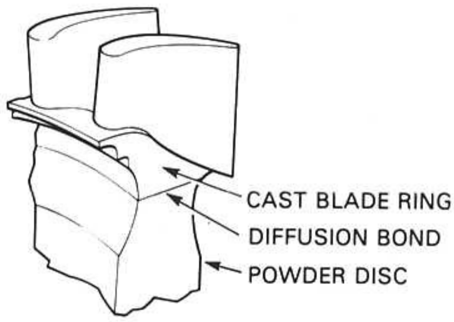


Fig. 5-11 Section through a dual alloy disc.

Nozzle guide vanes

25. Due to their static condition. the nozzle guide vanes do not endure the same rotational stresses as the turbine blades. Therefore, heat resistance is the property most required. Nickel alloys are used, although cooling is required to prevent melting. Ceramic coatings can enhance the heat resisting properties and, for the same set of conditions, reduce the amount of cooling air required, thus improving engine efficiency.

Turbine discs

26. 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.

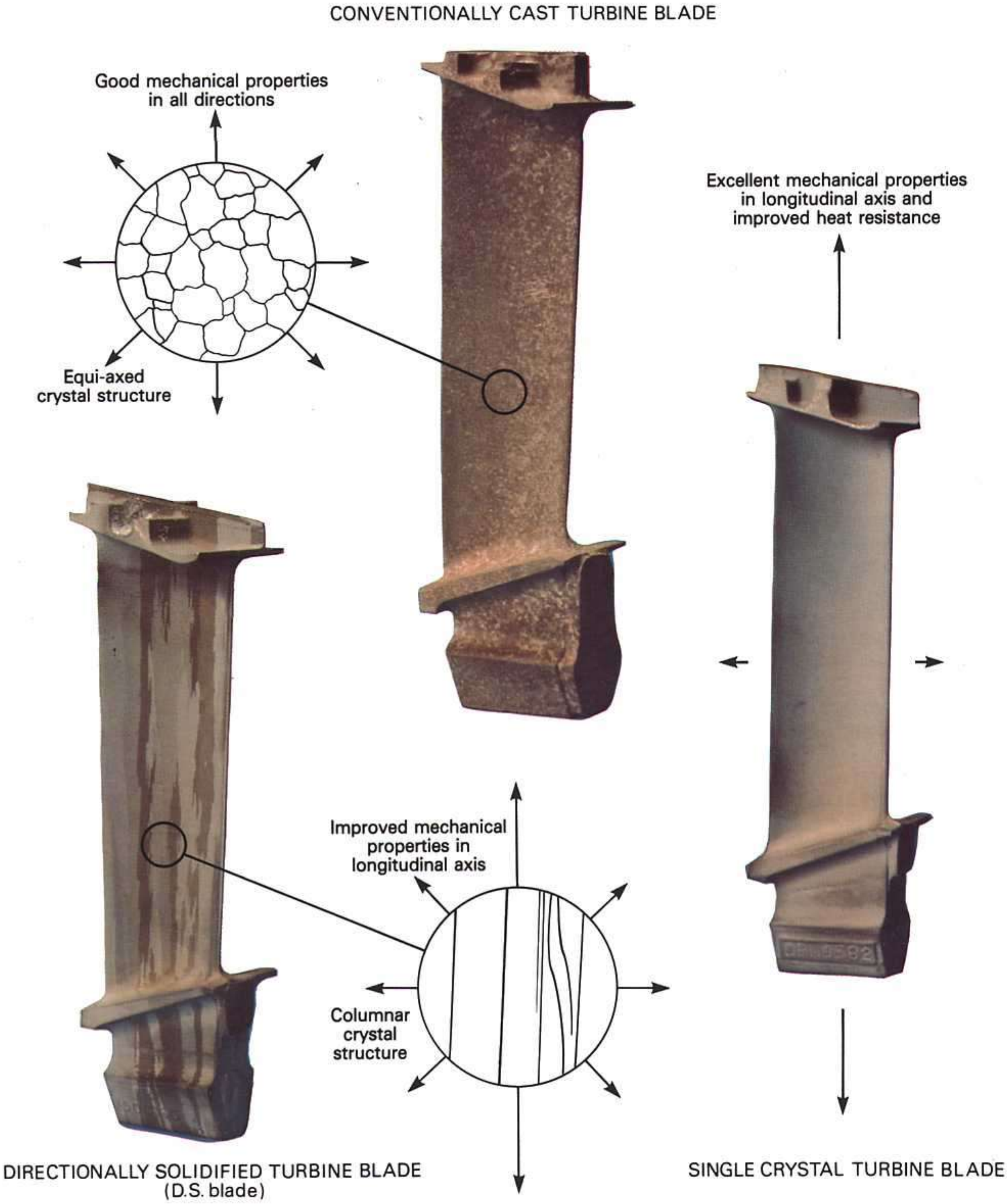


Fig. 5-11 Section through a dual alloy disc.

27. In the past, turbine discs have been made in 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

28. 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.

29. 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 met-allurgists and designers are constantly searching for better turbine blade materials and improved methods of blade cooling.

30. 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.

31. 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.

32. 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

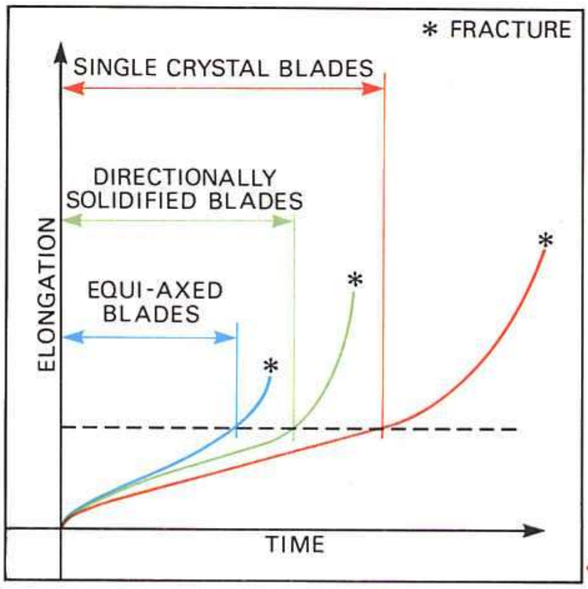


Fig. 5-13 Comparison of turbine blade life properties.

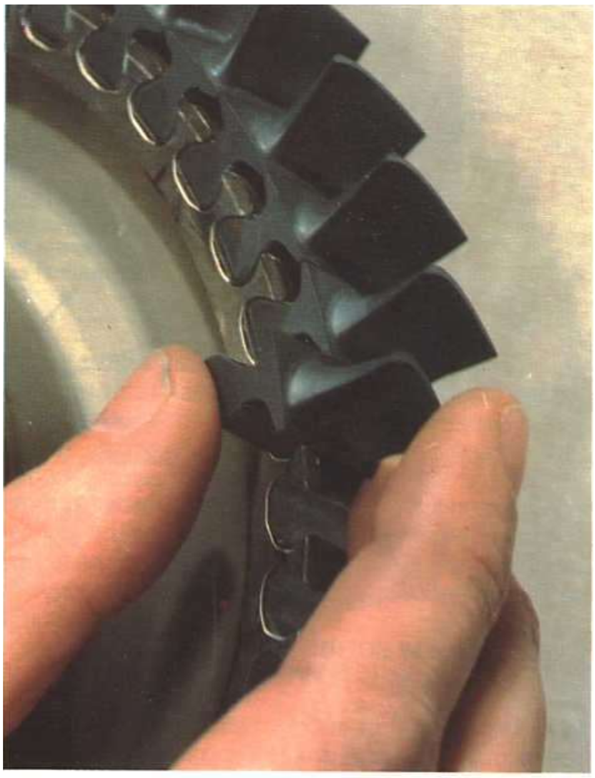


Fig. 5-14 Ceramic turbine blades.

crystal, Examples of these structures are shown in fig. 5-12. Each method extends the useful creep life of the blade (fig. 5-13) and in the case of the single crystal blade, the operating temperature can be substantially increased.

33. A non-metal based turbine blade can be manufactured from reinforced ceramics. Their initial production application is likely to be for small high speed turbines which have very high turbine entry temperatures. An example of a ceramic blade is shown in fig. 5-14.

BALANCING

34. The balancing of a turbine is an extremely important operation in its assembly. In view of the high rotational speeds and the mass of materials, any unbalance could seriously affect the rotating assembly bearings and engine operation. Balancing is effected on a special balancing machine, the principles of which are briefly described in Part 25.