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CFD Analysis of Gas Turbine Blade Cooling with Staggered Holes

S. R. Veerabhadra* and B. P. Madhu

School of Mechanical Engineering, REVA University, Bengaluru – 560064, Karnataka, India; ronadveerabhadras@gmail.com

Abstract

The role of turbine inlet temperature plays a pivotal role in determining overall turbine performance. As the temperature at the turbine inlet increases, it leads to an enhancement in the turbine's average efficiency. Gas turbines operate under extremely elevated temperatures, reaching levels of 1200°C to 1500°C. This extreme heat poses the risk of turbine blade melting and potential failure. Consequently, the need arises for a sophisticated cooling mechanism for the turbine blades. Optimally increasing the inlet temperature of the turbine blades can certainly elevate the turbine's overall efficiency. However, it's important to recognize that this increase in temperature directly impacts the durability of the turbine blades. To address this challenge, various innovative cooling technologies have been devised, including the implementation of distinct blade cooling hole configurations. These methodologies aim to ameliorate blade temperatures and consequently enhance turbine performance.Turbine blades are engineered using superalloys, renowned for their ability to withstand high thermal stress. Advanced software tools are harnessed to assess their performance under extreme temperatures. Computational Fluid Dynamics (CFD) software is commonly employed for analyzing turbine blades. A prevailing approach for blade temperature reduction entails employing diverse cooling systems, often utilizing air as a cooling agent. This directed airflow over the blades significantly curtails their temperatures. In this context, blade design featuring staggered hole layouts is applied, and both STATIC and CFD simulations, grounded in defined boundary conditions, are executed, yielding commensurate outcomes. Comparative analysis demonstrates that staggered hole configurations provide superior temperature distribution uniformity across blade surfaces, effectively reducing peak temperatures in contrast to blade configurations devoid of cooling holes..

Keywords: *Static Analysis, Superalloys Computational Fluid Dynamics (CFD), Staggered Holes Cooling, Turbine Inlet Temperature*

1.0 Introduction

A gas turbine, often called a combustion turbine, operates as an internal combustion engine of remarkable versatility. It stands as the chief propellant in diverse domains—ranging from power generation and aircraft propulsion to industrial processes of consequence. The symphony of gas turbines unfolds as it orchestrates the convergence of scorching gases—born within the combustion chamber—directed towards the turbine's revolving blades, operating under the duress of elevated temperature and pressure. This mechanical ballet, in turn, kindles the expansion phenomenon, igniting an intricate dance of heightened thermal efficiency. Rising to the forefront are cutting-edge gas turbine advancements, a symposium of innovations that strives to optimize both efficacy and yield within this turbine tableau, the role of turbine blades assumes eminence integral components of the turbine's anatomy, devoted to harnessing energy from the cauldron of high-temperature, high-pressure gases birthed by the combustor. As paramount players in the gas turbine ensemble, these blades wield the power

**Author for correspondence*

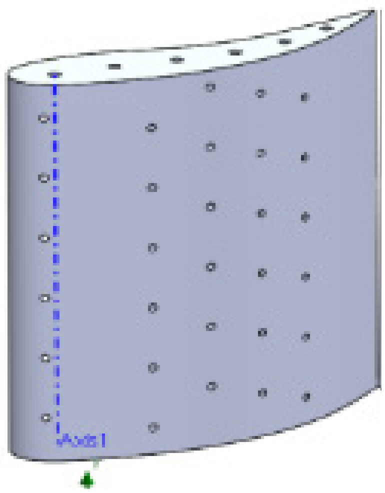

Figure 1. Geometry of staggered hole arrangement.

to shape the operational thresholds of these engineering marvels. Contemporary gas turbines, aspiring for heightened potency and effectiveness, thread into the realm of elevated temperatures. A consequence of such endeavors is the imperative for cooling architectures—defensive ramparts against the peril of blade materials inching towards their molten thresholds. Turbine blade cooling methods can be internal or external, as surpassing the material's melting point can lead to blade failure. Hence, advanced materials and cooling systems are pivotal for the safe and high-performance operation of gas turbines. One approach involves extracting air from the compressor through the turbine blades, directing it into a plenum, and then channeling it within the blade.

Material analysis focused on Inconel 718 revealed varying elongation and stress patterns along the blade's sections, with maximum values observed at the tip and root sections, respectively. Stress concentration near film cooling holes was identified. Strategies such as reducing hole count or introducing a fillet at the root section mitigate stress concentration. Computational Fluid Dynamics (CFD) investigations evaluated heat transfer across gas turbine models with distinct hole arrangements, confirming staggered hole configurations as superior due to uniform temperature distribution and increased heat transfer (Figure 1).

The evolution of gas turbine technology necessitates efficient blade cooling methods and innovative material choices to optimize performance. Staggered hole layouts offer enhanced heat transfer characteristics and temperature distribution. The synergy of material advancements and cooling solutions underpins the continued advancement of gas turbine efficiency and reliability.

1.1 Problem Definition

Examine the impact of altering the quantity of cooling passages on the distribution of temperatures and the rate of heat transfer. Place particular emphasis on the detailed analysis of the turbine blade to unveil the optimal count of cooling holes. The overarching objective is to fine-tune the heat transfer rate, thereby elevating the blade's overall efficiency and extending its lifespan significantly.

2.0 Literature Survey

Patel, Singhai (2018): Gas turbines play a pivotal role as prime movers in crucial sectors like power generation, processing plants, and aircraft propulsion. The evolution towards greater efficiency and firing temperatures has led to a rise in gas turbine inlet temperatures. In this context, turbine blades emerge as the decisive components of gas turbines. The modern pursuit of elevated power outputs, enhanced thermal efficiency, and superior turbine performance has driven gas turbines to operate under immensely high temperatures (1200-1500°C). However, these soaring temperatures can encroach upon the limits of blade material melting points, necessitating the implementation of robust cooling systems to ensure their durability. Turbine blade cooling options encompass both internal and external approaches. Cooling blades in turbines constitutes a pivotal factor in the perpetual and secure operation of high-performance gas turbines. Various techniques are employed to cool these blades effectively. The meticulous evaluation of heat transfer dynamics involves the exploration of 14, 15, and 16 staggered holes configurations. For this purpose, the analysis employs the Computational Fluid Dynamics (CFD) tool ANSYS FLUENT. Upon scrutinizing the contour plots depicting pressure, velocity, and velocity vectors, intriguing insights surface. The temperature distribution across the 16 staggered holes showcases a remarkably uniform dispersion over the blade's expanse in comparison to the 14 and 15 staggered configurations. Notably, altering the number of staggered holes from 14 to 16 yields a noteworthy 3.98% reduction in the average blade temperature. Furthermore, the augmentation of staggered holes from 14 to 16 induces a significant 14.96% upswing in the heat transfer rate.In essence, the meticulous exploration of cooling methodologies and their impact on gas turbine blade performance underlines the pivotal role of temperature management in ensuring prolonged, high-performing operations[1].

Singh, Shukla (2019): In the realm of gas turbine engines, the turbine blades operate at temperatures exceeding the melting point of their constituent materials. Consequently, effective cooling strategies for these blades become paramount to ensuring the sustained safe operation and high-performance capabilities of gas turbines. Various cooling methods have been proposed, and one such innovative approach involves incorporating radial holes to facilitate the passage of high-velocity cooling air along the expanse of the blade.This study delves into Computational Fluid Dynamics (CFD) analysis, which serves as a robust tool for investigating heat transfer dynamics within gas turbines. The investigation encompasses six distinct models, including those with 5, 9, and 13 inline holes in a single row, as well as comparisons with models containing 9 and 13 holes arranged in staggered fashion across three rows. A novel configuration is also explored, featuring 14 holes arranged in a staggered pattern. The predictive power of the CFD software FLUENT is harnessed, employing a turbulence realizable k-e model with enhanced wall treatment.Upon scrutiny of contour plots pertaining to pressure, velocity, and velocity vectors, a notable revelation emerges. The temperature distribution across the 13 staggered holes exhibits a remarkable uniformity spanning the blade area, distinguishing it from the distribution seen in 13 inline holes. Additionally, the application of 13 and 14 staggered hole arrangements is found to correlate with heightened heat transfer efficiency. This investigation contributes valuable insights into the intricate heat transfer mechanisms within gas turbines, crucial for optimizing their operational and thermal performance[2].

Narendar et al. (2019): The augmentation of the turbine inlet temperature yields a corresponding escalation in the overall turbine yield. As such, the implementation of intricate strategies becomes imperative to foster this elevation in the turbine inlet temperature. Nonetheless, due to the existing constraints posed by material properties, achieving higher turbine blade temperatures without adequate cooling remains an unfeasible proposition.

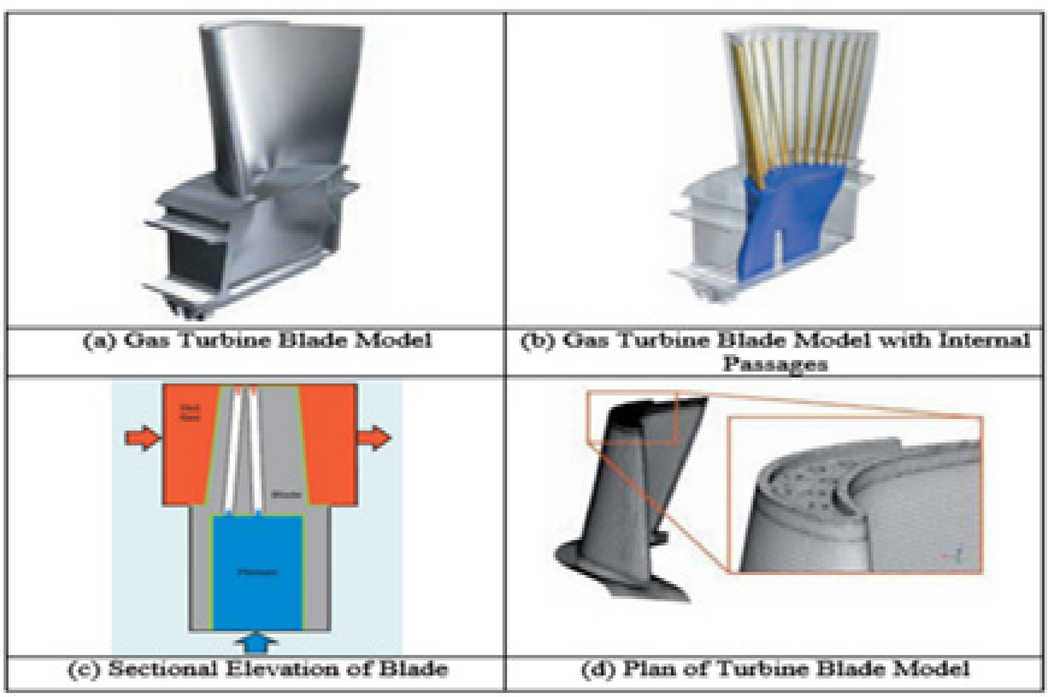

Figure 2. Segmental view and design gas turbine.

Consequently, a pragmatic approach involves devising cooling methodologies to facilitate the augmentation of the turbine inlet temperature. Among these methods, the blade cooling technique, entailing varied arrangements of cooling holes, takes center stage.This study focuses on the Computational Fluid Dynamics (CFD) analysis of gas turbine blade cooling via staggered hole configurations. The research delves into two distinct blade geometries, one featuring inline holes and the other adopting staggered holes on the blade's surface. The analyses are meticulously conducted under uniform boundary conditions, enabling a comprehensive comparison of the outcomes between the two models. The findings underscore that the staggered hole arrangement manifests superior uniformity in the distribution of temperature across the blade's surface, in stark contrast to the arrangement of inline holes. Furthermore, the peak temperature experienced across the blade's surface is notably diminished compared to the scenario where inline holes are employed[3].

Dhamecha *et al.* [2016]: The structural analysis of the turbine blade was conducted utilizing ANSYS 16 Workbench Solver, with a focus on comprehending its mechanical behavior. In this endeavor, Inconel 718 was chosen as the material for assessment. The investigation unveiled intriguing insights; notably, the blade exhibited maximum elongation at its tip, while the root section displayed minimal elongation. Akin to this, stress distribution revealed its own narrative—the root section demonstrated higher stress concentrations, juxtaposed against the relatively lower stress levels at the blade's tip. Particularly intriguing were the regions surrounding the film cooling holes, where stress concentrations peaked due to the geometry's intricacies. Addressing this, the study delved into strategies for stress mitigation. One avenue explored was the reduction of cooling holes near the root section, which displayed marked effectiveness in alleviating stress concentrations. Furthermore, the proposition of introducing a fillet at the root exhibited the potential to mitigate abrupt cross-sectional changes and consequent stress concentration in that specific region. In essence, this structural analysis not only underscored the dynamic interplay between the blade's geometry and stress patterns but also illuminated pathways to enhance its mechanical integrity[4].

Chandrakant *et al.* [2012]: They undertook a comparative assessment of the performance of blade cooling involving helicoidal ducts combined with turbulators of varying geometric proportions. Their analysis illuminated a noteworthy enhancement in the cooling efficacy of turbine blades, particularly for the turbulator geometry characterized by a larger e/D ratio. Furthermore, their investigations highlighted a discernible elevation in performance for turbulator geometries with increased thickness.In the course of their study, they designated e as the radial thickness of the turbulator rib and D as the outer diameter of the helicoidally duct. By utilizing the non-dimensional ratio e/D as a parameter, they delved into diverse rib geometries, uncovering noteworthy trends. Intriguingly, their innovation introduced a helicoidal cooling passage, ingeniously augmenting the convective area to facilitate superior heat dissipation. The helicoidal configuration also engendered turbulence, thereby extending the rates of heat dissipation due to its distinctive geometry.The interplay of factors such as the diameter and pitch length of the helicoidal duct emerged as pivotal in refining the geometry of the helicoidal cooling passage. Their meticulous analysis further ascertained that an e/D ratio of 0.08, coupled with a turbulator thickness of 0.75 mm, manifested as the most optimal geometric configuration in terms of augmenting heat dissipation characteristics[5].

Ragul *et al.* [2017]: This research paper delves into enhancing the overall thermal efficiency of a high-pressure, high-temperature gas turbine operating under elevated inlet temperatures. The aim is to craft a gas turbine design that minimizes any adverse impact on engine thermal efficiency. The interplay of fluid dynamics and thermal effects holds paramount significance in the design process. Within this study, we address dual fluid domains: the passage of hot gases through the turbine and the flow of coolant air across the plenum and blade. The blade itself is considered a distinct solid domain, its mesh created independently via Ansys CFD meshing software. Introducing Generalized Grid Interfaces (GGIs), we establish connections between mesh topologies of disparate domains, accommodating their non-matching nature. For seamless integration, a one-dimensional simulation interfaces with Ansys, wherein coolant air courses through the plenum. Simultaneously, the CFD simulation, operating as an all-encompassing Ansys model, bridges the gap from laminar to turbulent transition, thus providing a holistic perspective[6].

2.1 Literature Summary

Table 1. Summary of literature review

SL. No	Author's Name	Paper Title	Target Achieved
1	Patel, Singhai	CFD Analysis for Cooling of Gas Turbine Rotor Blade Cooling through Staggered Holes	• Diverse techniques exist to facilitate blade cooling. Investigating heat transfer analyses, evaluations were conducted using 14, 15, and 16 staggered holes configurations. The analysis was performed employing the CFD software ANSYS FLUENT. • Upon scrutinizing contour plots of pressure, velocity, and velocity vectors, it becomes evident that the distribution of temperatures over the 16 staggered holes is uniformly spread across the blade area, distinguishing it from the 14 and 15 staggered configurations. • The average blade temperature exhibited a decrease of 3.98% when transitioning from 14 to 16 staggered holes. Simultaneously, the heat transfer rate recorded an increase of 14.96% within the same range of staggered hole variations.
2	Singh, Shukla	Heat Transfer Analysis of Gas Turbine Rotor Blade Cooling Through Staggered Holes using CFD	• Within this study, Computational Fluid Dynamics (CFD) analysis has been harnessed to scrutinize the intricacies of heat transfer within a gas turbine. The investigation encompasses six distinct models, encompassing configurations with 5, 9, and 13 inline holes, in conjunction with a comparative assessment against 9 and 13-hole staggered models, further complemented by the introduction of a novel model featuring 14 staggered holes. • The CFD software of choice for prediction is the widely utilized FLUENT, employing a turbulence realizable k-e model augmented by enhanced wall treatment. • Upon a meticulous examination of pressure, velocity, and velocity vector contour plots, discernible trends emerge. Specifically, the temperature distribution exhibited uniformity across the blade area within the context of the 13 staggered holes configuration, as opposed to the 13 inline holes counterpart. Furthermore, the adoption of 13 and 14 staggered hole arrangements coincided with amplified heat transfer effects.

3	Narendar *et al.*	CFD Analysis of Gas Turbine Blade Cooling With Staggered Holes	• Conducting Computational Fluid Dynamics (CFD) analysis on gas turbine blade cooling utilizing staggered hole configurations. • Results indicate an improved uniformity in temperature distribution over the blade surface with staggered holes compared to inline hole arrangements. • Moreover, the maximum temperature observed across the blade surface is lower in staggered hole arrangements in comparison to inline hole configurations.
4	Dhamecha *et al.*	Design and Analysis of Gas Turbine Blade with Varying Pitch of Cooling Holes	• An analysis of the turbine blade's structural integrity was carried out employing ANSYS 16 Workbench Solver. • Peak stress levels were notably concentrated in the vicinity of film cooling apertures, primarily attributed to the heightened stress concentration prevailing along these openings.
5	Kini	Design and Analysis of Gas Turbine Blade with Varying Pitch of Cooling Holes	• The spiral trajectory also serves as a source of turbulence generation, leading to heightened rates of heat dissipation attributable to the distinctive geometry. • The design of the turbulator geometry features an elevated e/D ratio.
6	Ragul *et al.*	Modelling, Structural Analysis and CFD Fluent Analysis of High Speed Gas Turbine Blades	• In design considerations, numerical calculations involving fluid-thermal interactions hold significant importance. • The utilization of CFD meshing software is integral to the process.

3.0 Methodology

Singh, Shukla (2019)

- CFD (Computational Fluid Dynamics) encompasses the scrutiny of thermal dynamics through computer-based simulations, rooted in fluid flow, heat transference, and interconnected phenomena, such as chemical reactions.
- This endeavor employs CFD analysis to investigate the interplay of flow and heat exchange. The domains wherein gas turbines find application span diverse realms, encompassing aerodynamics involving lift and drag (as witnessed in the anatomy of airplane or windmill wings), power plant combustion dynamics, intricate chemical processes, the intricate orchestration of heating and ventilation systems, and even extending to

the intriguing domain of biomedical engineering (facilitating simulations of blood circulation within arteries and veins).

- The journey initiates with a comprehensive overview of the essential tools indispensable for executing CFD analysis, in tandem with the requisite procedural workflows. A compendious exposition of the governing equations and turbulence models unfolds, followed by an elucidation of the underpinning solution algorithm.
- The foundational stages to orchestrate a CFD analysis can be distilled into elemental actions:
    1. Preprocessing - Engaging in CAD modeling and intricate mesh generation.
    2. Solution - Instigating the computational solution, predicated upon iterations, fostering convergence.
    3. Post-processing - Effecting a pivotal phase dedicated to result assimilation, visualization, and multifaceted interpretation.

Narendar et al. (2019)

- This study delves into the realm of Computational Fluid Dynamics (CFD) analysis concerning the cooling of gas turbine blades via staggered hole configurations. Within the scope of this paper, two distinct blade geometries were considered: one featuring inline holes and the other embracing a staggered hole arrangement across the blade's surface. Employing identical boundary conditions for both models, a comprehensive analysis ensued, culminating in a comparative evaluation of outcomes.
- Turbines stand as quintessential power-generating mechanical marvels. They derive their might from the incendiary combustion of gases emanating from the combustor, channeling this energy directly to the turbine blade's domain.
- At the epicenter of any turbine's prowess resides the blade, a pivotal component tasked with harnessing the potential of high-temperature, high-pressure gases.
- The blade's mettle is exemplified by its choice of material, one that braves the rigors of elevated temperatures. The alloy of choice, Inconel 718 (a nickel-chromium alloy), showcases the blade's resilience against thermal extremities

Ragul et al. (2017)

- In this study, we have taken into account two distinct fluid domains: one involving the passage of hot gas through the turbine, and the other encompassing the flow of coolant air over the plenum and within the blade structure. This delineation has been achieved through independent meshing using Ansys CFD meshing software.
- An aero-thermal analysis has been undertaken to delve into the intricate temperature dynamics within a turbine blade, particularly when coolant is expelled from the trailing edge, incorporating a spanwise vector.
- Gaining insights into the nuanced temperature fluctuations under varying coolant flow conditions is poised to yield valuable insights for the application of analytical methodologies in discerning aerodynamic losses.
- The central pursuit in attaining these objectives revolves around the accurate determination of coolant mass flow rates and the precision of coolant ejection mechanisms.

4.0 Results and Analysis

Singh, Shukla (2019)

The process of creating the model was initiated within the framework of CAD modeling. Within the working

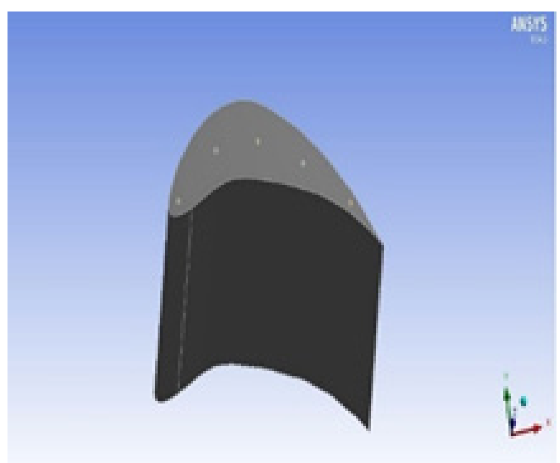

Figure 3. Geometry of blade

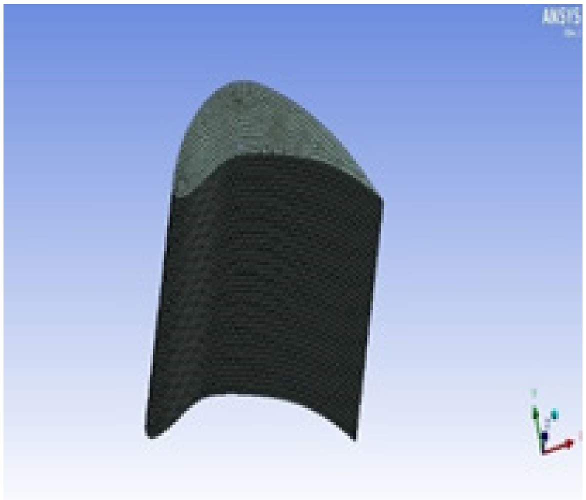

Figure 4. Meshing of blade.

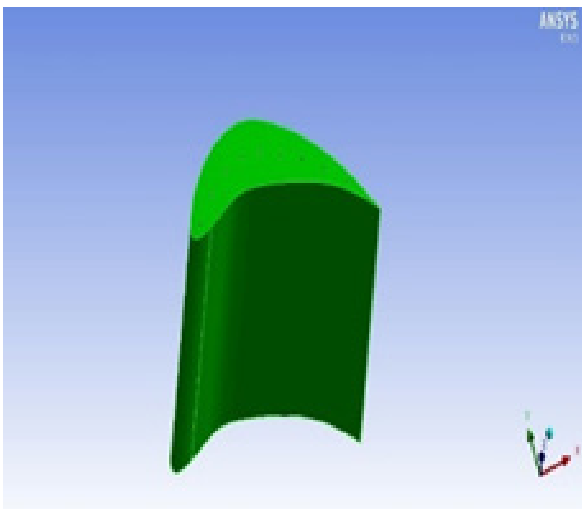

Figure 5. Geometry of 5 inline holes blade.

plane, strategic key points were established, subsequently interconnected through spline curves executed via the spline command in the CAD software. The objective was to achieve a seamless and harmonious contour representative of the desired structure. Following this, the contour, initially in 2D, underwent transformation into an area and subsequently evolved into a volumetric representation through the application of the extrude command, thus resulting in the final 3D model.

Concurrently, the hub component was meticulously generated. The inception of this segment was facilitated through the execution of the rectangle command, giving rise to a 2D form. Through a subsequent process of transformation, this 2D configuration metamorphosed into its 3D equivalent, thereby laying the foundation for the application of the extrude command. By its culmination, these individual volumes were adeptly amalgamated into a singular coherent volume, effectively culminating in the culmination of the model.

- **Solver Type:** Employing a pressure-based solver**.**
- **Physical Modeling:** The incorporation of turbulence modeling via the k-epsilon approach, along with the inclusion of the energy equation.
- **Material Properties:** Utilizing fluid properties pertinent to the specific medium, in this case, air.
- **Boundary Conditions:** Defining and applying boundary conditions encompassing parameters like pressure, velocity at inlet, velocity at outlet, and specifications for walls.
- **Solution Methodology:** Selecting and implementing solution methodologies, including the momentum equation and the turbulent energy equation, to effectively address the system.
- **Solution Initialization:** Executing the necessary initialization steps to establish the initial solution state, serving as the foundational point for subsequent iterations.Solution Execution: Commencing the solution process, setting the convergence criteria, and orchestrating the solution iterations for the attainment of a converged solution**.**

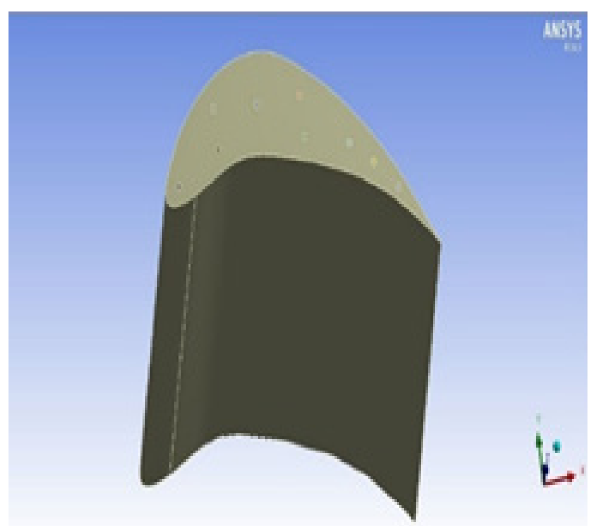

Figure 6. Geometry of 14 staggered holes.

Table 2. Mechanical properties of Chromium steel andInconel 718

Properties	Units	Chromium steel	Inconel 718
E	Mpa	80705	205005
P	Kg/m^3	7754	8192
K	W/m-k	24.5	25.8
μ	- - -	0.291	0.293
Cp	j/kg-k	435.801	586.253
Melting point	^0C	1415	1346
Yield stress	Mpa	656	1068

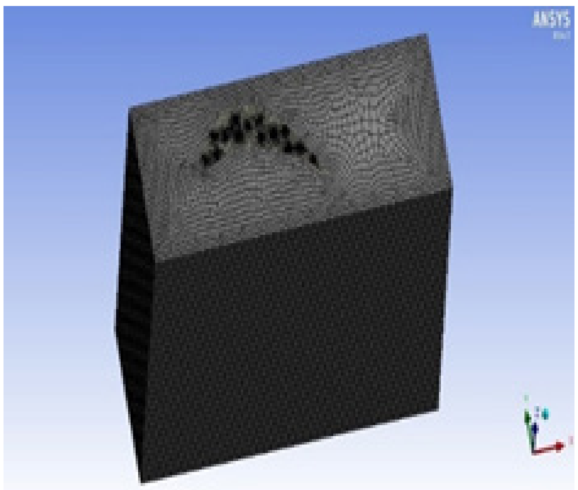

Figure 7. Meshing of 14 staggered holes.

The determination of heat transfer coefficient entails the utilization of iterative techniques, with turbulence realizable (k-e) models being prominently employed. Notably, the investigation underscores the presence of elevated temperatures primarily concentrated at the leading edge of the blade geometry. A discernible trend reveals a gradual temperature reduction spanning from the aforementioned leading edge to the trailing edge. With specific regard to the configuration featuring nine inline cooling holes, strategically integrated to facilitate the passage of cooling air, pertinent observations are gleaned. This is visually corroborated by referring to the accompanying diagram, wherein a palpable temperature reduction is evident in the vicinity of the cooling apertures..

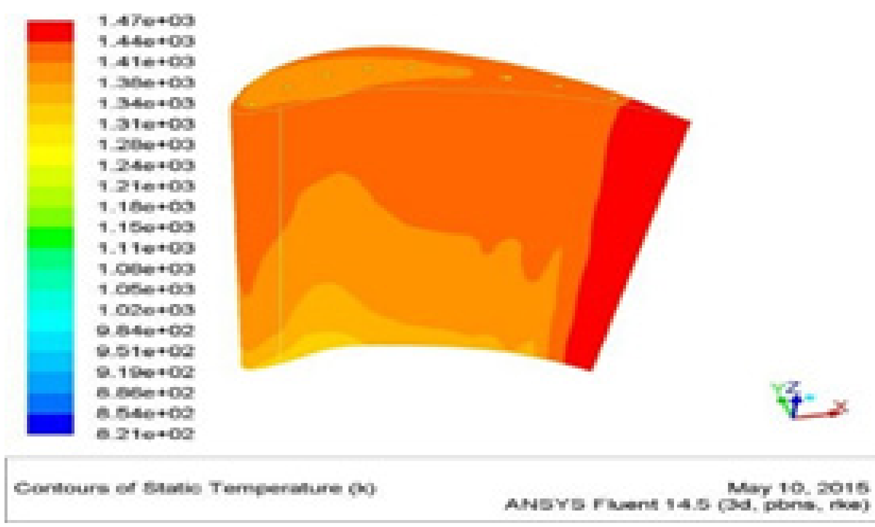

Figure 8. Counter Flow of static temperature 9 inline holes.

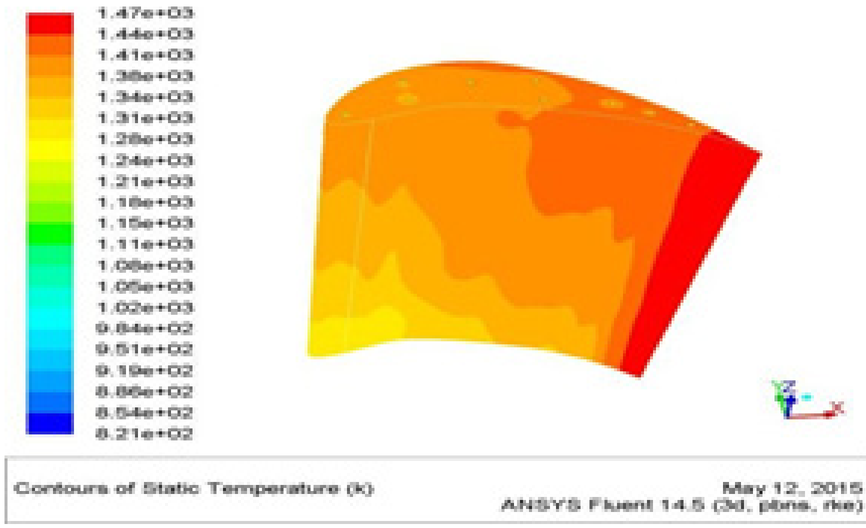

Figure 9. Contour of static temperature of 09 staggered holes.

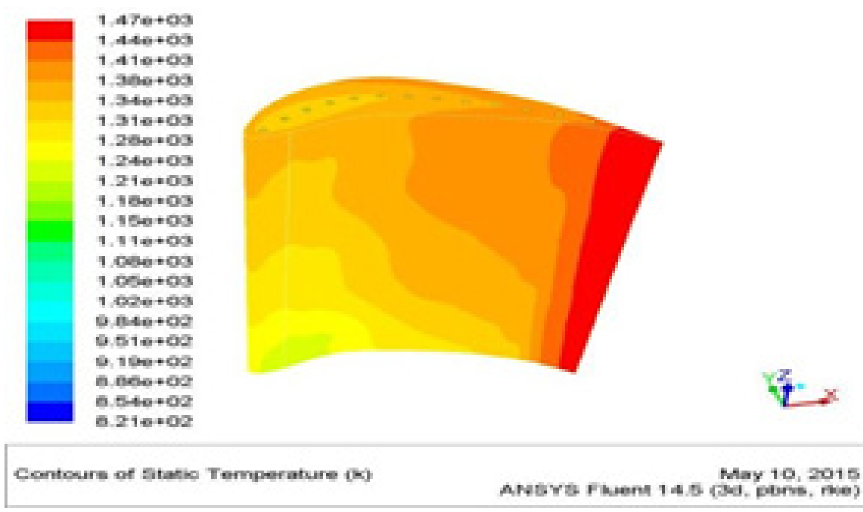

Figure 10. Contour of static temperature of 14 inline holes.

- Implementing a staggered arrangement of 9 drilled holes yielded distinct temperature variations, as illustrated in the corresponding figure. Notably, the blade's temperature demonstrated a marked reduction compared to inline-drilled holes. The temperature dwindled from 1397.663K to 1343.653K through the mere alteration of hole arrangement while maintaining the same number of holes.
- An investigation into the effects of 13 inline holes merits attention due to constrained hole numbers. This aspect finds resonance in previous studies by RDV Prasad, wherein a minimum temperature of 1099.96K was reported for 13 holes. Similarly, K Hari Brahmaiah reported a temperature of 1112K. However, my examination uncovered a temperature of 1303.689K for 13 staggered holes, introducing a noteworthy divergence.
- The consequential decrease in temperature can precipitate a reduction in thermal efficiency, primarily attributed to an augmented utilization of air for cooling purposes. This inevitably leads

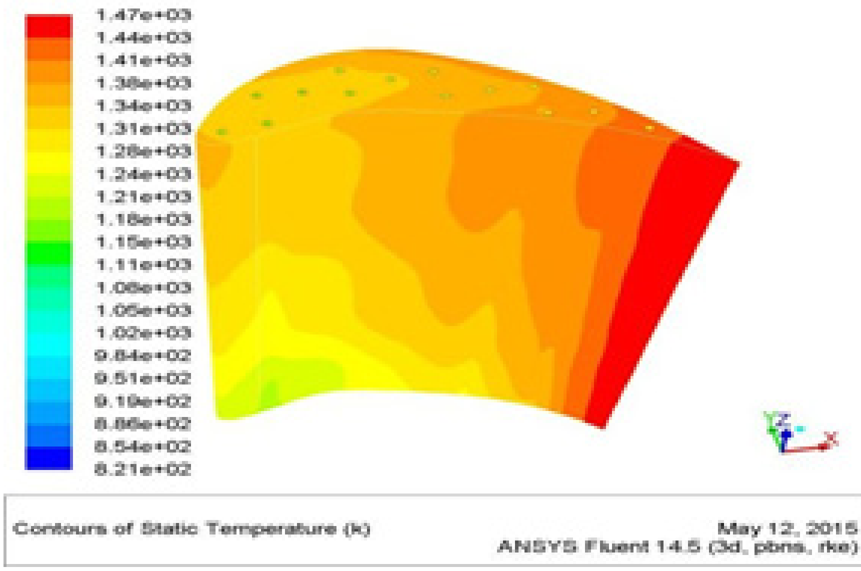

Figure 11. Contour of static temperature of 13 inline and staggered holes.

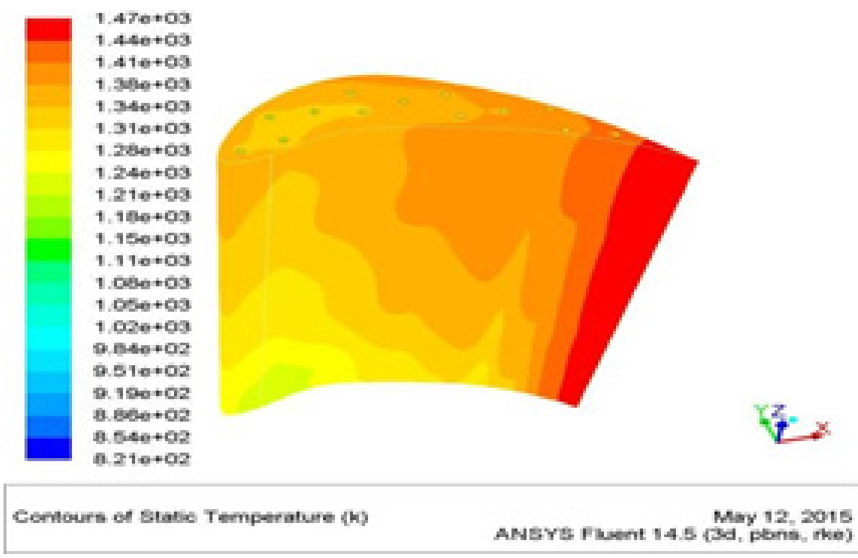

Figure 12. Contour of static temperature of 13 inline and staggered holes.

to a diminished influx of air into the combustion chamber of the gas turbine plant.

- Notably, the 13-hole configuration yielded a temperature of 1303.689K for identical material conditions. In light of this, I delved into the performance of a staggered arrangement involving 14 drilled holes, subsequently determining a temperature of 1291.784K.
- Among candidate materials, Inconel 718 stands out as the optimal choice for blade cooling, attributed to its ability to yield maximum heat transfer rates while simultaneously mitigating stresses and strains relative to Chromium steel. This informed selection is supported by pertinent references,

Table 3. Total heat transfer rate and No of holes (staggered) [Inconel 718]

No of Holes	9	13	14
Total heat transfer rate (watts)	3752	5081	5336.5

thereby solidifying Inconel 718's standing as the superior material choice.

Narendar *et al.* (2019)

The role played by the turbine inlet temperature is undeniably pivotal in influencing the overarching

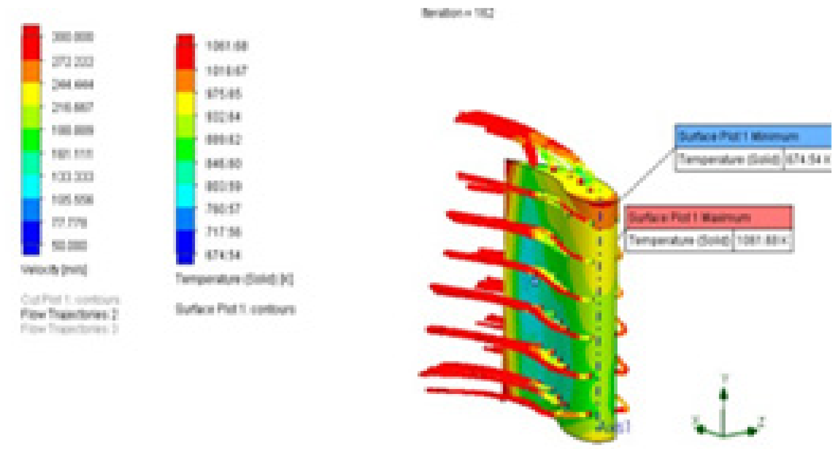

Figure 13. Representation of fluid flow Velocity on blade surface on pressure side in inline hole arrangement.

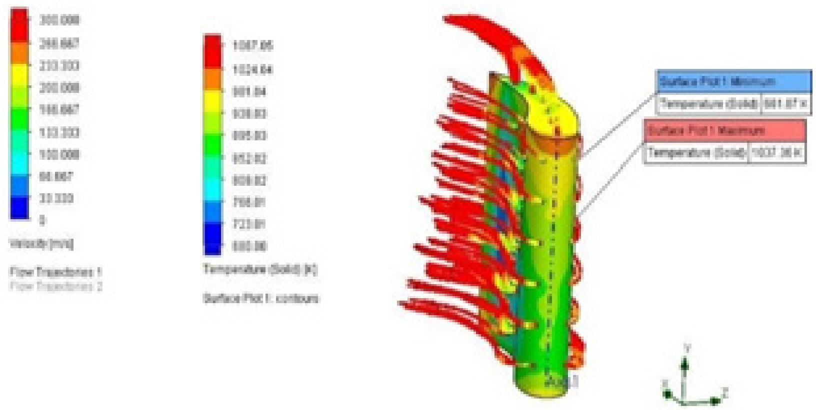

Figure 14. Representation of fluid flow Velocity on blade surface on pressure side in staggered hole. arrangement.

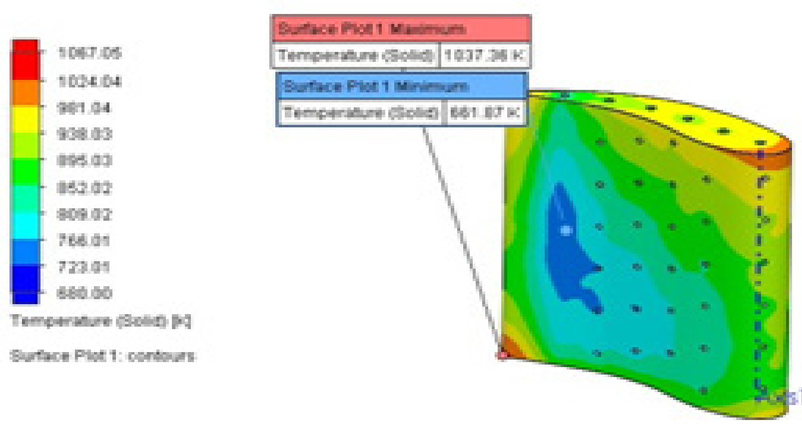

Figure 15. Representation of blade surface temperature on Pressure side of blade in staggered hole arrangement.

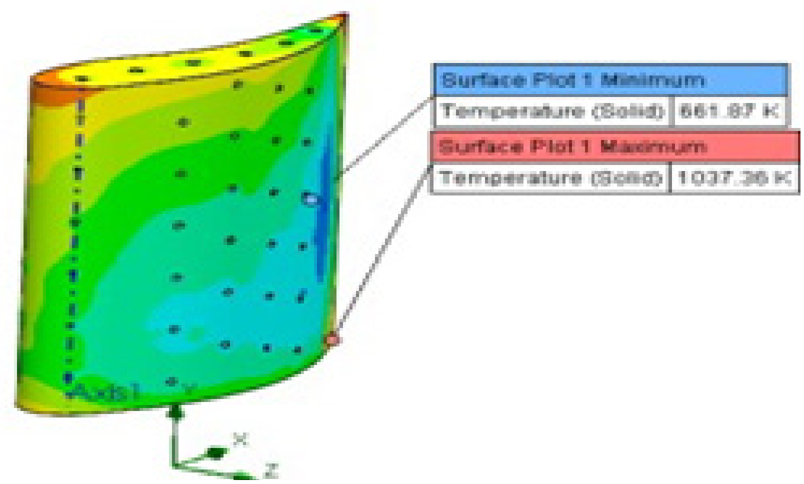

Figure 16. Representation of blade surface temperature on suction side of blade in staggered hole arrangement.

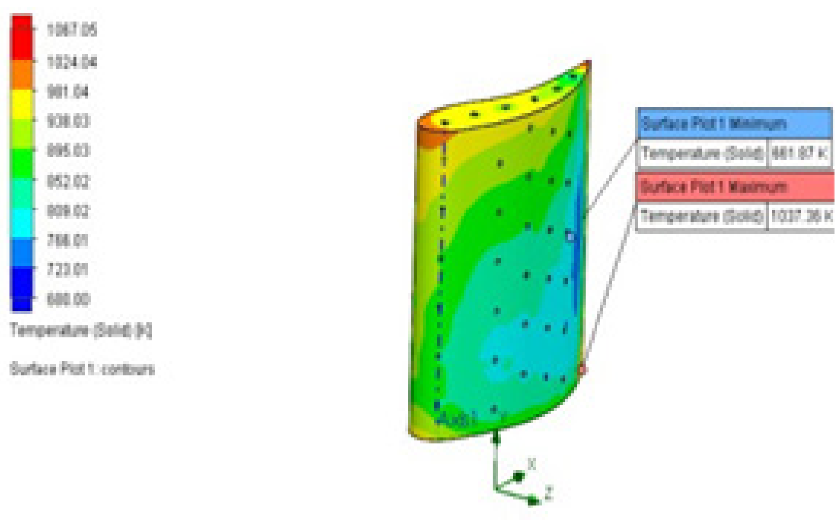

Figure 17. Representation of blade surface temperature on suction side of blade in inline hole arrangement

performance of the turbine. Even a seemingly modest increment of 1% in the turbine inlet temperature yields a noteworthy 2 to 3% surge in the engine's comprehensive output. This underlines the paramount significance that the turbine inlet temperature holds within this context. The current investigation is centered on the modeling and comprehensive analysis of turbine blade film cooling. Employing the "SolidWorks R2018" software, a detailed Computational Fluid Dynamics (CFD) analysis was conducted on the turbine blade. The ensuing results have been meticulously examined and subjected to thorough discussion.

- The visual analysis of the presented figures reveals a discernible temperature distribution spanning the blade surface, registering values within the range of 674.54 K to 1061.89 K within the context

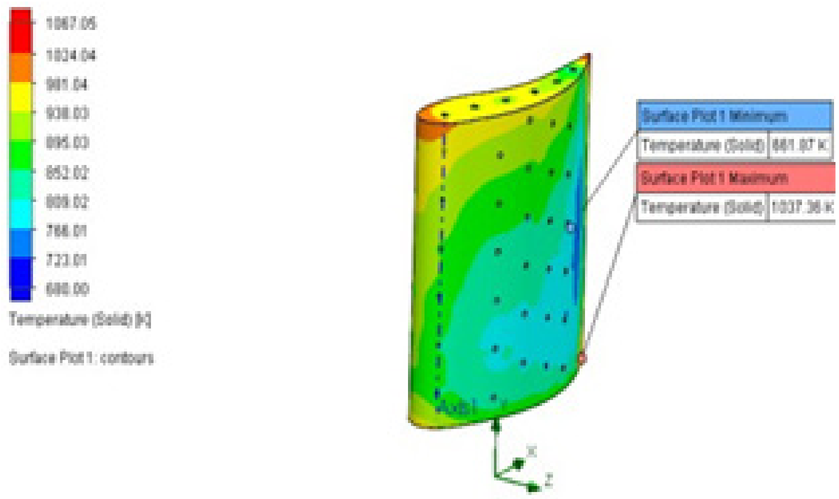

Figure 18. Representation of blade surface temperature on suction side of blade in staggered hole arrangement.

of inline hole arrangement. Notably, the zenith of temperature on the blade surface corresponds to 1061.89 K.

- Equally noteworthy is the discovery that, regardless of hole arrangement—inline or staggered—the aggregate fluid temperature demonstrates a variance spanning 574 K to 1236 K.

Ragul et al. (2017)

- To facilitate temperature measurements, the central blade is identified as indicated in Table 1, outlining its dimensional properties. Concurrently, the wind turbine's specifications are illustrated in Figure 1. The sectional flow configuration, depicted in

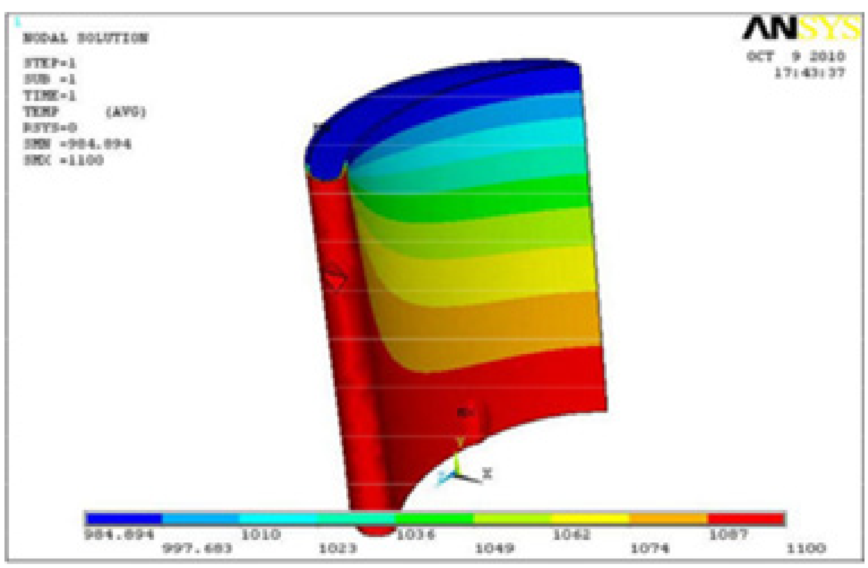

Figure 19. Temperature distribution analysis of turbine blade.

Table 4. Blade specification

Number of blades	1
Chord length	140 mm
Pitch	105 mm
Pitch to chord ratio	0.75
Axial chord length	83 mm
Throat width	30 mm
Gauging angle	74°
Inlet flow angle	0°
Outlet flow angle	70°-78°
Stagger angle	51.9°
Span	454 mm
Trailing edge thickness	3.2 mm

Figure 2, was meticulously devised utilizing Pro/Engineer (Pro/E) commercial software.

- Utilizing the Finite Element Method through Ansys software, a comprehensive structural analysis encompassing diverse frequency modes is conducted for both the configurations of the gas turbine, with and without the presence of holes. The outcomes of this structural assessment across different modes are visually represented through the presentation of corresponding figures.
- To tackle fluid dynamics equations, Fluent harnesses the finite-volume methodology, offering a platform for Computational Fluid Dynamics (CFD) to replicate intricate fluid flow scenarios. In the scope of this study, Fluent has been employed for both problem resolution and subsequent post-processing. The visual representation of the meshed turbine blade model is illustrated in Figure 10, while the specific boundary conditions applied to the gas turbine blade are detailed in Figure 24. The outcomes derived from the CFD analysis encompass diverse parameters, including pressure and temperature distributions, showcased graphically in Figures.Within the domain of structural analysis, Table 5 serves as a repository, presenting a comparative evaluation between vibration-related results for gas turbines with and without holes.

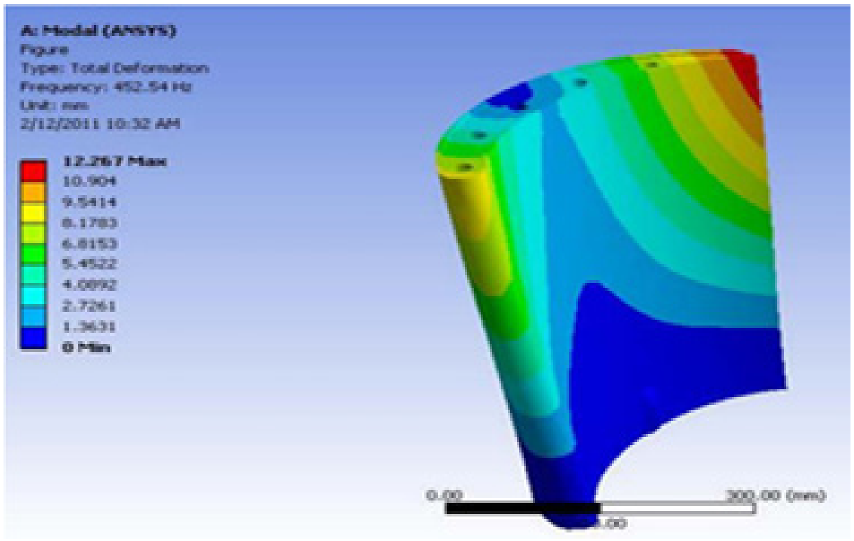

Figure 20. Vibration analysis of turbine blade without hole (frequency – 252.59 Hz).

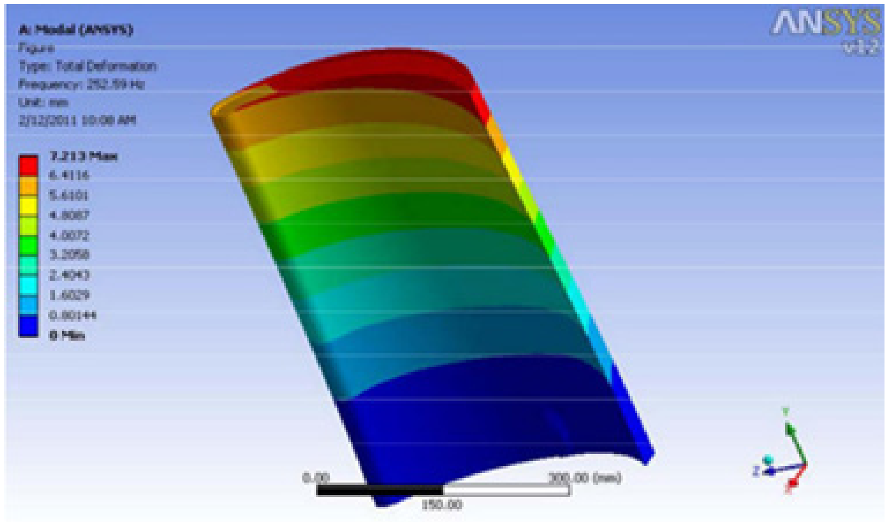

Figure 21. Vibration analysis of turbine blade with hole (frequency – 252.59 Hz).

Table 5. Comparison of gas turbine vibration analysis.

Turbine Blade With Hole			
MODE 1	252.59 Hz	MODE 1	254.43 Hz
MODE 2	450.63 Hz	MODE 2	452.54 Hz
MODE 3	836.11 Hz	MODE 3	841.40 Hz

5.0 Conclusion

Our study delves into the metallurgical intricacies of gas turbine blade design, with a central focus on the exceptional INCONEL 718 alloy, renowned for its metallurgical excellence. This alloy plays a pivotal role in enhancing the structural integrity and thermal efficiency of the turbine blades, serving as a testament to the indispensable role of metallurgy in advancing gas turbine technology.

Our findings underscore the critical influence of material selection, particularly the incorporation of INCONEL 718, on the mechanical and thermal performance of gas turbine components. The choice of this alloy has not only bolstered the overall durability of the blades but has also contributed significantly to improving their thermal efficiency. The meticulous exploration of INCONEL 718's properties and advantages within the context of these critical components offers valuable insights poised to make a meaningful contribution to the broader field of materials science and metallurgy.

By showcasing how INCONEL 718 enhances the performance and reliability of gas turbine blades, our research advances the state of the art in gas turbine blade design, further solidifying the alloy's position as a cornerstone in metallurgical advancements for high-performance applications.

6.0 References

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