DESIGN AND ANALYSIS OF TURBINE BLADES FOR TURBOJET ENGINE

Akanksha Gupta[a], Faizan Hasan[b]

a. Research Scholar, Department of Mechanical Engineering, Integral University, Lucknow

b. Associate Professor, Department of Mechanical Engineering, Integral University, Lucknow

Abstract

The design and analysis of turbine blades for turbojet engines play a crucial role in enhancing engine performance, efficiency, and longevity. This study presents a comprehensive approach to the design and structural analysis of turbine blades, emphasizing the importance of aerodynamic efficiency, thermal management, and material selection. Advanced computational techniques, including Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA), were employed to model and simulate the turbine blade under various operational conditions. The study also explores the effects of different materials on the mechanical properties and thermal behavior of the blades. The results indicate that optimized turbine blade designs can significantly improve the overall efficiency and performance of turbojet engines, providing valuable insights for future research and development in the aerospace industry.

Keywords *Turbine blades, Turbojet engine, Design, Analysis, Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA), Aerodynamic efficiency, Thermal management, Material selection, Aerospace engineering.*

1.1 Introduction

Due to its ability to achieve high-speed, high-altitude flying, the turbojet engine—a pivotal innovation in contemporary aerospace engineering—has completely changed air travel. Turbine blades are essential to these engines' efficiency and performance because they transform thermal energy into mechanical work, which powers the compressor and produces thrust. Turbine blade design and analysis are essential for increasing engine efficiency, lowering fuel consumption, and boosting general dependability and lifespan.

This work is motivated by the continuous need for aviation engines that are more dependable and efficient. Every engine component needs to be optimized since the aerospace industry is always pushing the envelope of performance. Due to their constant operation under harsh temperatures and stresses, turbine blades provide special challenges that call for cutting-edge materials, creative design strategies, and exacting analytical methods. Significant improvements in engine performance, environmental effect, and operating costs can result from better turbine blade design.

Developments in materials science and computational techniques provide fresh avenues for investigating novel concepts and refining already-existing ones. Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) are now essential tools for forecasting the aerodynamic efficiency and structural integrity of turbine blades under varied operating circumstances. Engineers can improve blade performance by utilizing these tools to explore intricate design spaces and make well-informed judgments.

Another source of motivation is the aviation industry's growing emphasis on sustainability and environmental effect. Improving the efficiency of turbine blades can help cut emissions and fuel consumption, supporting international efforts to mitigate climate change. By looking into cutting-edge design approaches and analytical strategies for turbine blades in turbojet engines, this study seeks to address these issues.

2. Literature Review

2.1 History and Evolution of Turbojet Engines

The inception of the turbojet engine can be traced back to the early 20th century. The need for faster, more efficient aircraft engines spurred significant advancements in aviation technology. The turbojet engine, a type of gas turbine engine, was first conceptualized by Sir Frank Whittle of the United Kingdom and Hans von Ohain of Germany independently during the late 1930s.

Whittle's engine, patented in 1930, underwent several iterations before achieving practical success. By 1937, his designs culminated in the construction of the first turbojet engine, the Power Jets W.1, which powered the Gloster E.28/39 aircraft in its maiden flight in 1941. Concurrently, Hans von Ohain developed the Heinkel HeS 3 engine, which powered the Heinkel He 178, the world’s first turbojet-powered aircraft, in 1939.

Post World War II, turbojet engines saw rapid development and widespread adoption. Early turbojets were characterized by their simplicity but were limited by their fuel efficiency and operational altitude. Subsequent decades witnessed the introduction of afterburners, improvements in materials, and advancements in aerodynamics, leading to the development of more efficient and powerful engines.

By the 1960s and 1970s, the turbojet engine had evolved to include features such as variable stator vanes and bypass ratios, which enhanced performance and fuel efficiency. The introduction of high bypass turbofan engines in commercial aviation further revolutionized the industry, making long-distance air travel more economical and reducing noise pollution.

The evolution of turbojet engines reflects the continuous quest for higher performance, efficiency, and reliability. Today, modern turbojets and turbofans incorporate cutting-edge materials and sophisticated design techniques, enabling them to meet the stringent demands of both military and commercial aviation.

2.2 Fundamentals of Turbojet Engine Operation

A turbojet engine operates on the principles of thermodynamics and fluid dynamics, primarily following the Brayton cycle. The engine comprises several key components: an inlet, compressor, combustion chamber, turbine, and exhaust nozzle.

The operation begins as air enters the engine through the inlet. The air is then compressed by the compressor, significantly increasing its pressure and temperature. The compressed air enters the combustion chamber, where it is mixed with fuel and ignited. The combustion process generates high-temperature, high-pressure gas.

This gas expands rapidly and flows through the turbine. The turbine extracts energy from the high-pressure gas to drive the compressor and other accessories. The remaining energy is expelled through the exhaust nozzle, producing thrust according to Newton’s third law of motion.

Key performance parameters of a turbojet engine include thrust, specific fuel consumption, and thermal efficiency. Thrust is the force generated by the engine to propel the aircraft forward. Specific fuel consumption measures the fuel efficiency of the engine. Thermal efficiency is the ratio of useful work output to the heat input from the fuel.

Advancements in turbojet engine design focus on improving these parameters through better materials, advanced aerodynamics, and enhanced combustion techniques. Modern engines incorporate sophisticated control systems to optimize performance across different flight conditions.

2.3 Turbine Blade Function and Importance

A turbojet engine's turbine blades are essential parts that are used in the energy conversion process. Their main job is to transform the energy generated by the combustion chamber's high-pressure, high-temperature gas into mechanical work that powers the compressor and other engine systems.

Turbine blade design is a very intricate process that necessitates striking a balance between structural integrity, heat resistance, and aerodynamic performance. Extreme temperatures (over 1,000°C) and rotational speeds (up to 20,000 RPM) can be applied to blades. Modern materials and cooling methods are required under these circumstances.

The efficacy of the turbine blades has a major impact on the performance and efficiency of a turbojet engine. Aerodynamically efficient blades increase thrust production while reducing energy losses. Blades with good structural integrity bear the mechanical strain and avert disastrous engine breakdowns. Thermally resistant blades keep their longevity and performance at high temperatures without degrading.

Turbine blade design entails a thorough computer study as well as experimental validation. While Finite Element Analysis (FEA) evaluates the structural integrity, Computational Fluid Dynamics (CFD) optimizes the aerodynamic profile. High-quality blades are made using sophisticated manufacturing processes including additive manufacturing and precise casting.

3. Methodology

1. Define the issue.
2. Determine the blade profile's measurements.
3. Create the computer models in three dimensions.
4. Create the 3D computer model's finite element model.
5. Prepare the 3D model according to the specified geometry.
6. For accurate results, mesh the geometry model and fine-tune it while taking sensitive zones into account.
7. Post-process the model so that the necessary assessment can be completed.
8. Find the highest stress that can be applied to blades.
9. Find the distribution of temperature along the blade profile.
10. Summarize the findings.

4. Design and Cad Modelling

The dimensions of the blade geometry are calculated theoretically using conventional assumptions. Table 4.1 provides the design parameters.

Table 4.1: Design parameters.

PARAMETER	VALUE	UNIT
Blade height, **h**	0.081833	m
Chord width, **c**	0.02727	m
Pitch, **s**	0.02264	m
Number of blade	69	
Blade inlet angle, $\boldsymbol{\beta_2}$	18.3^0	deg
Blade outlet angle, $\boldsymbol{\beta_3}$	54.56^0	deg
Mean radius, $\mathbf{r_m}$	0.2475	m

The 3D CAD model is created using the software CATIA V5; it is shown in fig 4.1.

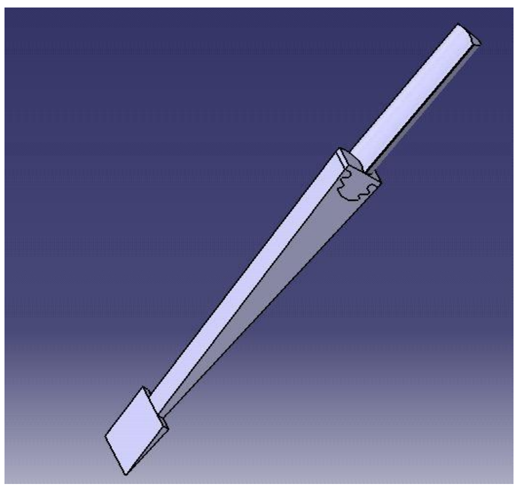


Fig 4.1: - Sector Model of Turbine Blade

5. Details of Turbine Blade Material

The turbine blade is subjected to rotational speed of 10800 rpm and firing temperature of 6190C. Factor of safety is 1.6.

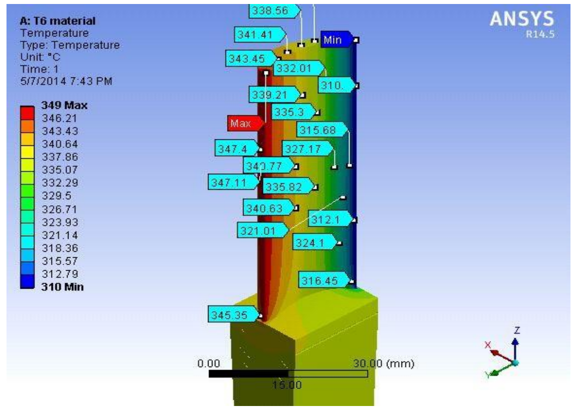
Table 5.1:-Material properties.

Properties	**Unit**	**Inconel 718**	**Titanium T6**
Young's modulus	MPa	2E5	1.06E5
Density	kg/m^3	8193.3	4420
Poisson's ratio		0.31	0.3

Tensile yield strength	MPa	1069	530
Allowable stress	MPa	641.8	318
Allowable Shear stress	MPa	385.08	190.8
Specific heat	J/kg-K	556.85	527.5

6. Results and Discussion

The heat transfer coefficient for gases and the material's thermal conductivity determine the blade's temperature distribution. The iterative approach used to obtain the heat transfer coefficients was also utilized. The analysis was done under conditions of steady state heat transport. Because of the stagnation effects, it is found that the leading edge of the blade experiences the highest temperatures. The blade's body temperature doesn't change significantly radially. As anticipated, there is a temperature drop from the blade's leading edge to its trailing edge. Figures 6.1 (Titanium T6) and 6.2 (Inconel 718) show that the solid blade model's blade temperatures are slightly lower for Inconel 718. This is explained by Inconel 718's reduced thermal conductivity.



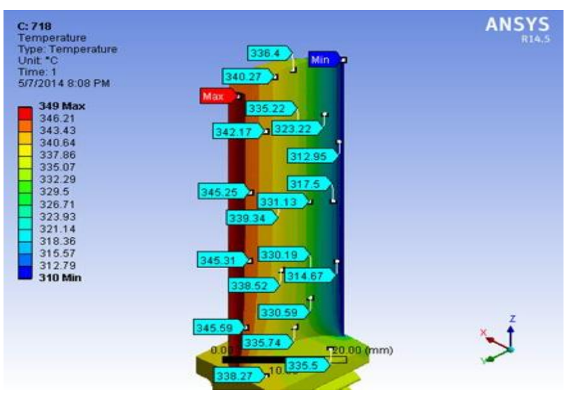
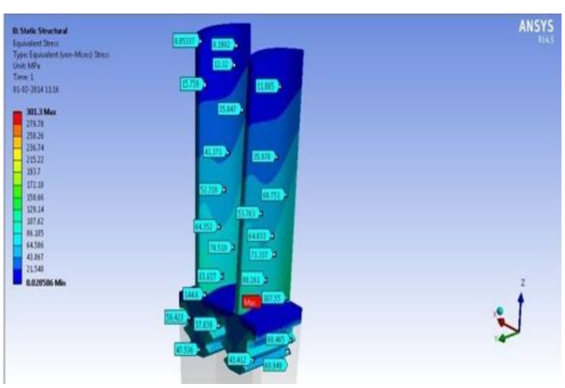


Fig 6.1:- Temperature distribution on Titanium T6. Fig 6.2: -Temperature distribution on Inconel 718.

Structural analysis imports the temperatures that are found in the thermal analysis. In structural analysis, the centrifugal forces operating on the blade are regarded as loads.



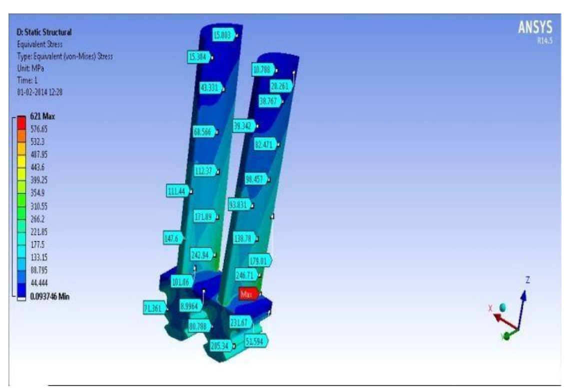
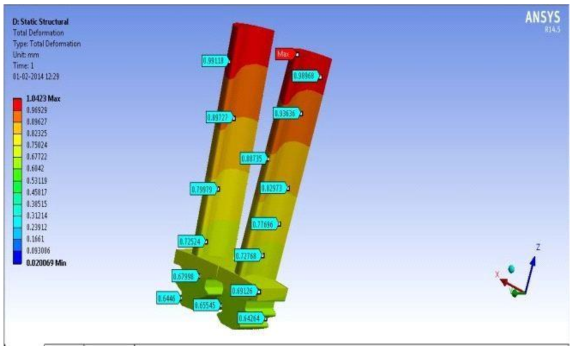


Fig 6.3:- Von-miss stress on Inconel Fig 6.4:- Von-miss stress on Titanium T6

The fluctuation of the von Misses stress on the blade and drum component is depicted in figs. 6.3 and 6.4 below. Inconel 718 and titanium T-6 were used in the blade, whereas steel 286 was used in the drum. As a result of not being covered, the stress on the blade tips is lower and the stress at the blade roots is higher.



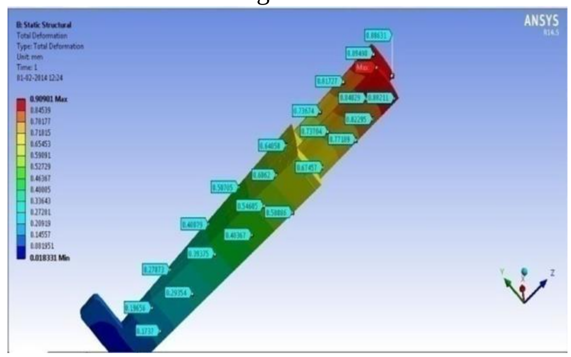


Fig 6.5:- Total deformation of Inconel 718 Fig 6.6:- :- Total deformation of Titanium T6

Since titanium T6 has less thermal expansion than Inconel 718, it is less expansive overall. This difference in thermal expansion can be attributed to the material's characteristics. Table 6.1 presents the results.

Table 6.1: Comparison of results.

PARAMETERS	**INCONEL 718**		**TITANIUM T6**	
Total Deformation(mm)	1.0448		0.90901	
	Analytical Results	Computational Results	Analytical Results	Computationa l Results
Von Misses Stress(MPa)	641.8	621	318	301.3

7. Conclusion

As can be seen from the findings above, both materials are producing noteworthy results; in the end, a decision can be made based on the materials' cost and availability.

- If the price of the materials is not the main consideration, we can choose titanium T6, which has a lower density, a lower value of deformation at the same time as a lower yield strength and a lower young modulus at higher temperatures.
- However, if material cost is the main concern, Inconel 718 can be chosen; whereas titanium T6 will distort less at high temperatures, Inconel 718 will. However, it will also have higher yield and elastic strength values, which will result in less stress being placed on the blade.
- Compared to titanium T6, Inconel 718 is also shown to have better material qualities at higher temperatures.
- Appropriate cooling techniques should be used to reduce hot corrosion and creep strain distribution on the turbine blade's trailing edge (Inconel 718)

Thus, based on the plots and observations above, we can conclude that the structure is safe under the specified loading conditions and that Inconel 718 is a superior material in terms of both affordability and strength at higher temperatures than titanium T6.

REFERENCES

1. S.Gowreesh, N.Sreenivasalu Reddy and N.V.Yogananda Murthy. “CONVECTIVE HEAT TRANSFER ANALYSIS OF AERO GAS TURBINE BLADE USING ANSYS”, International journal of Mechanics of solids, vol4, No.1, March 2009(ppt55-62).
2. P.Kauthalkar, Mr.Devendra S.Shikarwar, and Dr.Pushapendra Kumar Sharma. “ANLYSIS OF THERMAL STRESES DISTRIBUTION PATTERN ON GAS TURBINE BLADE USING ANSYS”, International journal of Engineering Education and technology, Vol.2, No.3, Nov 2010.
3. John.V, T.Ramakrishna. “THE DESIGN AND ANALYSIS OF GAS TURBINE BLADE”, International Journal of Advanced Research and Studies, Vol 2, No.1, Dec 2012.
4. V.Raga Deepu, R.P.Kumar Ropichrla. “DESIGN AND COUPLED FIELD ANALYSIS OF FIRST STAGE GAS TURBINE ROTOR BLADES”, International journal of Mathematics and Engineering, Vol 13, No.2, Pages: 1603-1612.
5. V. Veeraragavan Effect Of Temperature Distribution In 10c4/60c50 Gas Turbine Blade Model Using Finite Element Analysis.
6. V.R.S.M. Kishore Ajjarapu[1], K. V.P.P.Chandu[2] D.M.Mohanthy Babu[3] “DESIGN AND ANALYSIS OF THE IMPELLER OF A TURBOCHARGER FOR A DIESEL ENGINE”
7. R D V Prasad[1], G Narasa Raju[2], M S S Srinivasa Rao[3], N Vasudeva Rao[4] Steady State Thermal & Structural Analysis of Gas Turbine Blade Cooling System.
8. Timoshenko, “STRENGTH OF MATERIALS PART 1” third edition.
9. **Jack D Mattingly**, “Elements of Propulsion: Gas Turbine and Rockets”.
10. **H.S.Manohar ,** Finite Element Method ,first edition.
11. **Singiresu S. Rao**, “The Finite Element Method in Engineering”.