

Geared Turbofan with Water Alcohol Technology

Abhinav Purohit

Aeronautical Engineering
Hindustan College of Engineering and Technology
Coimbatore, India
abhinavae@hotmail.com

Abstract - In today's world, aviation industries are using turbofan engines (permutation of turboprop and turbojet) which meet the obligatory requirements to be fuel competent and to produce enough thrust to propel an aircraft. But one can imagine increasing the work output of this particular machine by reducing the input power. So in striving to improve technologies, especially to augment the efficiency of the engine with some adaptations, which can be crooked to new concepts by introducing a step change in the turbofan engine development. One hopeful concept is, to de-couple the fan with the help of reduction gear box in a two spool shaft engine from the rest of the machinery to get more work output with maximum efficiency by reducing the load on the turbine shaft. By adapting this configuration we can get an additional degree of freedom to better optimize each component at different speeds. Since the components are running at different speeds we can get hold of preferable efficiency. Introducing water alcohol mixture to this concept would really help to get better results

Keywords: Low emission, weight reduction, noise reduction, high performance.

emissions on environment, International Civil Aviation Organization (ICAO) as well as local authorities have been defining increasingly stringent regulation for aircraft engine emissions and community noise. As an example Figure 1 shows the development in airport noise restrictions from 1980 to 2010. A clear trend towards tighter restrictions can be observed, which will not only impact landing fees but mid-term limit an airline's ability to use a particular airport. From this perspective flight noise (and hence engine noise contribution) is becoming an important economic factor for the airline as well as the airport region.

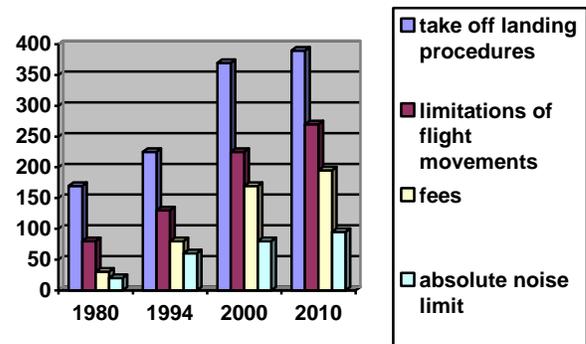


Figure1. Growth of Air Traffic

1 Introduction

1.1 Air Traffic Growth

Air traffic has been growing continuously over the last decades – in terms of passenger kilometer per year as well as in terms of the active aircraft fleet (number of aircrafts actively participating in air transport) – and it is predicted to grow further. So keeping these details and predictions in considerations we have to canalize the aircraft industries to a better approach.

1.2 Environmental and Economy Challenges

Along with this generally positive development for the aviation industry there obviously come serious challenges for the environment (emissions), the community (noise) and the available fuel resources which will limit the future growth at some point. In an effort to minimize the impact of

2 The Geared Turbofan Concept

2.1 High bypass ratio turbofan

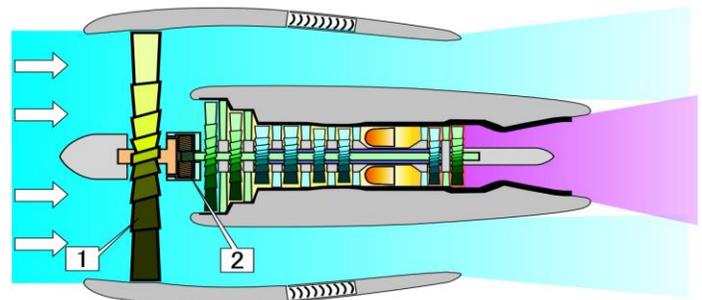


Figure 2 with Schematic Diagram of Pratt and Whitney's GTF

- 1) High bypass ratio fan.
- 2) Reduction gear box.

As laid out in chapter 1 one fundamental objective for the next generation product is to reduce mission fuel burn, which is largely driven by Thrust specific fuel consumption (TSFC). Traditionally the reduction of TSFC has been achieved by two methods as per **Gas Turbine Theory**.

By improving gas turbine cycle thermodynamic Efficiency and by improving propulsive efficiency.

Improved cycle efficiency can be achieved by the increase of overall pressure ratio and peak cycle temperatures, which is usually limited by available materials and/or cooling techniques. Obviously improved component efficiencies are also a major contributor. Propulsive efficiency of a turbofan engine in turn is mostly dependent on bypass nozzle jet velocity for a given flight condition. Propulsive efficiency will be high when is low. Low By pass jet nozzle velocity can be achieved by low Fan pressure ratio which requires a large Fan diameter for a given thrust demand. Therefore the Fan speed has to be reduced to keep Fan tip speed in a reasonable order of magnitude in terms of transonic losses and resulting efficiency. The natural outcome of applying this design philosophy is a high bypass ratio turbofan engine with a rather low flow specific thrust.

It can be done by the formula propulsive efficiency

$$N_p = 2V_i / (V_j - V_i) \quad (1)$$

V_i is inlet air velocity and V_j is jet nozzle velocity.

2.2 Geared Turbo fan as a next step

After applying the above described concept of low flow specific thrust and large Fan diameters, which goes along with slow Fan speed, the direct drive turbofan suffers from increasing length, weight and cost of the other low spool turbo machinery (Low Pressure Compressor, Low Pressure Turbine). This is due to the fact that the LPC and LPT have to convert shaft horse power into work potential and vice versa at a low spool speed level, which requires a large number of stages and as a result a large Air Flow count. Additionally the torque transmission requirement for the low pressure shaft increases, while the maximum diameter is limited by a more and more reduced diameter of the core engine. This problem can be overcome by de-coupling the Fan from the low spool speed by means of a Fan Drive Reduction Gear System (FDGS). The Fan Driven Gear System allows the LPC and

the LPT to run at higher and more appropriate speeds. Since the low pressure compressor and low pressure turbine would run at high speeds, we would not require more number of blade stages because same amount of pressure ratios we can expect without extra blades and stages, thus reducing length, weight and cost for the same engine. Nevertheless the FDGS losses have to be kept as low as possible. These losses are an additional heat source for the oil system as well. Therefore the thermal management system has to be designed carefully to avoid oil overheating by providing sufficient cooling capacity of the fuel-cooled and air-cooled oil coolers. Key to success is obviously to reduce heat rejection as far as possible by minimizing fan drive gear system losses.

2.3 What do we get?

As derived from the fundamental thoughts in subject 2.1 and 2.2, the geared engine configuration offers the Advantages of a high bypass ratio turbofan engine with correspondingly

- Slow Fan speed,
- Low Fan pressure ratio and bypass nozzle jet velocity,
- High propulsive efficiency and
- Low Fan noise and jet noise,

But avoids the drawbacks of a direct drive high bypass Ratio concept like

- Low LPC and LPT efficiency and
- increased overall engine length and weight stemming especially from the low spool components LPC and LPT on the low speed level.

2.4 Challenges

As per the theoretical research a new concept like the GTF™ engine (Geared Turbofan) could bring some challenges to the table, which have to be addressed carefully in order to get the technology ready for the product application. As a matter of fact the GTF™ engine concept focuses on the low spool components. The high spool components are not different compared to those of the high spool of an advanced twin-spool direct drive turbofan engine.

2.4.1 System Level

When compared to a direct drive turbofan with the same Fan diameter (and hence similar TSFC), the GTF™ Engine weight could be brought down because the FDGS weight is easily outweighed by the long and heavy LPC and LPT components (more blades and compression stages) of the direct drive due to the increased stage count and size relative to the GTF™ engine. When comparing the GTF™ engine to a lower bypass ratio direct drive turbofan (more the optimum direct drive configuration) the GTF™ engine might come out a bit heavier, but obviously could have a significant TSFC benefit. For the GTF™ engine the Fan and LPC

groups including the FDGS add up to a significantly higher portion of the total propulsion system weight, which is compensated for mostly by the LPT and the low shaft.

2.4.2 Low Spool Components

The major low spool components which need attention are

- a) The Fan,
- b) The Fan Drive Gear System,
- c) The high speed LPC and LPT.
- d) The water alcohol mixture

Fan

The Fan is not too different from a direct drive design. It features highly 3D swept aerodynamic profiles, and due to the lower spool speed losses are fundamentally reduced. As mentioned already the higher bypass ratio and higher Fan diameter result in a larger contribution of the Fan component to engine weight. Hence design methods and/or alternate materials (lightweight aluminum, composites) are key to Weight reduction.

Fan Drive Gear System

As with any other new or additional component to a propulsion system one has to be concerned about reliability in terms of flight safety as well as maintenance cost. Gearboxes have been used in engines for flight application for a long time.

High Speed LPC and LPT

Both the LPC and the LPT are exposed to elevated levels of rotational speed and hence tip speed. These results in high Mach number flow, but less turning is required for the given specific work. Fundamentally aerodynamic Efficiency will benefit from those conditions, but high Mach numbers (potentially in combination with low Reynolds Numbers for low thrust applications) have to be handled carefully. The high rotational speeds on the other hand cause high structural loading of the rotating airfoils and subsequently the disks. Therefore blade and rotor design has to be done carefully in order to achieve well balanced structural loads avoiding stress peaks, otherwise the low Stage count weight benefit will be compensated by heavy rotating hardware.

The Water-Alcohol Mixture

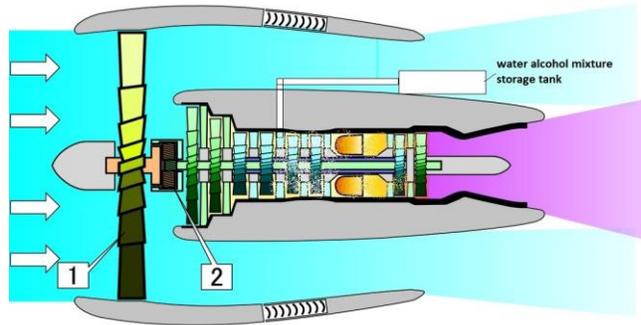


Figure 3 : The Water Alcohol Concept.

Water-alcohol mixture has been used in Learjet aircrafts from past many years to increase the thrust during high rate of climb and take off on short runways. The main components of water alcohol mixture are H₂O and methanol. The primary objective of adding this mixture to increase mass flow. As the water alcohol mixture is injected from the first stage of compressor it reduces the temperature up to compressor delivery. Due to vaporization of water, the generated steam increases the mass flow and methanol present in the mixture acts as a fuel. In the combustion chamber the blast of compressed air increases results in more thrust and more work output. The purpose of merging water-alcohol technology with geared turbofan is to reduce fuel consumption by increasing thrust for take-off and to achieve high rate of climb. The delivery of mixture can be controlled with the help of PLA (pilot lever angle) in other words throttle lever.

3 Opportunities And Challenges On The Component Level – Lpt

Opportunities and challenges of the high speed LPT result from the elevated rotational speed level due to decoupling from the Fan speed by means of the FDGS.

3.1. High Speed LPT Opportunities

3.1.1. Large Work Extraction per Stage

The high rotor speed allows for a significantly reduced stage count of the turbine for a given work extraction. Compared to a conventional turbine, the stage count can roughly be cut in half at rather low aerodynamic loading per stage. This leads to significantly reduced airfoil count and part numbers over all, and therefore lowers manufacturing costs and reduces maintenance costs as well. Figure 4 shows the V2500 LPT and the high speed LPT of the technology demonstrator CLEAN (Component Validate for environmentally friendly aero engine) which provide similar shaft horse power. The speed level was increased for CLEAN by 60% over the V2500, consequently the

stage count was reduced from 5 to 3 stages and the blade count went down to 40%. Figure shows Reduction of Part Numbers with High Speed LPT.

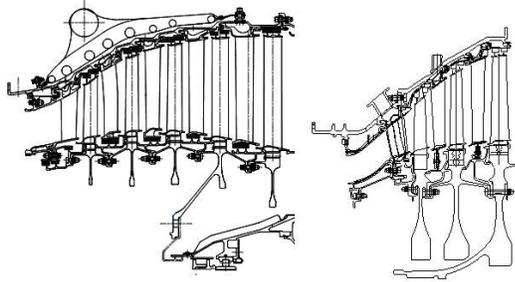


Figure 4. Stage Count(Reduction of Stages)

Even though the disks of the high speed LPT are much heavier due to elevated centrifugal loads, the overall design is much more compact, which leads to lower LPT weight in the end. Assuming an optimum bypass ratio for both the direct drive TF and the GTF™ engine, the weight of the high speed LPT can be reduced to about 70% of the conventional LPT weight. As described above the GTF™ engine has an additional TSFC benefit. To evaluate the weight opportunity of the LPT due to the GTF™ engine concept only, a direct drive TF and a GTF™ engine with the same (high) bypass ratio have to be compared. In this case the weight of the high speed LPT can be reduced even further down to 60% relative to the conventional LPT. This potential counteracts the weight increase of the GTF™ engine due to other new or heavier components.

3.1.2 High Efficiency Level

The high speed LPT achieves high specific work output by means of high rotational speed per stage. This allows keeping the aerodynamic loading DH/u^2 in a reasonable range, which is typically on a lower level than in conventional turbines. Therefore efficiency levels can be kept high. Additionally the average row velocity ratio can exceed values of $c_2/c_1 \gg 2.3$, while conventional modern turbines are more in the range of around 1.8. This enlarges the area of laminar flow at the airfoil and reduces friction losses. The aerodynamic design of high speed LPTs was subject of a number of technology programs in the past.

3.1.3 High Blade Passing Frequency

The fundamental tone frequencies (Blade Passing Frequency) of the high speed LPT at landing condition (approach) are in the Order of 7 kHz and higher. However, sound of high frequencies propagating through the atmosphere is highly attenuated. Furthermore the frequency

related noisiness of the high speed turbine tones perceived by the human Ear (Perceived Noise Level Tone corrected weighing) is significantly lower. Advantageous for the frequency characteristic is the absence of turbine tones at the higher harmonics (2BPF, 3BPF etc.) (BPF: Blade Passing Frequency) even at approach condition enabled by a favorable choice of blade numbers. In consequence, the tonal turbine sound at higher rotational speed terms of take-off condition is even more dampened or not hear able beyond the frequency of 10 kHz. bearing, an immediate axial shift of the LPT occurs. In this case a mechanical intermeshing system can avoid a critical over speed of the rotor. Because rotor speed is much higher than in conventional turbines, the driving torque of the shaft is much lower for a given power demand. This torque has to be counter balanced by blade to vane interactions at the intermeshing location to avoid a rapid acceleration of the turbine. On the other hand the high speed LPT rotor moment of inertia and speed are significantly higher than in conventional turbines and hence the total energy of rotation is very high. This energy has to be dissipated during the intermeshing event into heat.

4 Conclusion

In a world of continuously growing air traffic the demand for environmentally friendly aircraft engines is strong. Market requirements focus on emission and noise reduction, but also on purely economically driven objectives like fuel burn and TSFC caused by the increasingly high fuel prices, and production and maintenance cost. After doing all the theoretical research part the geared turbofan could be the only turbofan engine concept which allows significant reduction in fuel burn? Maintenance cost and noise at the same time, and which will be technology ready near-term to support EIS dates the aircraft manufacturers and airline customers are envisioning. While the ducted counter-rotating Fan engine architectures are promising in terms of TSFC and fuel burn, their technology readiness is more than one decade away. Open rotor concepts (un-ducted Fans) are likely to provide even higher TSFC and fuel burn benefits, but are struggling with achieving noise requirements as we understand them today, and are likely to require dramatic changes in terms of engine/airframe integration. Hence the GTF™ engine is THE best concept for the demands of the market. In order to mature the geared engine configuration technology MTU and its partners P&W, Avio and VAC (Volvo aero) have been following through a series of technology development programs on the parts, module and system level for the last two decades.

Acknowledgement

The author would like to thank Pratt and Whitney, MTU AERO ENGINES GmbH, Avio Propulsion Aerospataiale from whom the information has been collected and was really helpful in every context .It will definitely provide enough satisfactory results. The author would also like to thank his college faculties and friends who helped a lot for this research work.

References

[1] D. Crichton, e. Rosa Blanco, T. R. Law, J. I. Hileman, "Design and Operations for ultra low noise takeoff", AIAA 2007-0456.

[2] F. J. Malzacher, J. Gier, F. Lippl, "Aerodesign and Testing Of An Aero - Mechanically Highly Loaded LP Turbine", ASME GT - 2003-38338.

[3] J. S. Sabnis, 'Emissions and Noise' presented at the AIAA/FAC Aircraft Noise and Emissions Reduction Symposium, Monterey, California, USA. 2007

[4] G. Wilfert, B. Kriegl, H. Scheugenpflug, J. Bernard, X. Ruiz, S. Eury "CLEAN - Validation of a High Efficient Low NOx core, a GTF™ Engine High Speed Turbine and an Integration of a Recuperator in an Environmental Friendly Engine Concept", AIAA - 2005-4195.