High bypass ratio turbofan

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INTRODUCTION

Turbofan engines are basically turbojet engines which are provided with a large fan. These were developed to combine some of the best features of both turbojet and turboprop engines. The major advantage of turbofan engines are that it provides a better fuel efficiency. Most of the airliners today use turbofan engines. (Aviation History online museum c. 2008)

Bypass ratio: It is defined as the mass flow rate of air bypassing the combustion chamber to the mass flow rate of air passing through the core of the engine.

Figure I: Schematic diagram of Low and High Bypass Turbo fan (Yoon J. 2001)

Turbo fan engines may be sub-categorized based on the bypass ratio as:-

Low-bypass ratio turbofan

A small amount of air bypasses the combustion chamber, through the fan ducts and the fan is of very small diameter. These are compact in nature.

High-bypass ratio turbofan

The fan in a high-bypass turbofan is much larger to force a large volume of air through the ducts. These can generate more thrust, are better in fuel efficiency and are less noisy than the other engines. (Yoon J. 2001)

The three major companies to introduce turbofan engines were General Electric, Rolls Royce and Pratt & Whitney. All of these companies introduced there version of turbofan engine one after the other. The first high bypass turbofan engine was developed by general electric the GE-T39 in 1964; this was developed in response to the desire of the United States Air Force. (General Electric Co. 2008)

Figure III: Pratt & Whitney Turbofan engine (Serra 2008)

Currently the turbofan engine market is dominated by General Electric, Rolls-Royce plc and Pratt & Whitney. GE Aircraft Engines, a part of General Electric, has the largest share of turbofan engine market. (Opentia n. d.)

The major disadvantages of these engines is its complexity to manufacture as it contains a multiple shaft system, the large diameter of the engine and a requirement to contain such heavy front fan blades which make it a bulky machine. (WordIQ n. d.)

FUNCTIONS OF THE FRONT FAN

The front fan or the inlet cowl plays a multi-functional role in the running of a turbofan engine. These are comparatively larger in size than the other parts of the engine. This variation in size facilitates in the creation of a bypass air flow. The bypass air flow is defined as the air entering the engine but not flowing through the compression stages, it flows out of the engine as a bypass to the engine core. This bypass air flow is designed to develop an additional thrust as it passes from the outer surface of the engine core. This bypass air not only generates the additional thrust but helps in lowering the surface temperature of various parts in the engine as it acts as coolant acting on the external surface engine body. It also helps in reducing the noise created by the engine as it suppresses the exhaust noise.

Apart from the above functions, the fan blades play a major role in reducing the speed of the air entering the engine. For better fuel efficiency, the air entering the combustion chamber must be highly compressed (Compression ratio around 15). For this the air must pass through the compression stages at sub sonic speeds. The front fan blades act as an obstruction to the incoming air and reduce its speed. Also, the curvature provided on each fan blade direct the air evenly across the inlet of the engine, increasing efficiency. The air is guided in a manner to provide a radial inlet to the compressor. (Benson Jul 29 2008)

IN SERVICE CONDITIONS

The front fan blades are subjected to various conditions which they should be able to sustain in order for proper functioning of the engine. The may be classified as:-

Temperature: The fan blades are subjected to a temperature range of ± 60oC. The blade material should remain stable in this range of temperature.

Figure III: Turbofan engine temperature and pressure distribution by NASA

Pressure: The pressure range for fan blades can be classified between 0. 192atm (@40, 000ft) to 1atm (@sea level).

Stresses: The maximum stress concentration can be observed at the root of the blade. Maximum tensile stresses and laminar shear stress occur at the root of the blade. Maximum tensile stress concentrations, under steady state conditions, are concentrated about the undercut radius on either side of the shear slot key. This is due to the centrifugal loads incurred while the blades are rotating.

Icing: Ice may accumulate on the fan blades and on the fan rotor when flying under high humidity and temperature around freezing point. The ice on the surface of the fan blades disturbs the airflow and generates vortices. These vortices can lead to an unstable compressor operation. They facilitate stall and surge. This ice also induces an imbalance which leads to vibrations. Detached ice pieces from this can even create a risk for foreign object damage when they hit the fan rotor and components behind the fan. (Diesinger 2008: 179)

OPERATIONAL REQUIREMENTS

The various operational requirements of the material for the front fan blades of a turbofan engines can be summarized as a material with:-

Fatigue Resistance

Front fan blades undergo cyclic fatigue loads. It has been observed that the fatigue failure has often been a reason for initiation of fatigue crack on the blade surface.

Fatigue failure (No. of cycles) âË† 1/ Level of Stress

Corrosion Resistant

In rainy or overcast conditions, the fan blades must be corrosion resistant to avoid rusting on the blades. The rusting can cause abrasions on its surface which may result as an obstruction in the motion of flowing air.

Light in Weight

As discussed earlier, the turbofans are one of the heaviest turbine engines and the front fan blades add quite a lot to the weight of the engine due to its size. Hence, it is desirable to have a material which is effectively light in weight.

Vibrations

The material should be able to withstand vibrations produced in the engine due to the high speed incoming air. High frequency vibrations can cause de-stabilization to the aircraft.

Blades

The front fan blades must undergo super plastic forming at the tip to retain a blade angle. The blades are provided with a double circular arc blade profile for subsonic compression of the incoming air. After casting the blades should

undergo annealing at recrystallization temperature for the removal of residual stresses that may have induced during the forming process. (Babu 2009: 110-111)

Blades should have sharp edges to be able to crush any particle that comes in way of its operation. This is to avoid any foreign body from entering the turbine and damaging the engine.

High stiffness

The blade material should have a high stiffness so as to avoid any deformation on its surface in case an object strikes it while in operation.

Resistance to cracks

The materials of the blades should be resistant to cracks as even on crack initiation the material should resist the developing of the crack. In case if the material is not crack resistant then it might result in quick developing of crack resulting into failure of the fan blades, which can lead to further engine trouble.

MATERIAL CHARACTERISTICS

Various material characteristics that need to be considered while selecting the material for the front fan blades of a turbofan engine are:-

High tensile strength and fatigue strength.

Low density.

Resistance to corrosion.

Sustain temperature range ±60 oC.

High fracture toughness.

Damping capability.

Hardness: 327-339 HV. (ATSB 2001: 15)

Avoid any residual stresses as they can lead to cracks.

Avoid ice formation by providing sleek surface to the fan blades. (centrifugal action)

SUMMARY

From the above information we can summarize that the front fan blade plays a very crucial role in turbofan engines. These help in achieving better fuel consumption and hence are of great importance to the turbofan engine. Material selection for the blades should be done carefully considering the requirements such as High endurance Limit, Low density, removal of residual stresses, High fracture toughness, High damping Capability and resistance to corrosion.