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Determination of Thermal Stresses on Turbine Blades of Gas Turbine with Different NACA Series Airfoils

Payal N. Patel[1], Dr. Amit R. Patel[2]

[1]*Master of engineering student, Department of Mechanical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, India – 390002*

[2] *Associate Professor, Department of Mechanical Engineering, Faculty of Technology & Engineering, The Maharaja Sayajirao University of Baroda, India – 390002.*

ABSTRACT

In advanced gas turbines, the turbine blade operated temperature is for above the melting point of blade material. A cooling scheme must be developed for continuous safe operation of gas turbines with high performance. A vital role is played by the compressor on jet engine as it concerns about the initial compression on engine bleed system and aircraft cooling. Two types of compressor are used in jet engine and that is axial compressor and centrifugal compressor. Here we work on axial compressor. As its major application, gas turbine engines are in large use.

In this project NACA6409, NACA6412 and NACA64012 airfoil is taking for turbine blade. Turbine blade is designed in CATIA V5R19 and for analysis we are using ANSYS 18.1 software. Here we are using chromium steel, inconel-718 and inconel-625 as turbine blade material. Thermal and structural analysis is performing to determine the heat flux, temperature distribution and stress of the blade. And finally conclude which material is better with blade.

Keywords: Turbine Blade, NACA6409, NACA6412, NACA64012, ANSYS 18.1, Temperature, Stress, Heat flux.

NOMENCLATURE

N	Rotational speed (rev/sec)
U	Mean blade speed (m/sec)
A	Area of annular (m^2)
c	Chord length (mm)
h	Height of blade (mm)
r_{root}	Radius of blade at root (mm)
r_{tip}	Radius of blade at tip (mm)
r_m	Radius of mean rotor (mm)
ω	Angular velocity (rad/sec)
K	Thermal conductivity (W/m-k)
ρ	Density of material (kg/m^3)
Cp	Specific heat (J/kg-k)

1. INTRODUCTION

A Gas turbine engine is also known as a combustion turbine is type an internal combustion engine. It has an upstream compressor and downstream turbine with the combustor in between. Air is enters to a compressor with high pressure which compresses the air and delivers it to the combustion chamber. The fuel injector feed fuel continuously. Fuel and compressed air are mixed in combustion chamber and continuous combustion takes place at constant pressure. The high pressure and high temperature gases then enter into the turbine, where they expand to provide drive power for the turbine. The turbine is directly connected to the compressor (i.e. Turbine drives the compressor and provides power). After the turbine they expand further in exhaust. The schematic view of Gas Turbine Engine is shown in the Figure 1

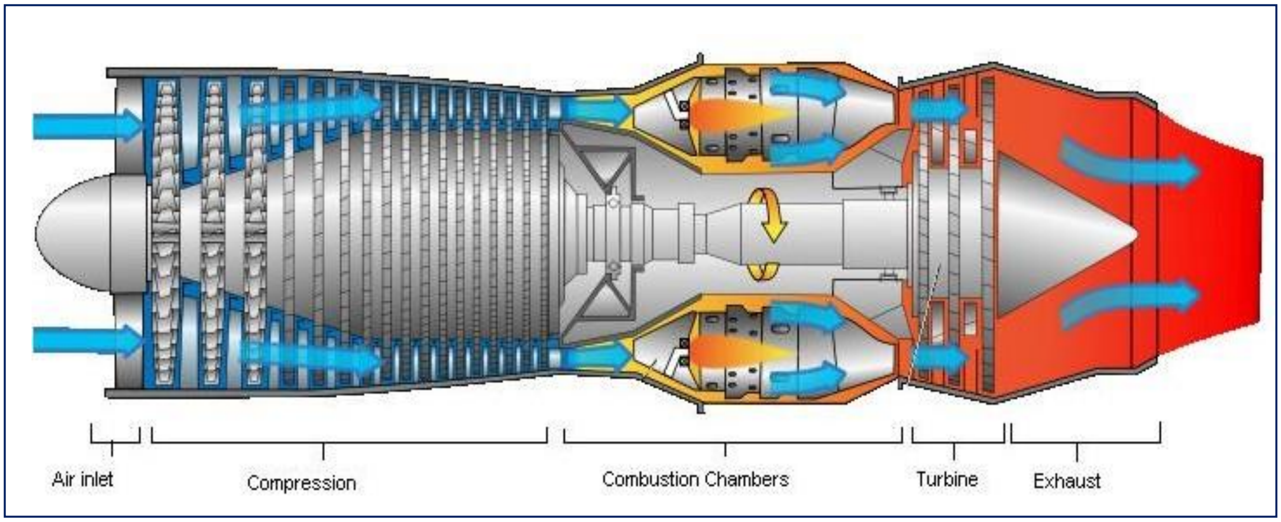


Figure 1: Schematic View of Gas Turbine Engine.(1)

Priyanka Singh, found that the temperature distribution on the 13 staggered holes, uniformly distributed along the blade area, as compared to 13 inline holes and the heat transfer is also increases in the 13 & 14 staggered holes arrangements.(3)Bathineedi Naga Babu, used NACA 6409 and NACA 4421 with ZAMAK, Y2O3, Zirconium material. And conclude that NACA6409 with ZAMAK material & Y2O3 coating was best application for the steam turbine blades for up gradation of steam turbine blade life cycle.(4)K Hari Brahmaiah, conclude that Inconel718 is better thermal properties and induced stresses are lesser than the Chromium steel.(5)Himanshu A Surakarta, conclude for the blade, the peak heat transfer coefficient value is at the leading edge, which then decreases gradually on the suction side until the trailing edge.(1)Ahmed Jbdulhussein Jabbar, used titanium alloy, stainless steel alloy and Aluminum2024 alloy as blade material and conclude Titanium alloy is better than stainless steel alloy and aluminium 2024 alloy for stability and stress.(6)Archana Pulicherla, used NACA 6412 for turbine rotor blade. She conclude that overall results of static and vibrational analysis, the deformation, stress, strain and vibrations are less for titanium material while compared with other materials .(7) Ravi Ranjan Kumar, worked on NACA6409 profile and has been selected as base model and then it is modified by bending it through 72.5° and 145°.These three different blade profiles have been analysed for three different materials Super Alloy X, Nimonic-80A and Inconel-625 at three different speed 20000, 40000 and 60000RPM. He found that NACA6409 with 72.5° result for all material at all speed. Among all the material Inconel-625 gives best result. Hence Blade of Inconel-625 having 72.5° bent profile is the best combination for all RPM.(8)Anilkumar Konderu, used NACA6409, NACA64012 aerofoils and has been selected as base model. Two various materials Nimonic-80A, Inconel-625 with 300rev/sec and 450rev/sec.(9)

2. MATERIALS AND METHODOLOGY

First we decide the geometry and after design geometry in CATIA V5R19 we designed CAD model of blade. After this CAD model we selecting a material for blade and analyzed in ANSYS 18.1. After validation we work further on another blade.

Table 2: Material properties (3, 9)

Propertie	Units	Chromium Steel	Inconel-625	Inconel-718
Yield Strength	MPa	275	448	1100
ρ	kg/m^3	7754	8440	8192
K	W/m-k	11.2	9.8	25.8
Cp	J/kg-k	435.801	550	586.253
Melting point	°C	1415	1350	1346
Young's Modulus	GPa	200	207.5	205
Poisson's Ratio	-	0.3	0.3	0.293

Table 2: NACA 6409 with speed of 300rev/sec (9)

Parameters	300 rev/sec
Height	49.2mm
Radius of blade at root	197.4mm
Radius of blade at tip	246mm
Chord	38.4mm

Inlet temperature: 1250 K

Rotational speed (N): 300rev/sec

Area of annular (A): 0.0692m^2

Mean blade speed U: 420m/sec

$U_m = 2\pi N r_m$ ....(1)

Height of the blade:

Figure 2: NACA 6409 airfoil with distance 49.2mm(9)

$h = \frac{AN}{U}$ ....(2)

Radius of blade at root and tip

$r_{tip} = r_m + \frac{h}{2}$ ....(3)

$r_{root} = r_m - \frac{h}{2}$ ....(4)

Adopting the height to chord $\left(\frac{\text{height}}{\text{chord}}\right)$= 1.28

$\omega = \frac{2\pi * RPM}{60}$ rad/sec ....(5)

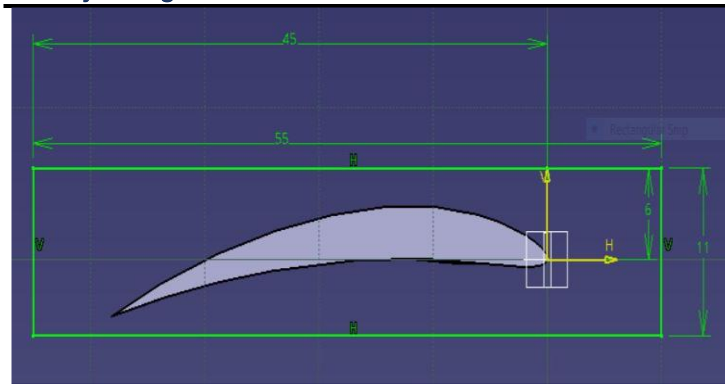


Figure 3: NACA 6409 blade with support dimension

2.1 Cad Design (9)

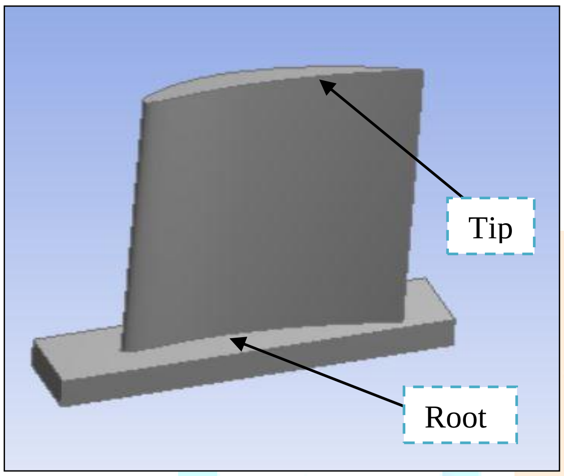


Figure 4: CAD model of Blade with support

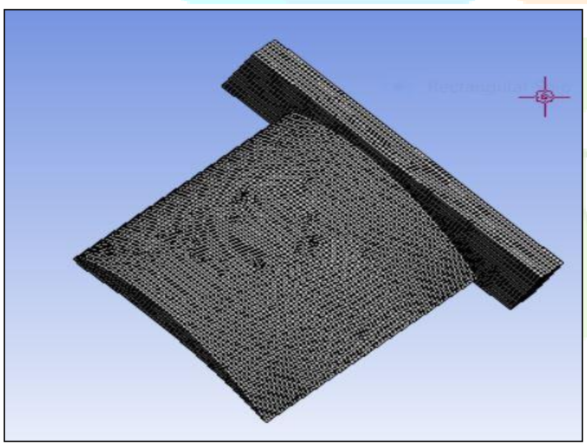


Figure 5: Meshing with support

2.2 Setup

The blade cooling problem was modeled as a Convection Heat Transfer problem and with the use of ANSYS 18.1-FLUENT, it was setup and simulated. The fluid material was chose to be air from ANSYS 18.1-FLUENT database.

2.3 Boundary Conditions

Thermal analysis (9)

- Inlet temperature: 1250 K
- Rotational speed (N): 300rev/sec (1885.7 rad/sec)
- Heat Transfer Coefficient (W/mm^{2}K) : 0.0025

3. RESULT

To finding heat flux first we done steady state thermal analysis and then for stress static structural analysis.

NACA 6409

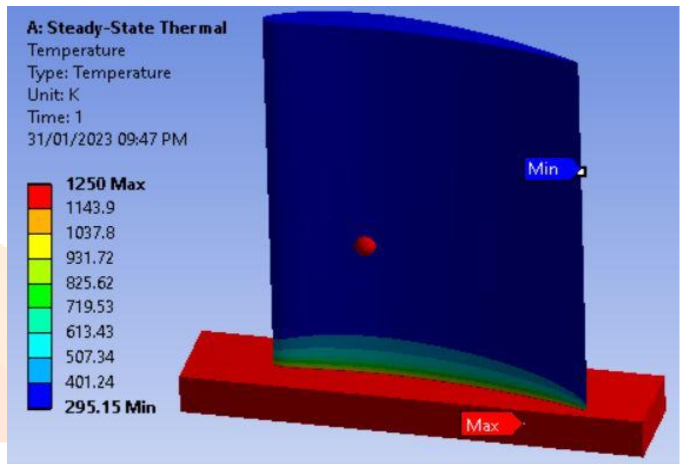


Figure 6: Temperature Distribution of Chromium steel

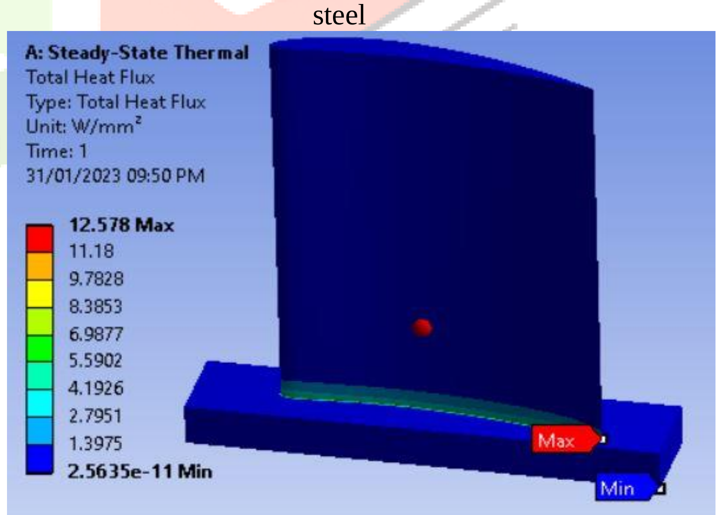


Figure 7: heat flux of Chromium steel

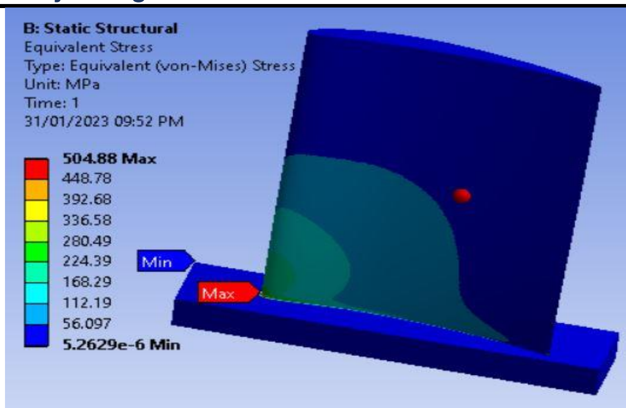


Figure 8: Stress of Chromium steel

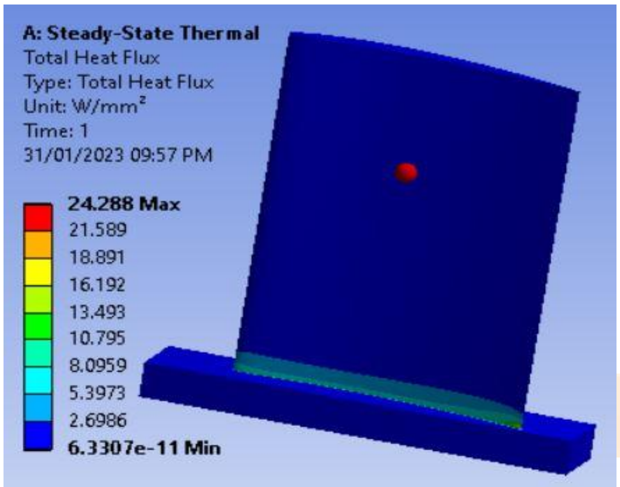


Figure 9: heat flux of Inconel-718

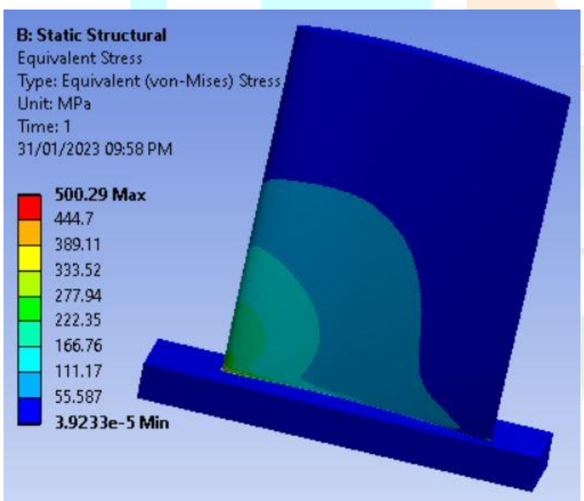


Figure 10: Stress of Inconel-718

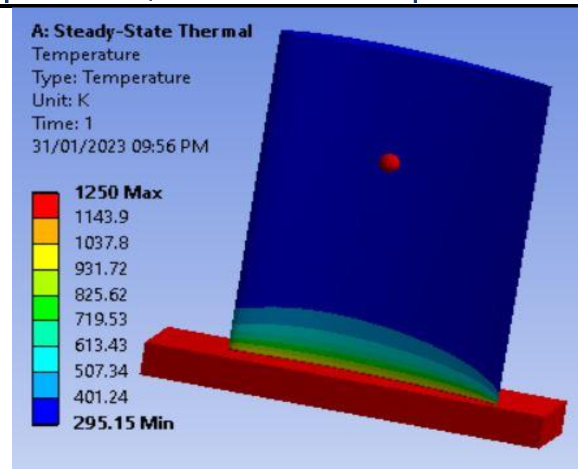


Figure 11: Temperature Distribution of Inconel-718

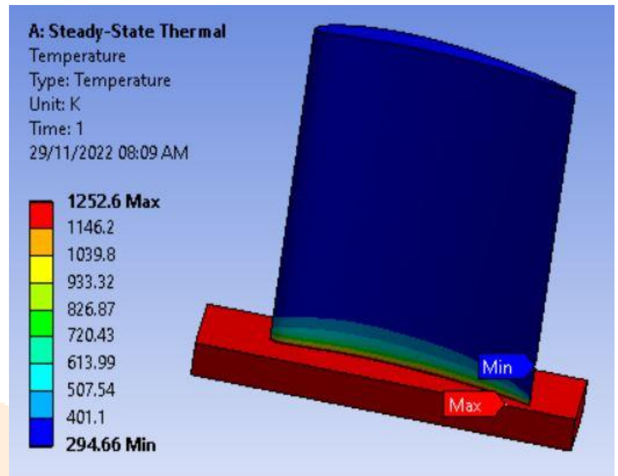


Figure 12: Temperature Distribution of Inconel-625

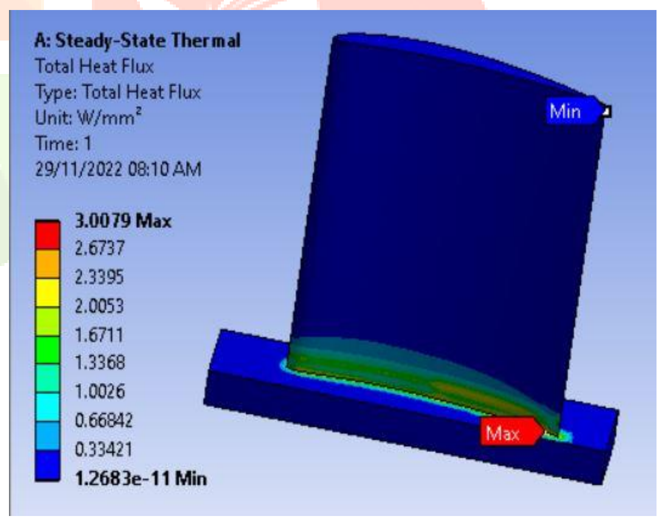


Figure 13: heat flux of Inconel-625

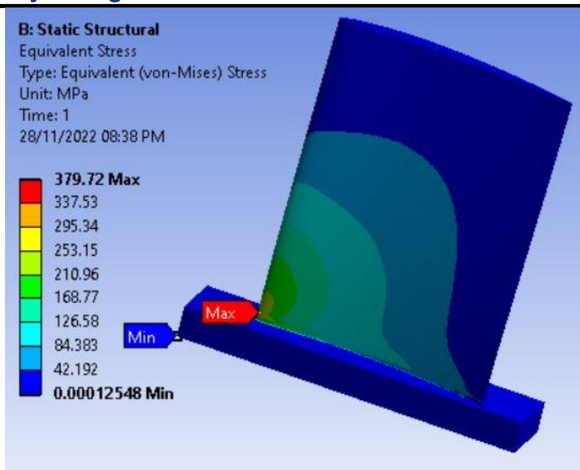


Figure 14: Stress of Inconel-625

NACA 6412

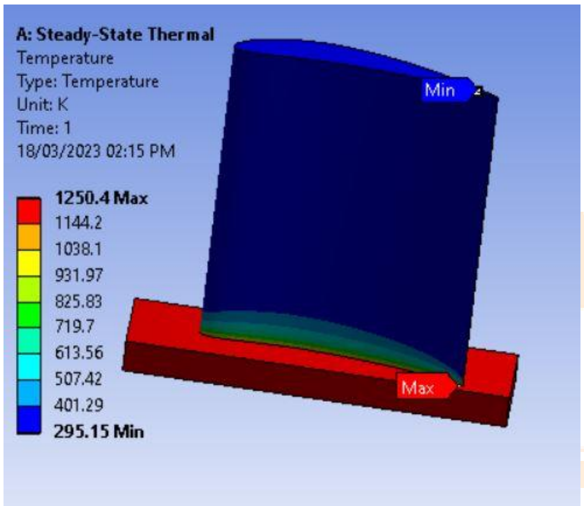


Figure 15: Temperature distribution of Inconel-625

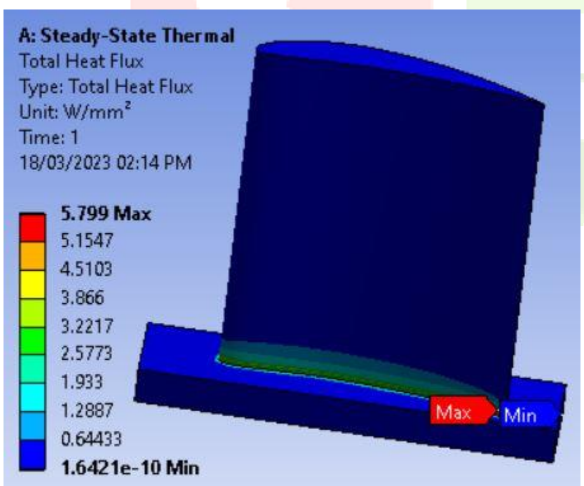


Figure 16: heat flux of Inconel-625

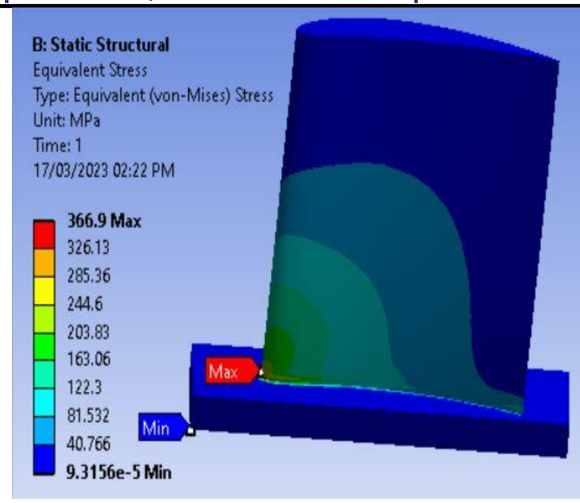


Figure 17: Stress of Inconel-625

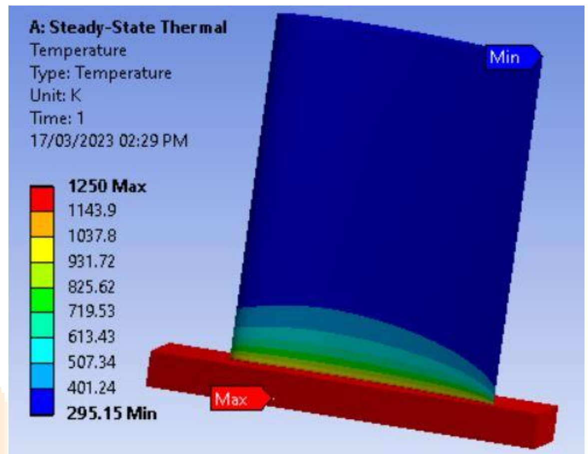


Figure 18: Temperature Distribution of Inconel-718

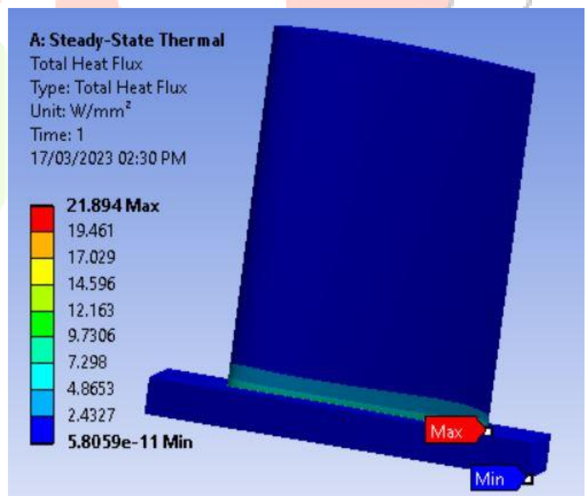


Figure 19: heat flux of Inconel-718

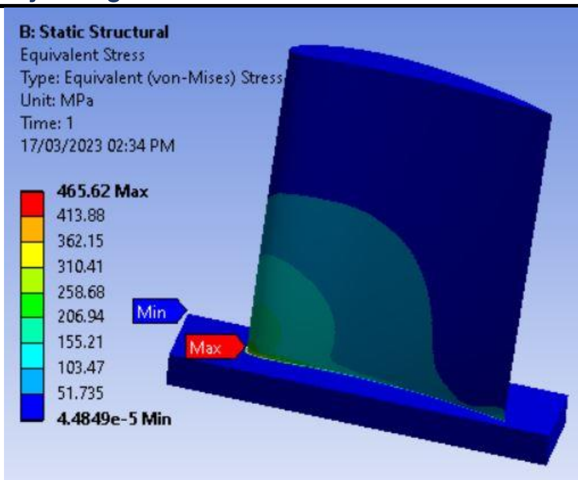


Figure 20: Stress of Inconel-718

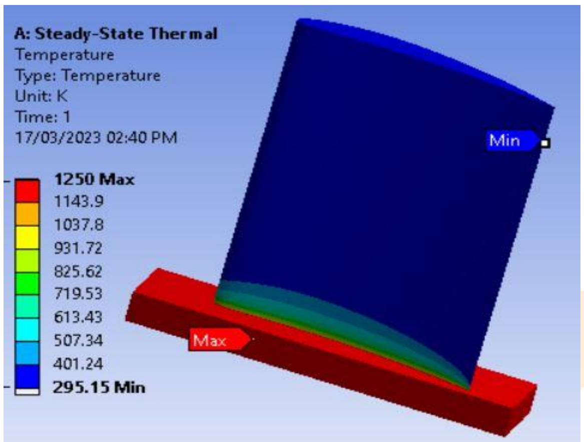


Figure 21: Temperature Distribution of Chromium steel

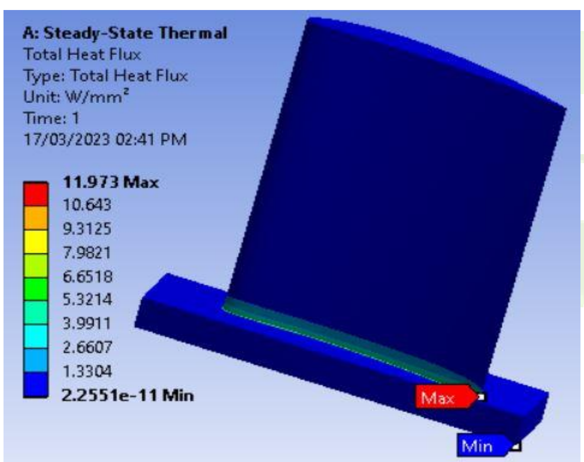


Figure 22: Heat flux of Chromium steel

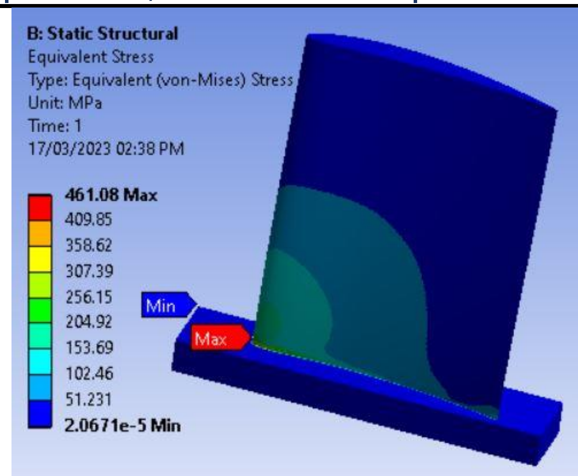


Figure 23: Stress of Chromium steel

NACA 64012

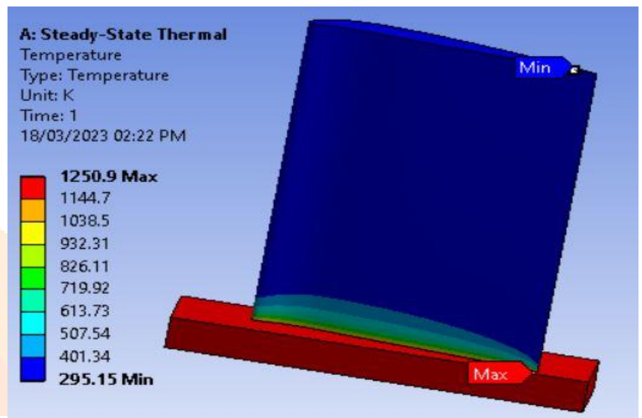


Figure 24: Temperature Distribution of Inconel-625

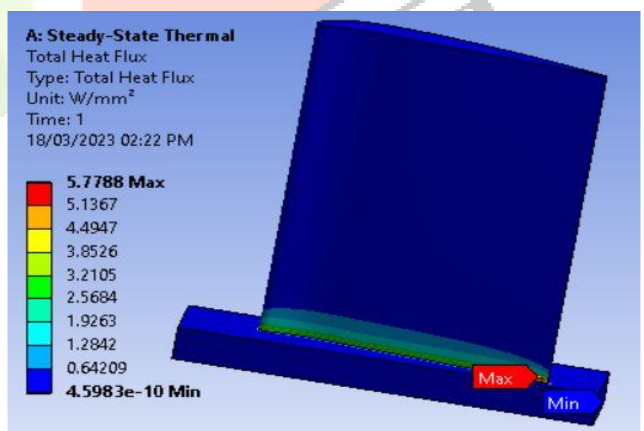


Figure 25: Heat flux of Inconel-625

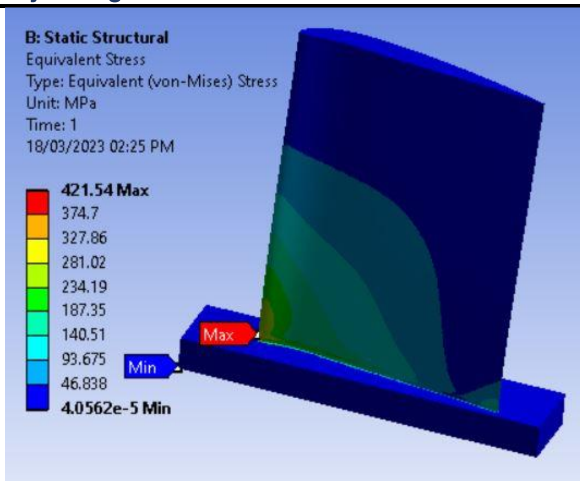


Figure 26: Stress of Inconel-625

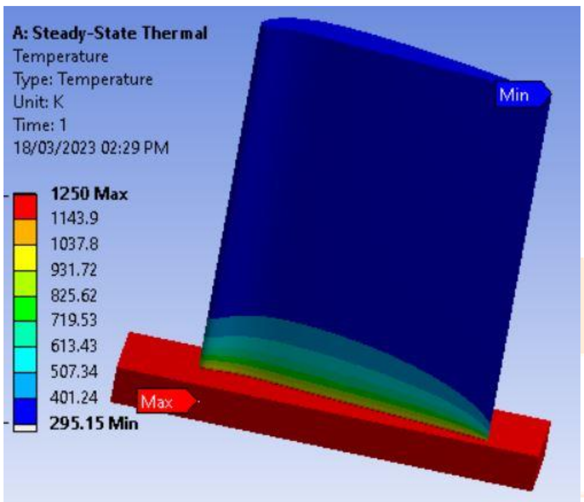


Figure 27: Temperature Distribution of Inconel-718

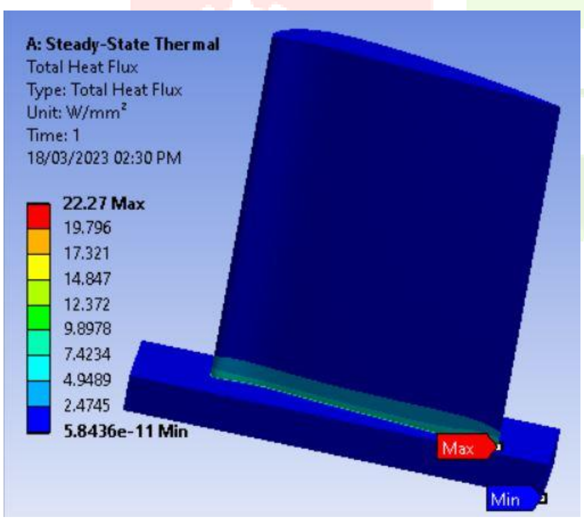


Figure 28: heat flux of Inconel-718

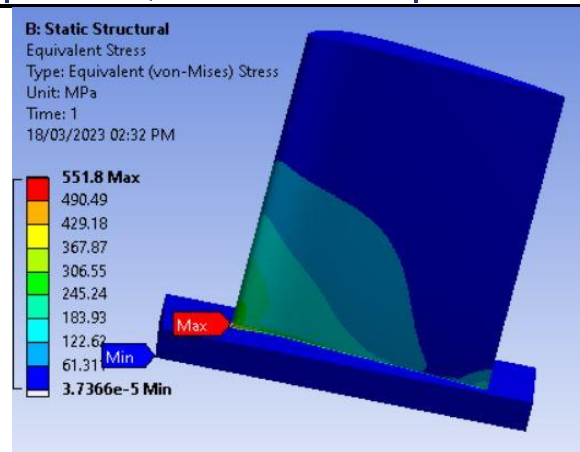


Figure 29: Stress of Inconel-718

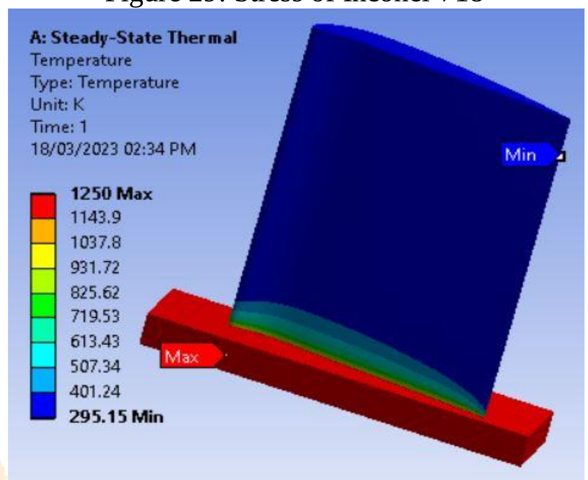


Figure 30: Temperature Distribution of Chromium steel

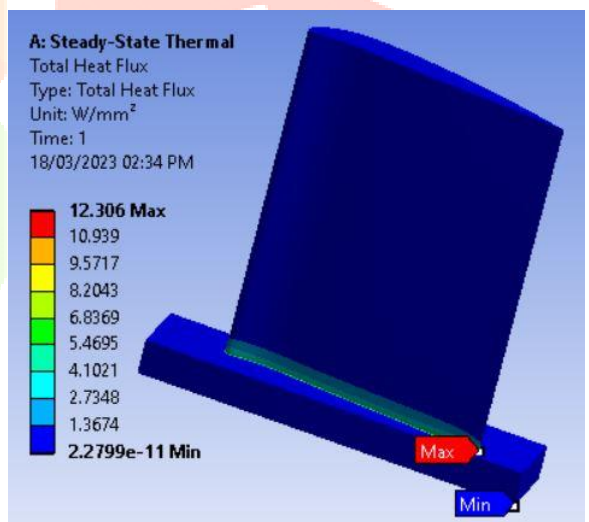


Figure 31: Heat flux of Chromium steel

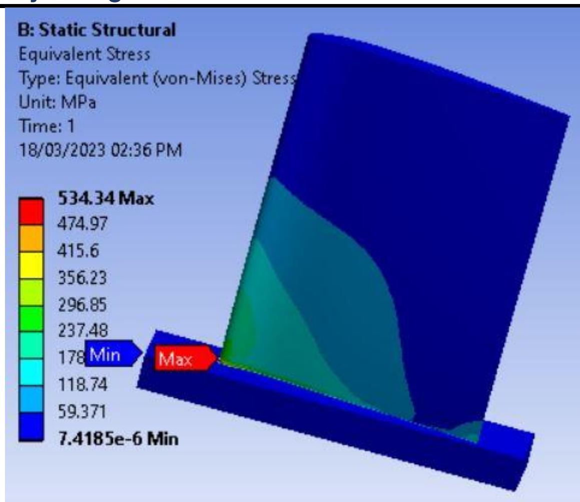
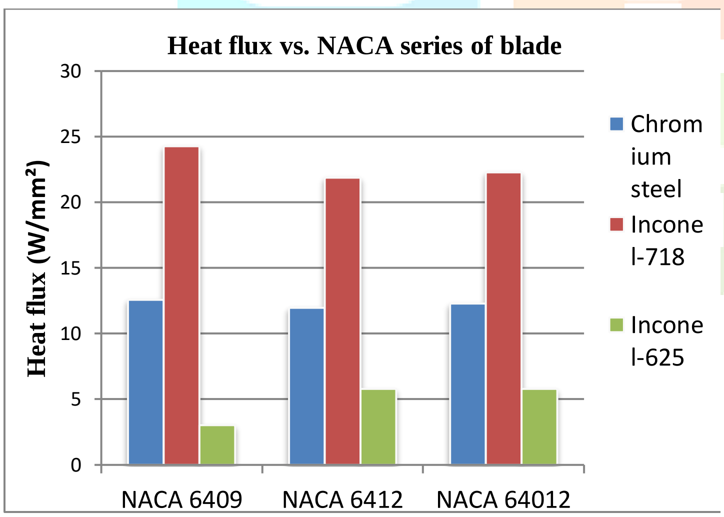


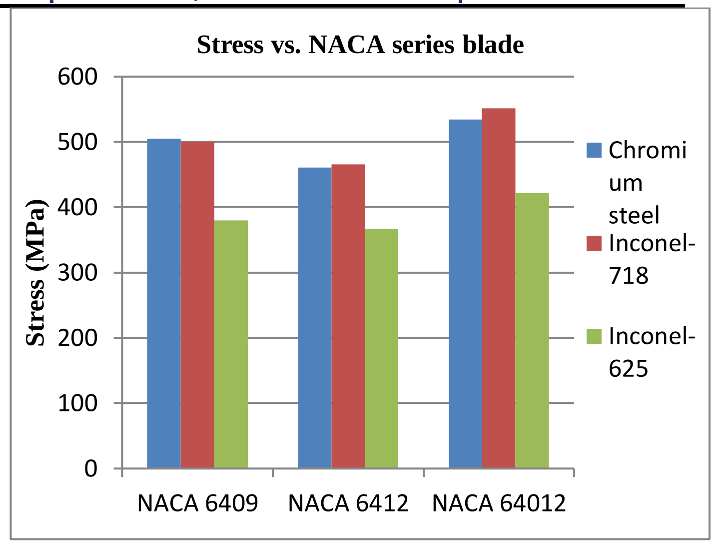
Figure 32: Stress of Chromium steel

Table 3: Stress and heat flux of materials

Models	Materials	Stress (MPa)	Heat flux (W/mm²)
NACA 6409	Chromium steel	504.88	12.578
	Inconel-718	500.29	24.288
	Inconel-625	379.72	3.0079
NACA 6412	Chromium steel	461.08	11.973
	Inconel-718	465.62	21.894
	Inconel-625	366.9	5.799
NACA 64012	Chromium steel	534.34	12.306
	Inconel-718	551.8	22.27
	Inconel-625	421.54	5.7788



Graph-1 heat flux vs. NACA series



Graph-2 Stress vs. NACA series

CONCLUSIONS

All 3 materials with different NACA series airfoils, are given considerable results, but final conclusion basis of stresses generated in the material.

- Blade is cantilever so that maximum stress generated at blade root.
- Temperature distribution is depend on thermal conductivity and heat transfere coefficient of material.
- Due to the stagnation effect we observe more temperature at blade root.
- From graph we can say that Inconel-625 has less heat flux and stress due to lower thermal conductivity and materials strength property.
- After observing all result we can say all 3 material are very strong for turbine blade, but as preference we can take Inconel-625 is give better result.

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