ISSN No:-2456 –2165

Determination of Thermal Stresses on Turbine Blades of Gas Turbine with NACA Airfoils By Finite Element Analysis

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Abstract— The compressor plays a vital role on jet engine as it concerns about the initial compression on engine bleed system and aircraft cooling. They are two types of compressor used in jet engine. They are axial compressor and centrifugal compressor. Here we discuss about the axial-flow compressor. As its major application were are in large gas turbine engines. This paper investigates the complications over the material selection, and temperature deformation that are majorly induced the stress deformations of blade in operating with different rps of 300 & 450, in the gas turbine engine. For this investigation, NACA6409, NACA64012 airfoils has been selected as base model and these are modelled by using CAD tool CATIA V5 and analysis had been done in ANSYS workbench 16.0, with two various materials viz. Nimonic 80A, Inconel 625.

Keywords:-Jet Engine, Turbine Blade, Thermal Stress Deformation, NACA6409, NACA64012, Catia V5, Ansys Workbench 15.0, Nimonic 80A, Inconel 625.

I. INTRODUCTION

The axial flow compressor compresses its working fluid by first accelerating the fluid and then diffusing it to obtain a resuired pressure increase. The working fluid is accelerated by a row of rotating airfoils (blades) called the rotor and then diffused (decelerated) in a row of stationary (blades) the stators. The axial flow compressor consists of a series of stages, each stage comprising a row of rotor blades followed by a row of stator blades. The accelerated fluid gains the velocity increase in rotor blade and it later passages to stator blade wherein the kinetic energy transferred in the rotor is converted to static pressure. A set of one rotor and one stator make-up a stage in a compressor. Frontal area in compressor inlet, one additional row of fixed blades called Inlet Guide Vanes (IGV) is commonly used to ensure that air enters the first stage rotors at the desired angle. The last row of stator vanes usually act as air straighteners to remove swirl from the air to entry into the combustion system.

The blades are curved in design, convex on one side is called suction side of blade and other side concave side is called pressure side of the blade. The chord line of an airfoil is a straight line drawn from the leading edge to the trailing edge of the airfoil. The blade shape is described by specifying the ratio of the chord to the camber at some particular length on the chord line, measured from the leading edge.

II. DESIGN OF NACA AEROFOILS

The airfoils are employed to accelerate and diffuse the air in the jet engines. The nomenclature describes the blade shapes are almost identical to that of aircraft wings. In most commercial axial flow compressors NACA series blades are used.

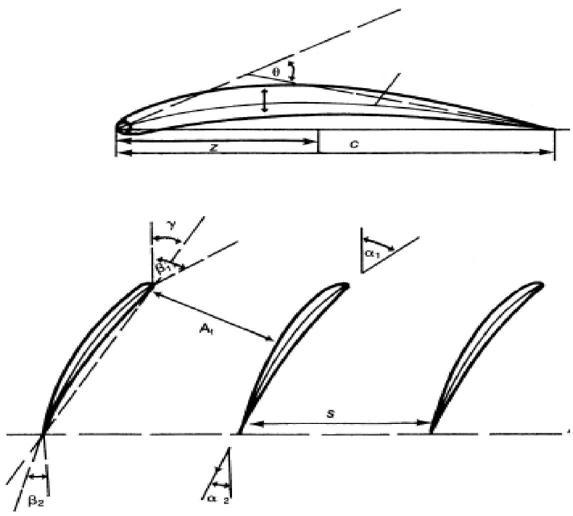

Fig. 1. Cascade Model of NACA Airfoil

A. *Following Parameters has been Considered for Modelling the NACA Airfoils:*

Inlet pressure: 5bar

Mass flow rate: 25kg/sec

Inlet temperature: 1250k

Rotational speed (N): 300rev/sec, 450rev/sec

Area of annular: 0.0692m2

Mean blade speed U: 420m/sec

$$U_m = 2\pi N r_m$$

Height of the blade:

$$h = \frac{AN}{U}$$

Radii of airfoil at root and tip

$$r_{tip} = r_m + \frac{h}{2};\ r_{root} = r_m - \frac{h}{2}$$

Adopting the height to chord (h/c) of 1.28:

$$\frac{height}{chord} = 1.28$$

NACA 6409 & 64012 with different rotational speeds		
Parameters	***300rps***	***450rps***
Height	49.2mm	74.1mm
r_{root}	197.4mm	111.4mm
r_{tip}	246mm	185.5mm
Chord	38.4mm	57.8mm

Table 1: NACA 6409 & 64012 with Different Rotational Speeds

Mechanical properties of meaterials		
Properties	***Inconel 625***	***Nimonic 80A***
Density (kg/m^3)	8440	8160
Tensile Modulus (mpa)	207500	222000
Possion's Ratio	0.3	0.3
Yield Strength (mpa)	448	780
Thermal Conductivity (w/m-k)	9.8	28.4

Table 2: Mechanical Properties of Materials

B. Nomenclature:

α – Angle of attack
β – Inlet blade angle
θ – Camber angle
c – Chord length
s – Blade spacing
z – Position of max camber
i – Angle of incidence ($\alpha_1 - \beta_1$)
t – Thickness of blade
AR – Aspect ratio of blade
γ – Stagger angle
h – Height of blade
r_{root} – Radius of blade at root
r_{tip} – Radius of blade at tip
r_m – Radius of mean rotor
ρ – Density of material
A_{cs} – constant cross sectional area of blade
r_b – distance b/w centre of rotor disc to tip of blade
ω – Angular velocity
F_c – Centrifugal force acting on per blade

C. Modelling Airfoils in CAD Tool:

By using standard assumptions, theoretical calculations are made to obtain the dimensions of the NACA 6409 & 64012 airfoils and modelled by using cad tool Catia V5 as shown in Fig 2. The design parameters are given in table I.

Fig. 2. NACA Airfoil Model in Catia V5

III. THERMAL STRESSES BY USING FEA

The finite element analysis for thermal stress analysis of gas turbine engine, rotor blade is carried out by using Ansys 16.0 software. Catia models are imported to Ansys workbench for simulating the thermal stresses on both NACA airfoils blades, with two different materials at different speeds of 300rev/sec and 450rev/sec. Discretization of geometry is done by using Ansys meshing workbench, with multizone meshing technique of solid90 elements.

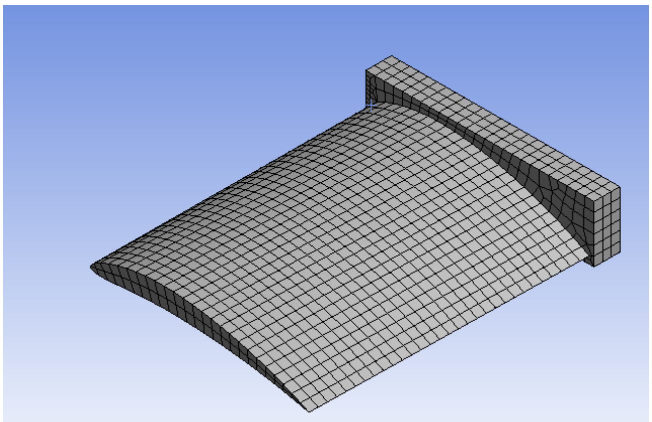

Fig. 3. Discretizing the Blade Geometry Using Ansys Wb

A. Boundary Conditions of Rotor Blade:s

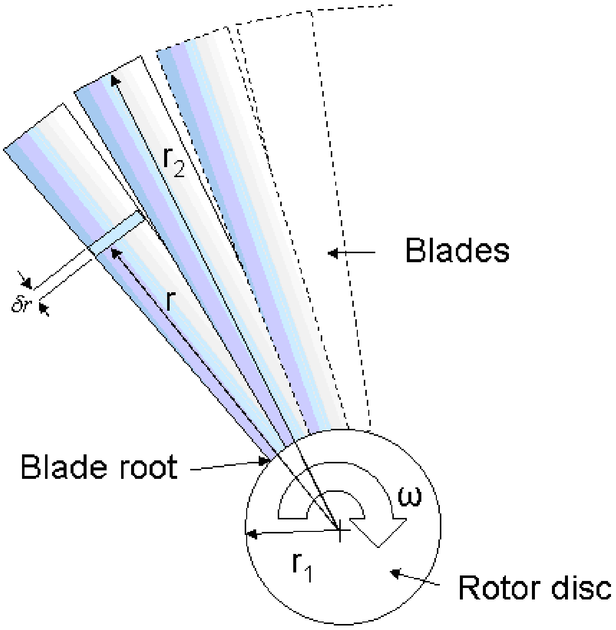

Fig. 4. Load Acting Rotor Blade

Centrifugal force acting on per blade:

$$F_c = \varrho A \omega^2 \left(\frac{r_b^2 - r_m^2}{2} \right)$$

$$\omega = \frac{RPM * 2\pi}{60} \ rad/sec$$

IV. RESULTS

To determine the thermal stresses, first steady state thermal analysis is carried out for acquire temperature distribution and heat flux for rotor blade.

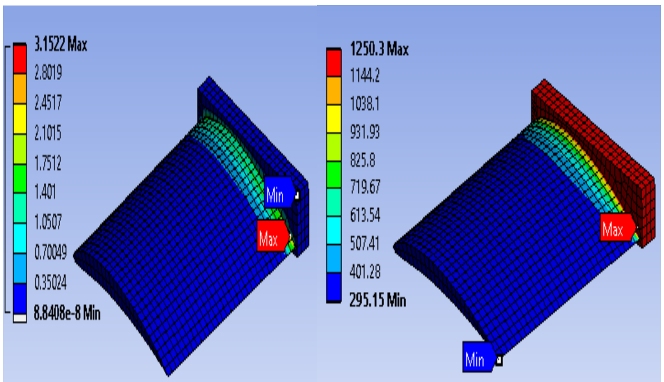

Fig. 5. Heat Flux & Temperature Distribution of NACA 6409 of Inconel 625 At 300rev/Sec

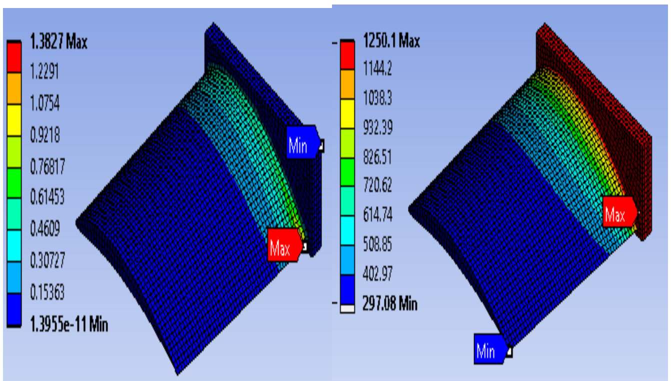

Fig. 6. Heat Flux & Temperature Distribution of NACA 6409 of Inconel 625 At 450rev/Sec

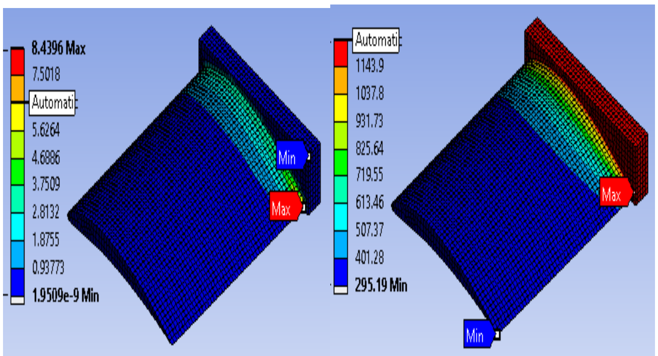

Fig. 7. Heat Flux & Temperature Distribution of NACA 6409 of Nimonic80A At 300rev/Sec

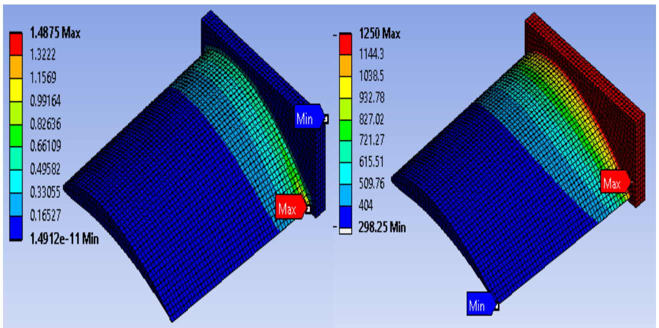

Fig. 8. Heat Flux & Temperature Distribution of NACA 6409 of Nimonic80A At 450rev/Sec

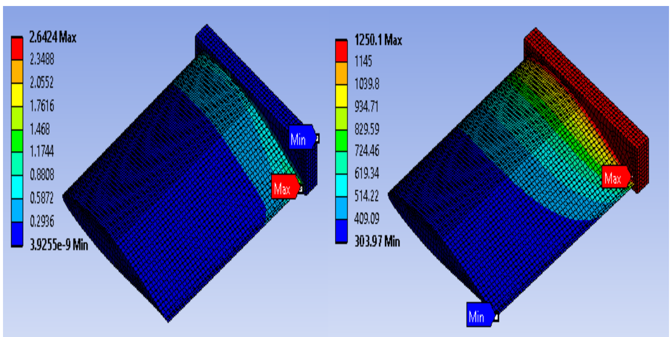

Fig. 9. Heat Flux & Temperature Distribution of NACA 64012 of Inconel 625 At 300rev/Sec

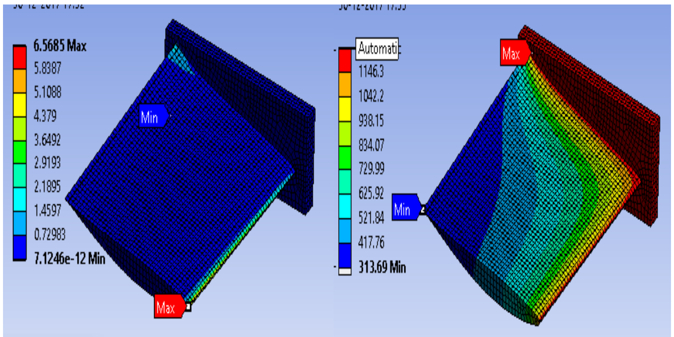

Fig. 10. Heat Flux & Temperature Distribution of NACA 64012 of Inconel 625 At 450rev/Sec

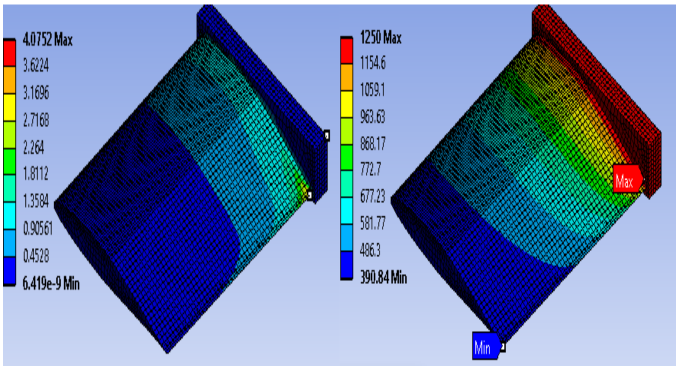

Fig. 11. Heat Flux & Temperature Distribution of NACA 64012 of Nimonic80A At 300rev/Sec

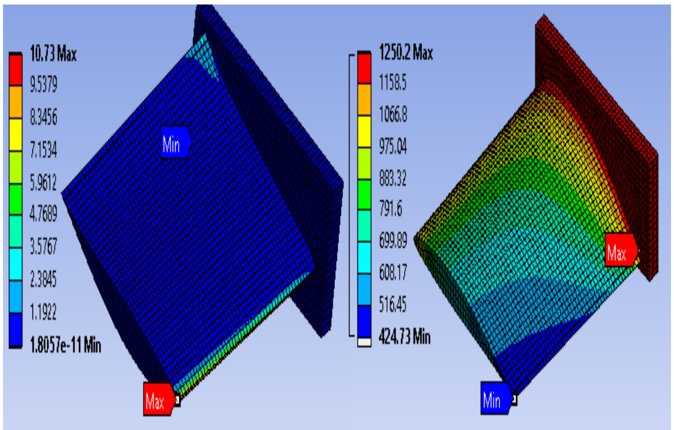

Fig. 12. heat flux & Temperature distribution of NACA 64012 of Nimonic at 450rev/sec

NACA 6409 heat flux (W/mm²)		
Rev/sec	***Inconel 625***	***Nimonic 80A***
300	3.1522	8.4396
450	1.3827	1.4875

Table 3: NACA 6409 Heat Flux (w/mn²)

NACA 64012 heat flux (W/mm²)		
Rev/sec	***Inconel 625***	***Nimonic 80A***
300	2.6424	8.4396
450	6.5685	1.4875

Table 4: NACA 64012 Heat Flux (W/mn²)

The obtained thermal results are coupled to the static structural analysis to acquire the equivalent stresses and displacements, with participated centrifugal loads on rotor blade.

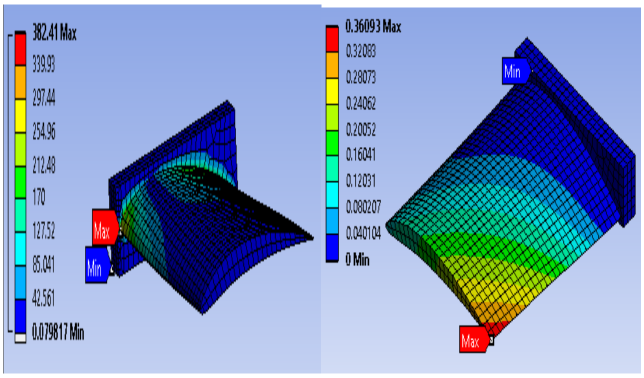

Fig. 13. Eqv Stress & Total Deformation of NACA 6409 of Inconel 625 At 300rev/Sec

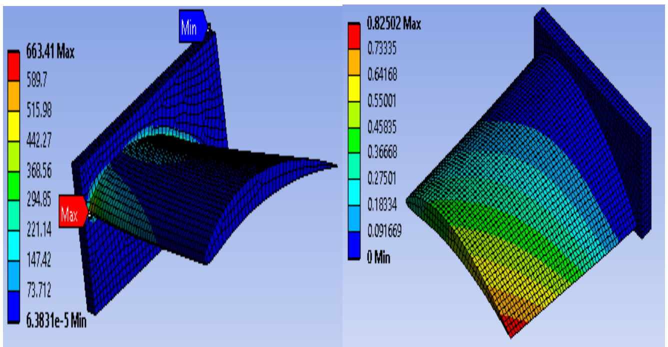

Fig. 14. Eqv Stress & Total Deformation of NACA 6409 of Inconel 625 At 450rev/Sec

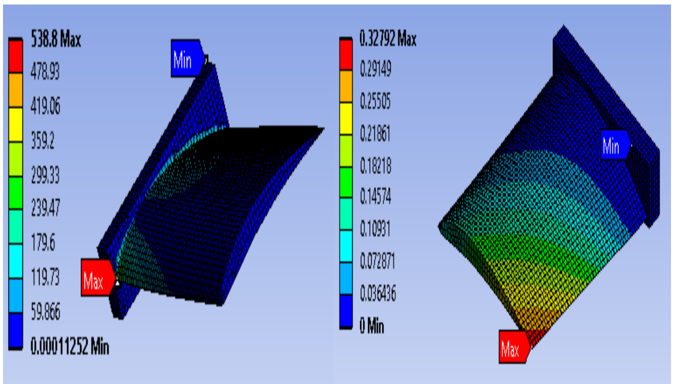

Fig. 15. EQV Stress & Total Deformation of NACA 6409 of Nimonic80A At 300rev/Sec

ISSN No:-2456 –2165

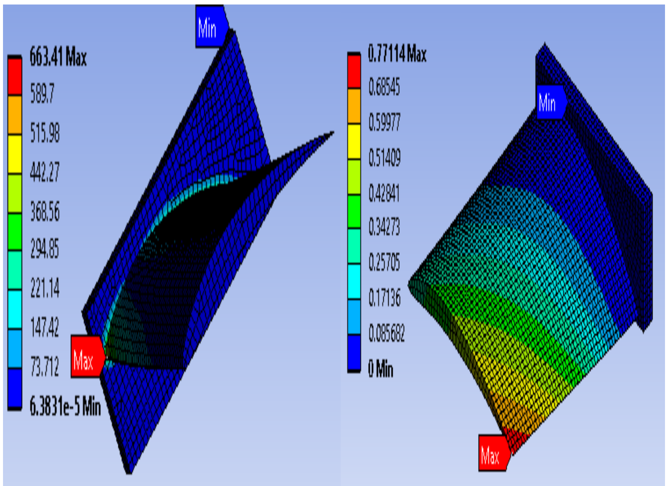

Fig. 16. Eqv Stress & Total Deformation of NACA 6409 of Nimonic80A At 450rev/Sec

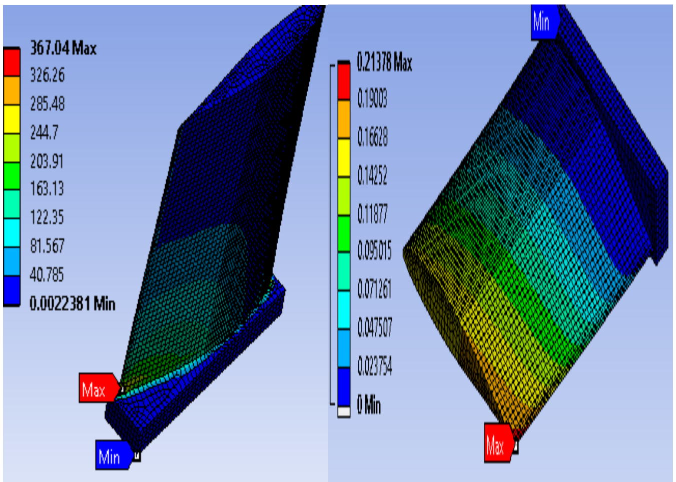

Fig. 17. Eqv Stress & Total Deformation of NACA 64012 of Inconel 625 At 300rev/Sec

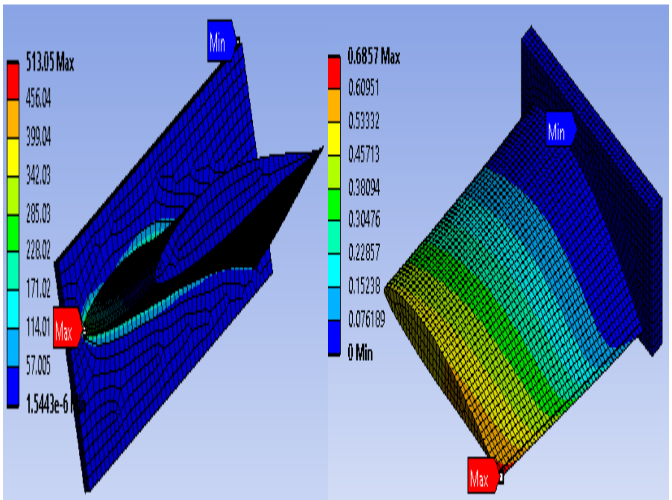

Fig. 18. EQV Stress & Total Deformation of NACA 64012 of Inconel 625 At 450rev/Sec

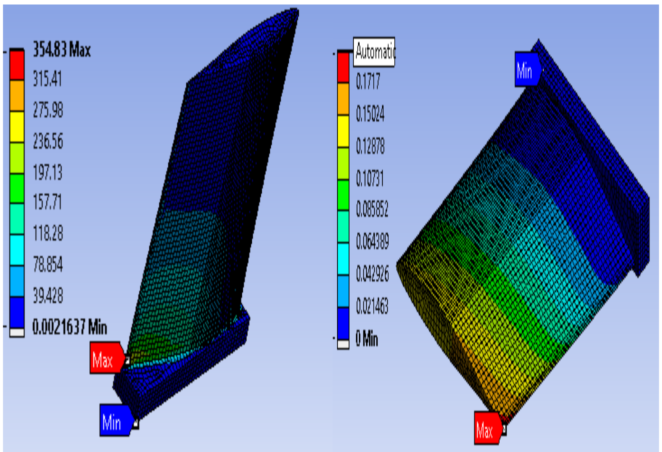

Fig. 19. Eqv Stress & Total Deformation of NACA 64012 of Nimonic 80A at 300rev/sec

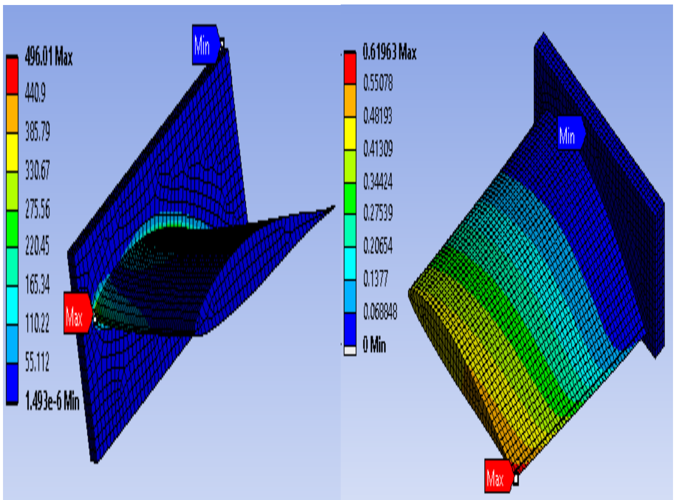

Fig. 20. Eqv Stress & Total Deformation of NACA 64012 of Nimonic 80A at 450rev/sec

NACA 6409 at 300rev/sec		
parameters	***Inconel 625***	***Nimonic 80A***
Deformations (mm)	0.3609	0.379
Eqv Stress (MPa)	382.41	538.8

Table 5: NACA 6409 AT 300rev / sec

NACA 6409 at 450rev/sec		
parameters	***Inconel 625***	***Nimonic 80A***
Deformations (mm)	0.8250	0.7711
Eqv Stress (MPa)	663.41	663.41

Table 6: NACA 6409 at 450rev/sec

NACA 64012 at 300rev/sec		
parameters	***Inconel 625***	***Nimonic 80A***
Deformations (mm)	0.2137	0.1931
Eqv Stress (MPa)	367.04	354.83

Table 7: NACA 64012 at 300rev/sec

NACA 64012 at 450rev/sec		
parameters	***Inconel 625***	***Nimonic 80A***
Deformations (mm)	0.6857	0.6196
Eqv Stress (MPa)	513.05	496.01

Table 8: NACA 64012 at 450rev/sec

V. CONCLUSION

- Both the materials with different rpm and airfoils, are given considerable results, but final conclusion can be done on the basis of stresses induced in the material.
- The temperature distribution is depends upon the heat transfer coefficient and thermal conductivity of the material.
- From the results we can observe the maximum temperature at the root of the blade due to stagnation effects at root.
- Heat flux is marginally lower on NACA 6409 airfoil at 450rev/sec of Inconel 625 material, because of lower thermal conductivity.
- NACA 64012 airfoil at the speed of 300rev/sec, has induced comparatively lesser stress than yield strength of the material; with Nimonic 80A material, because of young's modulus of material.
- More stresses are induced at the blade root, because of, blade is cantilever (one end is fixed)
- From this analysis it is concluded that Nimonic 80A material can be used for gas turbine rotor blade.

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