DOCUMENT

GSM-AUS-ATP.018

DOCUMENT TITLE

GAS TURBINE ENGINES (CASA ATPL)

CHAPTER 4 – ENGINE CONSTRUCTION PART 2

Version 2.0

June 2014

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TURBINE PRINCIPLES

The turbine section of a jet engine follows the combustion stage. The function of the turbine is to provide the mechanical energy necessary to turn the compressor stages, and any accessory drives. Rotation of the turbine stages is effected by the transfer of energy from the very hot combustion gases to the turbine blades. This is achieved by the process of adiabatic expansion, the turbine causing the combustion gases to expand and so reduce in temperature and pressure. In turbojet engines, including by-pass engines, only the energy required by the turbine stages is removed from the gases, leaving sufficient energy to produce the thrust required for propulsion. In turbo-propeller engines, where little propulsive energy is required at the exhaust jet pipe, more of the heat from the gases is converted into mechanical motion by the turbine, which by means of a shaft and suitable gearing, drives the propeller. Refer to Figure 4-1.

On most types of engine design the mechanical rotation of the turbine is achieved by similar means. After leaving the combustion stage, the gases are directed into a group of stationary nozzle guide vanes (NGVs). These are arranged to form convergent passages, and their function is twofold:-

- They accelerate the gases to extremely high speeds of up to 2,500 feet per second. This speed is just below a supersonic value to prevent generation of shock waves.
- They are constructed in such a way to be able to efficiently direct the accelerated gas onto the revolving turbine.

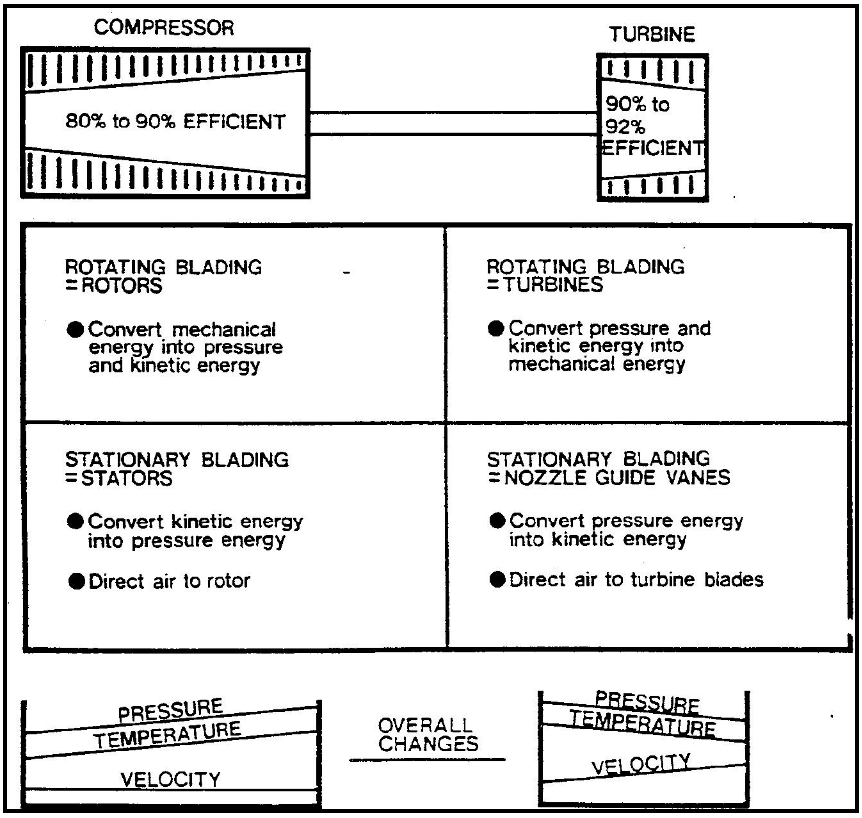

Figure 4-1 Turbine Vs Compressor Performance

The turbine may be likened to a compressor in reverse, with a series of aerofoil shaped blades attached to a turbine disc. The blades are arranged, as with the NGVs, to form convergent passages, in order to further accelerate the incoming combustion gases. Each blade is progressively twisted from root to tip so that the combustion gases deliver an equal force along the blade. This twisting also assists in controlling the degree of swirling in the air delivered to the exhaust nozzle, giving that air a suitable axial flow characteristic. The leading edge of each blade has a rounded profile allowing it to operate efficiently through a wide range of incidence angles. The air gap between the turbine blade tips and the turbine casing must be sufficiently large to be able to cater for the expansion and contraction of the turbine during normal operation. The gap varies in size depending on the operational temperatures.

BLADE DESIGN

There are basically two principles compelling a turbine to rotate, and the construction of the turbine determines whether it makes use of one of these principles, or both. As stated above, the combustion gases are directed by the NGVs onto the turbine blades.

Three design principles are used in the turbine to convert kinetic energy into rotation energy. They are;

- Impulse type, which can be likened to the water wheel effect,.
- Reaction type, which rotate as a reaction to the lift they produce, and
- A combination of the two, called impulse/reaction. Refer to Figure 4-3.

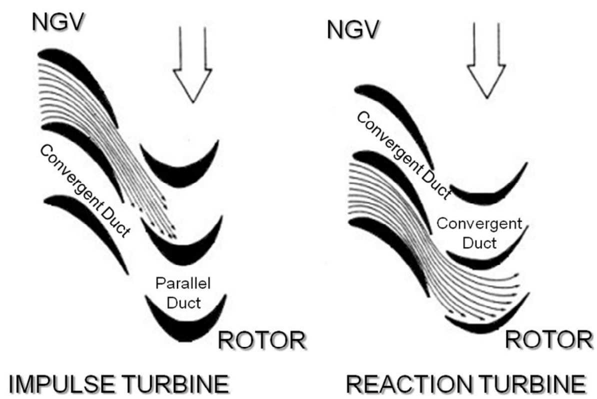

Figure 4-2 Impulse and Reaction Design

Impulse Turbine A pure impulse turbine is designed to take full advantage of the high gas velocity from the convergent NGVs. The impulse force caused by the impact of the gas on the blades drives the turbine and the passageways between the blades are parallel. Refer to Figure 4-2.

Reaction Turbine *In the case of a pure reaction turbine, the NGV's are convergent ducts*. They alter the direction and accelerate the gas flow. *The passageways between the blades of a reaction turbine are also convergent to further accelerate the air.* The reaction to this acceleration is felt and drives the turbine. Refer to Figure 4-2.

Impulse/Reaction Turbine Either the gases impinging on the blade or accelerating between the blades produces torque. Whilst it is possible to have a completely impulsive turbine (e.g. air starter motors), no blades are completely reaction based. Some degree of impulsive force always exists. Therefore, modern turbine engines normally use a combination blade that is both impulse and reaction. Refer to Figure 4-3.

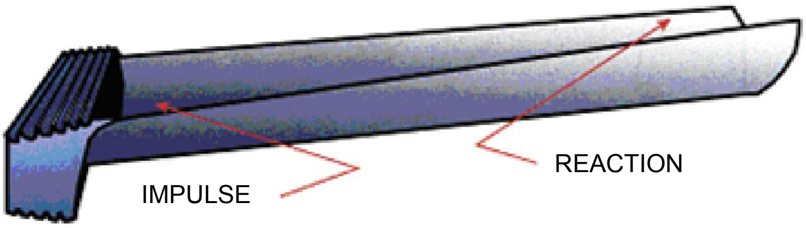

Figure 4-3 Combination Impulse and Reaction Design

As the gas flows through the turbine section, its pressure and velocity decrease due to the work it does in rotating the turbine discs. In addition, this increases the need for each subsequent turbine disc to have longer blades to obtain the maximum usable energy. The gas having passed from the back of one turbine receives a swirl that is trued up by the following NGV prior to its entry to the next turbine. In the case of impulse reaction turbines, the NGV forms convergent ducts toward the centre and parallel ducts toward the outside. A cross section from the turbine disc to the housing forms a divergent gas flow annulus, to account for expansion.

Modern turbofan engines direct cooling air from the fan over the outer turbine casing to lessen the degree of expansion and contraction of the turbine, and consequently allow higher operating temperatures. This is known as Active Clearance Control. This will be covered in more detail in Chapter 8, Performance.

Turbine Blade Shrouding

To prevent excessive leakage of gas at the blade tips, most turbines incorporate a shroud which effectively joins the tips together. The shroud prevents gas leakage at the blade tips and increases turbine rigidity. The shroud also reduces vibration levels. Refer to Figure 4-4.

It is evident that the turbine section is most susceptible to component stress due to the nature of its function and operation. As stated in the previous section, the gas flow is significantly cooled in the later combustion chamber stages, but the turbine entry temperature remains high at up to 1400°C. The large changes in temperature, up to 200°C over single turbine stages, may cause thermal shock, leading to erosion and eventual blade failure. The blades are further stressed by the centrifugal forces caused by the high rotational velocity of the turbine, and also by the high speed at which the combustion gases are delivered to the turbine.

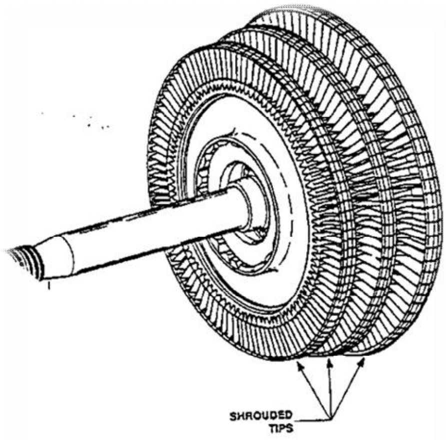

Figure 4-4 Shrouded Turbine Blades

Blade Attachment

The most common method of blade attachment to the turbine disc is the Fir Tree Root attachment. This provides for a secure method because of the large connecting surface areas. Turbine blades can be subjected to forces of over 18 tons/sq inch. Refer to Figure 4-5.

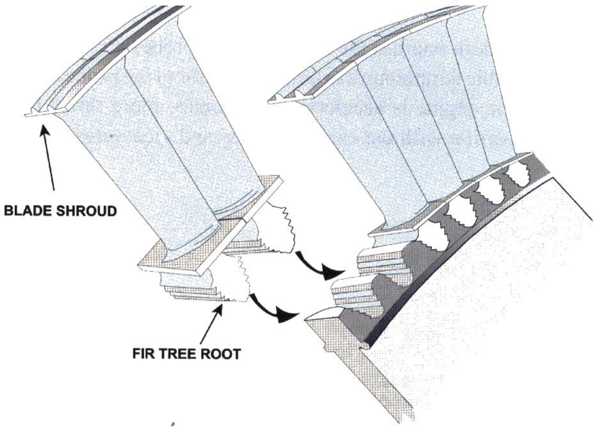

Figure 4-5 Fir Tree Root Attachment

THERMAL SHOCK

Engine starting is a very crucial time for the gas turbine engine. A sudden increase in temperature, or thermal shock, can result in a dramatic reduction in turbine life.

During start-up, a rich fuel mixture is scheduled to reduce the time to reach idle RPM. On reaching idle, the fuel control re-schedules the correct mixture.

During the acceleration to idle, the exhaust gas temperature must be carefully monitored to ensure that the maximum temperature limitation is not exceeded. If the engine maximum start temperature is exceeded, the engine should be shut-down and no further attempt made to restart the engine until a thorough maintenance inspection is carried out. Refer to start malfunctions in Chapter 7.

Some engines have a tolerance of approximately 20°C below the maximum start temperature, where the start should be discontinued, and, if it can be determined that the fuel control was not at fault, or the blade angle was not at minimum on a turbo propeller aircraft, then a second start may be attempted.

Thermal shock can also occur with the engine running. Rapid movement of the thrust lever will cause rapid changes in temperature.

Before an engine is stopped, it should normally be allowed to run for a short period at idling speed to ensure gradual cooling of the turbine assembly

The only action required to stop the engine is to close the high pressure fuel shut-off valve. The shut-off valve should never be re-opened during engine run-down, as the resulting supply of fuel can spontaneously ignite with consequent severe overheating of the turbine assembly.

Blade Creep

Over a number of operational cycles, the revolving turbine blades actually increase in length, this is referred to as blade creep. Careful inspection procedures must be rigorously maintained to ensure that the amount of blade creep does not exceed an acceptable value.

There are three stages of creep, Primary, Secondary and Tertiary. At the Tertiary Creep stage consideration would be given to replacing the turbine assembly. Refer to Figure 4-6.

It is essential that the pilot appreciates that any increase in operating temperature above the recommended maximum temperature will accelerate the effect of blade creep, resulting in shortened overhaul life and increasing the possibility of early failure.

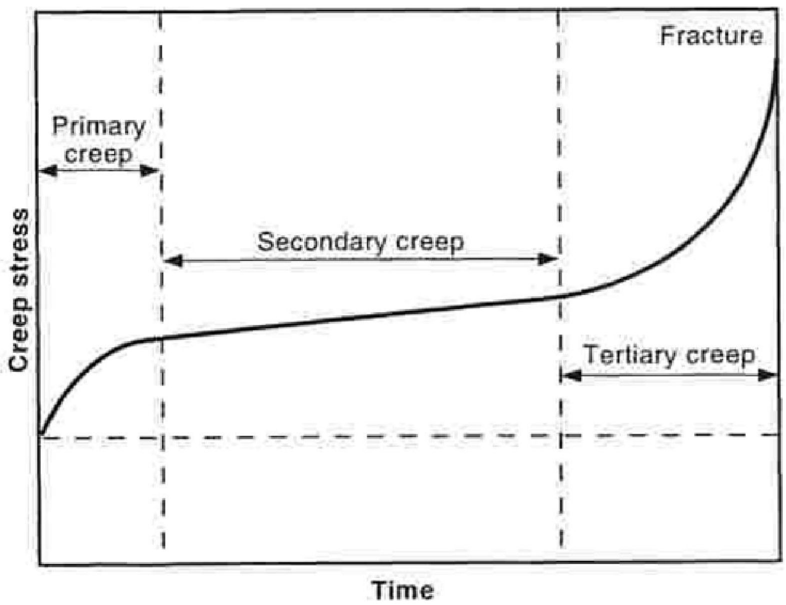

Figure 4-6 Turbine Creep Stages

TYPES OF TURBINES

Different types and applications of gas turbine engines will require different value drive torques to be produced by their turbine section. The simplest way of increasing the drive torque is to increase the number of individual turbine stages. An individual stage consists of a stationary row of NGVs and a rotating row of turbine blades. In its simplest form, a jet engine would have a single stage turbine, driving a single stage compressor, by means of a shaft. A development of this engine would use a low pressure and high pressure compressor to produce a higher compression ratio, driven by separate turbine spools through different shafts. Refer to Figure 4-7.

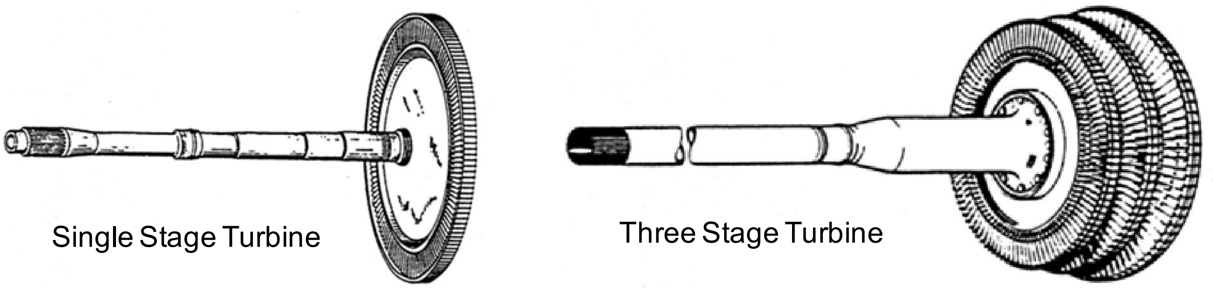

Figure 4-7 Turbine Configurations

A high by-pass ratio engine is likely to have three compressor spools driven through independent shafts, by three turbine spools. As an example, a three spool turbine arrangement, such as that used in a modern high by-pass ratio engine (Rolls Royce RB211) is shown in the following diagram, Figure 4-8.

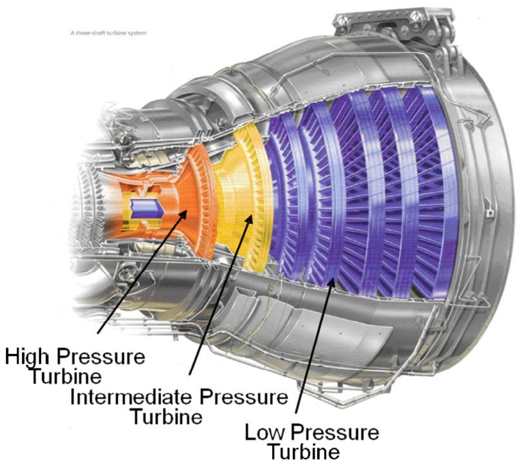

Figure 4-8 Three Spool Turbine

Free Turbine.

In certain turbo-propeller and helicopter engines, a free turbine system is used. In these engines a dedicated turbine spool is fitted after the rear main turbine. This free turbine is not connected to the other turbine spools, but drives a shaft connected to a gearbox, which in turn drives a variable pitch propeller or rotor blade assembly. Refer to Figure 4-9.

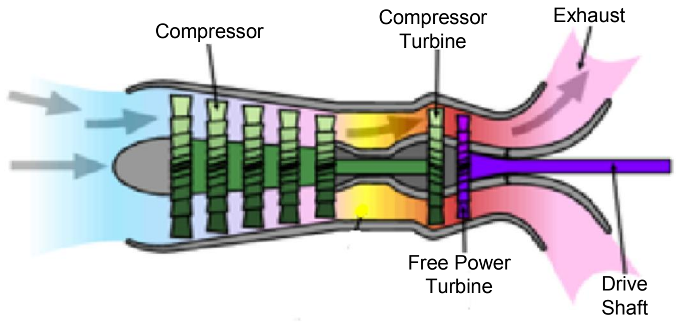

Figure 4-9 Free Turbine Engine

EXHAUST SYSTEMS

The function of the exhaust system is to convert the gases from the turbine section into the propulsive element of thrust. This is achieved by accelerating the gases and then efficiently directing them into the atmosphere.

In a turbojet engine the exhaust unit is made up from three sections; Refer to Figure 4-10.

- The Exhaust Cone,
- The Jet Pipe, and
- The Propelling Nozzle.

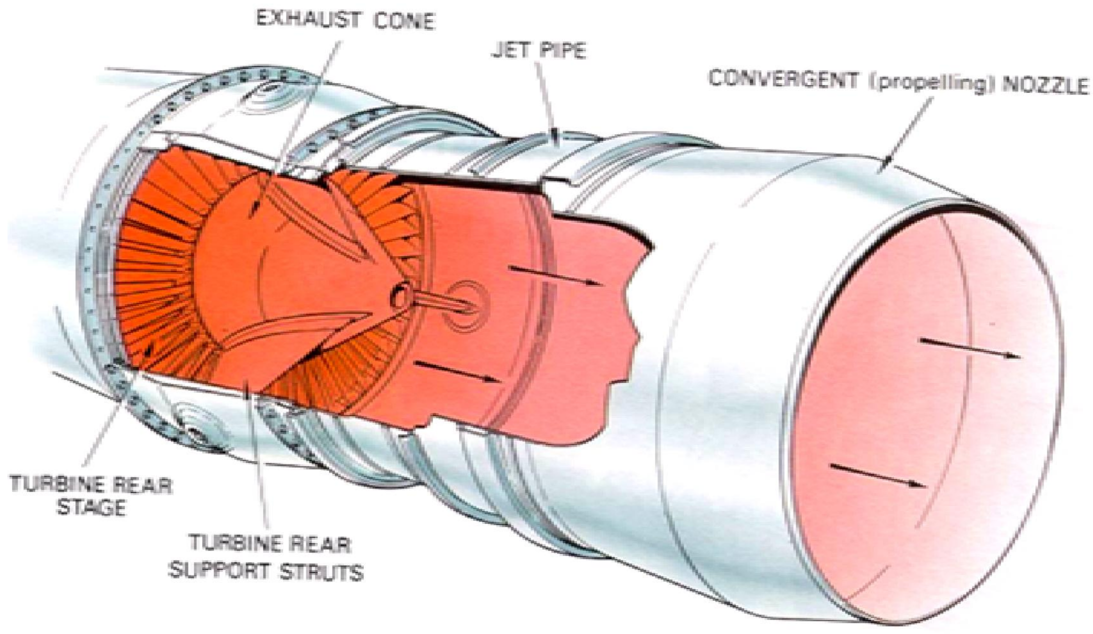

Figure 4-10 Turbojet (with Jet Pipe) Exhaust System

The Exhaust Cone and the outer casing combine to form a divergent passage for the gas flow to follow, after exiting from the final turbine stage. The reason for this divergence is so that the velocity of the gas can be kept as low as is practicable, to prevent excessive losses caused by friction. The turbine rear support struts which are used also to locate the exhaust cone are constructed and fitted in order to minimise swirling and restore an axial flow to the gas after passing through the turbine. Refer to Figure 4-11. The exhaust cone has a further purpose which is to protect the rear face of the last turbine stage from over-heating. On entering the exhaust system, the gas temperature will be between 550°C and 850°C, with speed between 800 and 1,200 feet per second. Refer to Figure 4-12.

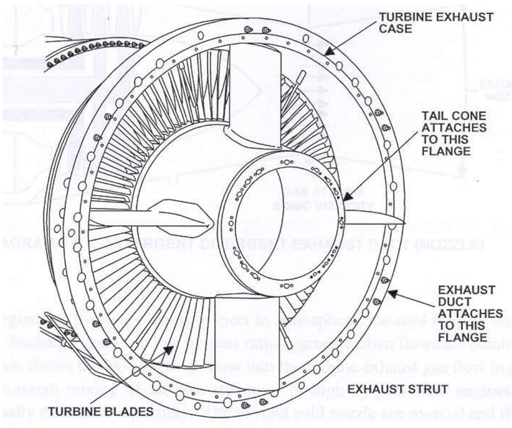

Figure 4-11 Exhaust Unit Struts

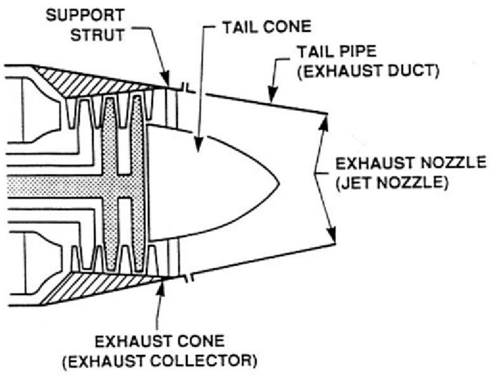

Figure 4-12 Turbojet Exhaust System

The Jet Pipe connects the exhaust cone section to the propelling nozzle, and is normally of equal diameter throughout. The length of the jet pipe is a function of aircraft design.

The hot gases from the engine must not be propelled onto any part of the aircraft structure. The longer the jet pipe is, the greater the possible loss of thrust due to friction and radiation. Because of the large amount of heat radiated to the jet pipe casing, it must be insulated in order to protect the aircraft structure. This is achieved by wrapping an insulating blanket, constructed from asbestos contained within dimpled stainless steel sheeting, around the jet pipe. Cooling air is directed onto the insulating blanket to assist in heat dissipation. The temperature within the exhaust section is displayed by the exhaust gas temperature gauge (EGT). Depending on engine design, thermo-couples may be fitted either in the outer casing of the exhaust cone, or in the jet pipe casing.

The Propelling Nozzle, a convergent duct provides the final acceleration of the exhaust gasses. On a turbofan engine the nozzle is a fixed opening and accelerates the core gases to just below the speed of sound. At this velocity the nozzle is said to be choked.

The term 'choked' implies that no further increase in velocity can be obtained unless the gas temperature is increased, for instance with the assistance of reheat.

Variable propelling nozzles are used on afterburning engines to accommodate the extra thrust available. Refer to figure 4-13.

The highest gas velocity in a gas turbine engine is found at the exit of the propelling nozzle.

Figure 4-13 Variable Propelling Nozzle,(fully open)

SILENCING

The jet engine has three principle sources of noise. The largest single source from turbo-jet and low bypass ratio engines is the contact of the high-speed exhaust gas flow with the relatively low speed atmosphere. The other two sources are the compressor and turbine sections. Engine designs now incorporate acoustically absorbent linings, which are very effective in reducing the noise produced in these areas. Refer to Figure 4-14

Special noise suppression components are fitted to partially remove the problem, by improving the manner in which the exhaust gases mix with the atmosphere.

In turbojet and low by-pass ratio engines, lobe or corrugated nozzles are fitted, which produce a number of individual jets of exhaust efflux streams whilst maintaining the same overall nozzle area. The smaller streams serve to increase the frequency of the sound. The higher frequency sound attenuates (reduces) more rapidly as distance from its source is increased. Refer to Figure 4-15.

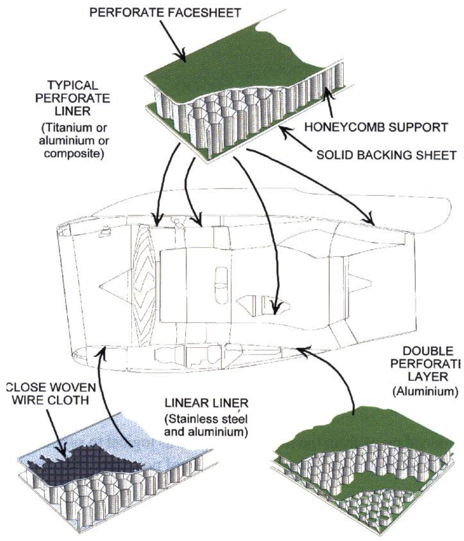

Figure 4-14 Acoustic Linings

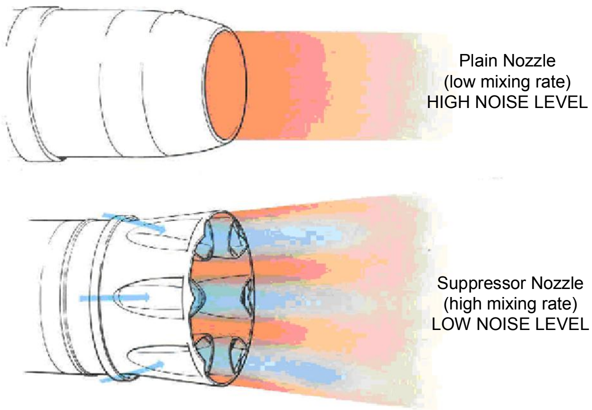

Figure 4-15 Silencing Nozzles

High by-pass turbofans continue to mix cold by-pass air with the core gasses to reduce their noise levels. They can either use internal or external mixing of the gasses, as detailed on Figure 4-16.

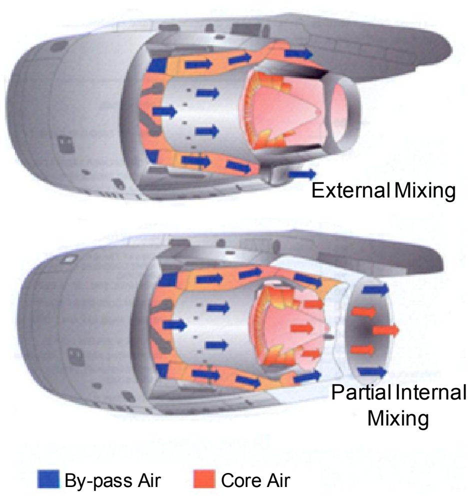

Figure 4-16 Internal and External Exhaust Mixing

Rolls Royce have added Chevrons and Tabs to the new RR Trent fitted to the new Boeing 787 Dreamliner. The chevrons are incorporated into the by-pass duct and the tabs form part of the exhaust nozzle. They reduce the noise level by 2.5 db. Refer to Figure 5-17.

Figure 4-17 B787 Dreamliner, Silencing using Chevrons and Tabs

Hush Kits are devices used to reduce noise emissions from low-bypass turbofan engines (JT8D), as fitted to older commercial aircraft. These devices generally mix cold (by-pass) air with the hot core gasses. Like modern high by-pass turbofans, this mixing attenuates the noise generated by the engine. Refer to Figure 4-18.

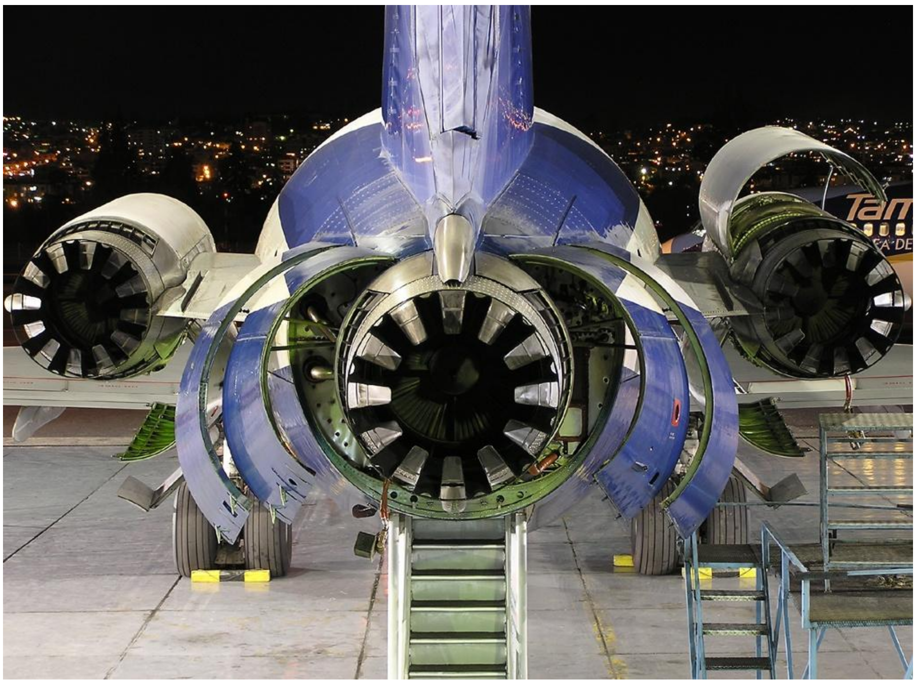

Figure 4-18 Hush Kits fitted to B727 with JT8D Engines

DANGER AREAS

With the development of larger and higher thrust turbofan engines, the danger areas around these engines have become increasingly more hazardous. Items such as dirt, stones nuts bolts, clothing and even the wearer of the clothing can all be ingested from amazing distances in front, to the sides and even from partly behind the inlet.

The damage caused by this material is called foreign object damage (FOD)

As can be seen in Figure 4-19, the intake and exhaust danger areas, at high power, extend a large distance forward and aft of a turbofan engine.

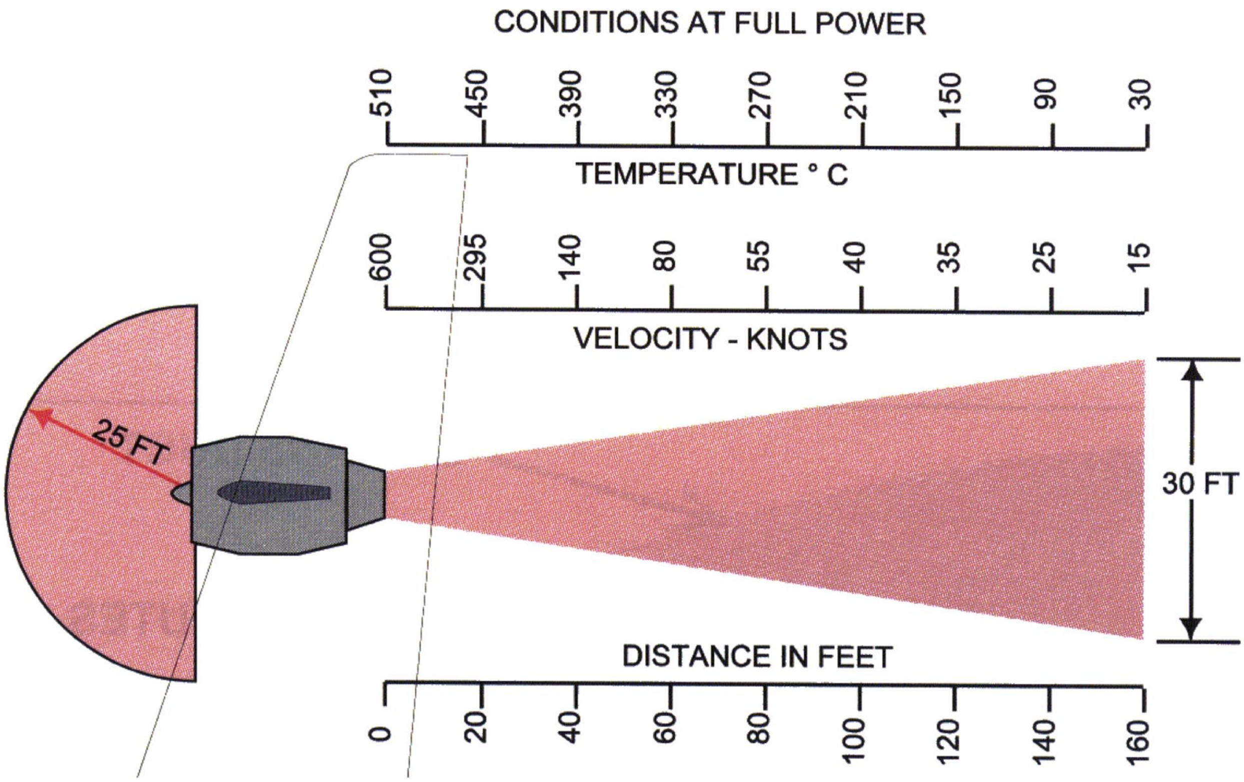

Figure 4-19 Inlet and Exhaust Danger Areas