The Design and Analysis of First Stage Gas Turbine Blade with a Modification on Cooling Passages Using ANSYS

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Abstract - Gas turbine blades will subject to high tangential, axial and centrifugal forces during their working conditions. While withstanding these forces gas turbine blades may subjected to elongation. Several methods have been suggested for the better enhancement of the mechanical properties of blade to withstand these extreme conditions. This project summarizes the design, analysis and modification of the cooling passage in the gas turbine blade design. On which CATIA V5 is used for design of solid model of the turbine blade with the help of the spline and extrude options. ANSYS 14.0 Software is used to analysis of finite element model generated by meshing of the blade by applying boundary conditions. From the analysis results the better material for first stage turbine blade is stated .After that by using the better material properties the cooling passage of the turbine blade is modified into serpentine model and changing the number of holes.

I. INTRODUCTION

This project specifies the analysis of the complex gas turbine blade geometrics with the effective use of ANSYS 14.0.by applying boundary conditions to examine the steady state thermal and structural performance of the blade for U-500,INCONEL-738,GTD-111 materials. Finally stating the best suited material among the three from the analysis report. Then analyzing the temperature change by modifying the cooling passage. The purpose of modification process is to reduce the overall of temperature over the surface of the turbine blade there by increasing the life of the turbine blade and reduce amount of bypass air needed for cooling purpose. Therefore the overall efficiency and performance of the gas turbine blade will increasing and it also increase the number of operating cycles and it reduce the cost due periodic maintenance. The statements can be stated by analyzing the results in the report.

A gas turbine, also called a combustion turbine, is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between.

The basic operation of the gas turbine is similar to that of the steam power plant except that air is used instead of water. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor and other devices such as an electric generator that may be coupled to the shaft. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines the design so that the most desirable energy form is maximized. Gas turbines are used to power aircraft, trains, ships, electrical generators, or even tanks.

Theory of operation

Gases passing through an ideal gas turbine undergo three thermodynamic processes. These are isentropic compression, isobaric (constant pressure) combustion and isentropic expansion. Together these make up the Brayton cycle. In a practical gas turbine, gases are first accelerated in either a centrifugal or axial compressor. These gases are then slowed using a diverging nozzle known as a diffuser; these processes increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gases then pass from the diffuser to a combustion chamber, or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition).

As there is no change in pressure the specific volume of the gases increases. In practical situations this process is usually accompanied by a slight loss in pressure, due to friction. Finally, this larger volume of gases is expanded and accelerated by nozzle guide vanes before energy is extracted by a turbine. In an ideal system these are gases expanded isentropically and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence. In practice it is necessary that some pressure remains at the outlet in order to fully expel the exhaust gases. In the case of a jet engine only enough pressure and energy is extracted from the flow to drive the compressor and other components. The remaining high pressure gases are accelerated to provide a jet that can, for example, be used to propel an aircraft.

This project deals with the analysis of the complex gas turbine blade geometrics with the effective use of ANSYS 14.0.by applying boundary conditions to examine the steady state thermal and structural performance of the blade for U-500,INCONEL-738,GTD-111 materials. Finally stating the best suited material among the three from the analysis report. Then analyzing the temperature change by modifying the cooling passage.

II. COMPUTER AIDED ANALYSIS OF FIRST STAGE GAS TURBINE ROTOR BLADE

The model is created and analyzed using CATIA and ANSYS. For automatic mesh generation and node selection is used. The structural, thermal modal modules of ANSYS 14.0 are used for the analysis of the rotor blade. The rotor blade was analyzed for mechanical stresses, temperature distribution, combined mechanical and thermal stresses. Then the cooling passage is changed into serpentine and increasing the number of holes. It is also designed by using CATIA software and analysis by ANSYS14.0.

III. TURBINE DESIGN CALCULATIONS

L=428mm,N=3000rpm

The mechanical properties of U-500, Inconel-738 (IN-738), GTD-111 are:

Properties	Symbol	Units	U-500	IN-738	GTD-111
Young's modulus	E	GPa	190-210	149	130
Melting Point	^0C	^0C	1360	1400	1699
Density	ρ	g/cm^3	7.8	8.55	8.87
Thermal Conductivity	K	W/m-k	16.2	14.3	16
Thermal Expansion	---	^0C	17.5	12.5e6	9e6
Poisson's Ratio	μ	-----	0.27-0.30	0.30	0.33
Yield strength	σ	MPa	275	792.897	564.32
Specific Heat	C_p	J/KgK	500	510	460
Bulk Modulus	k	Pa	1.583E+11	1.247E+11	1.0833E+11
Shear Modulus	G	Pa	7.307E+10	5.730E+10	5E+10

IV. RESULTS & DISCUSSIONS

MATERIAL ANALYSIS:

Material Type	Stress (N/mm^2)	Strain	Deformation (mm)	Temperature (^0K)
U-500	383.72	0.002169	0.39314	1127.7
IN-738	420.62	0.0030318	0.54952	1128.3
GTD-111	436.36	0.003605	0.6534	1130.9

Structural analysis

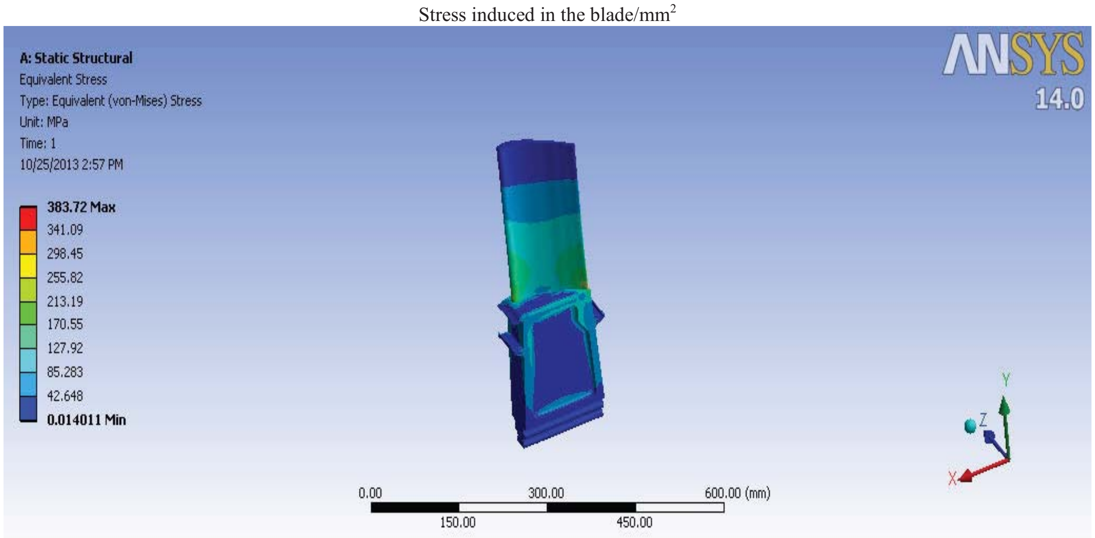
The von misses stress is obtained as shown in the figure. it id observed that the maximum von misses stress is 436.36N/mm^2 for GTD-111,420.62N/mm^2 for INCONEL-738(IN 738) and 383.72N/mm^2 for U-500

The strain graphs are obtained as shown in the figure .it is observed that the maximum strain is 0.003605 for GTD-11,0.0030318 for IN-738 and for U-500 the strain value is 0.002169

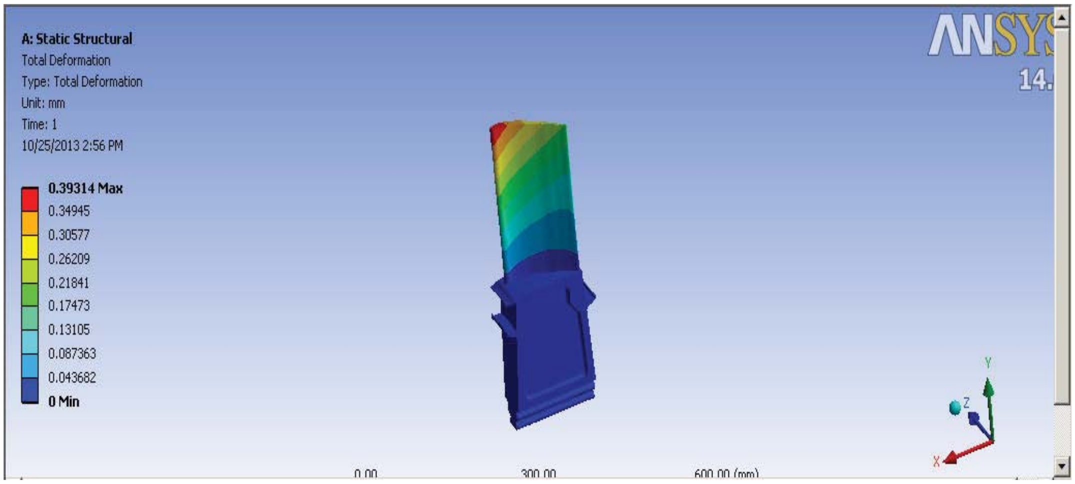
The deformations are obtained as shown in the figure, it is observed that the maximum deformation is 0.6534mm,0.54952mm and 0.39314mm for GTD-11,IN-738 and U-500 alloy respectively By comparing the above results the Maximum Stress and deformation is high for GTD-111

For U-500

Stress induced in the blade/mm^2

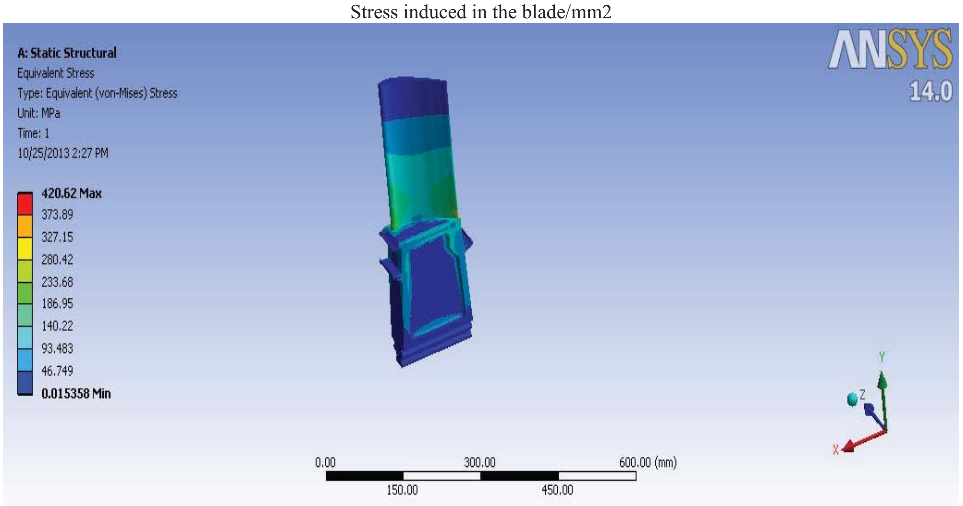


Deformation in the blade,mm

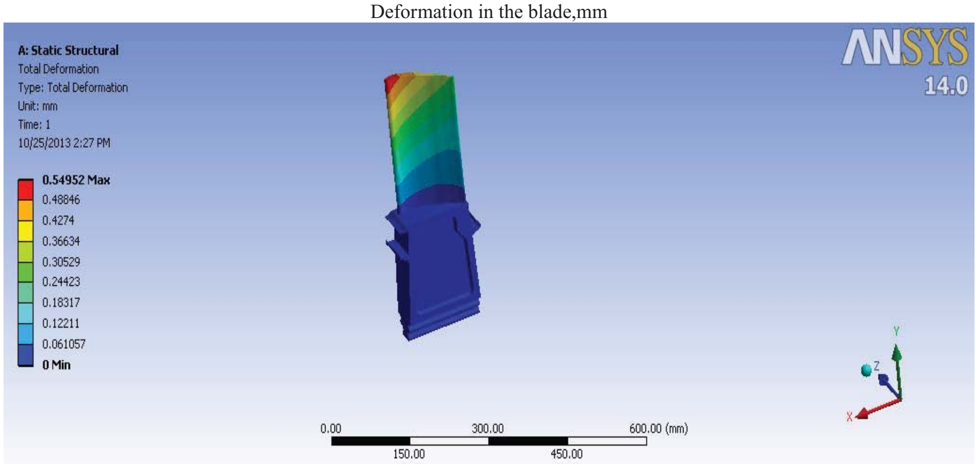


For INCONEL-738

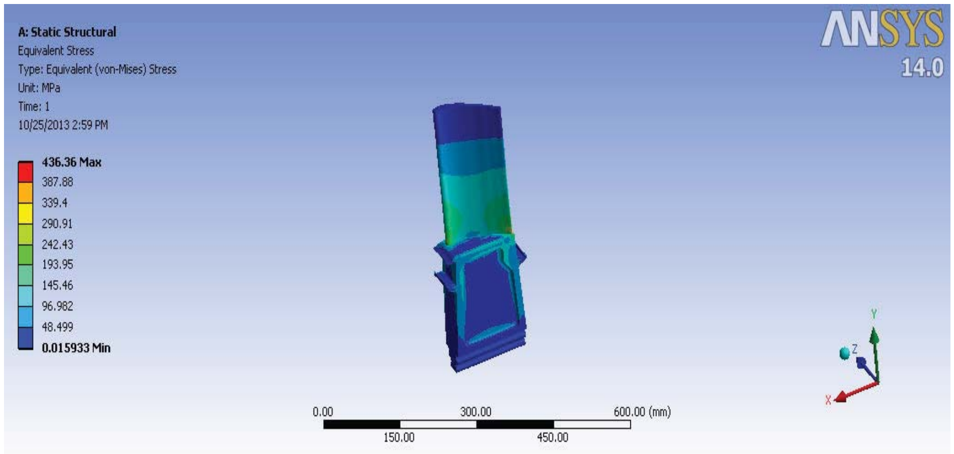
Stress induced in the blade/mm2



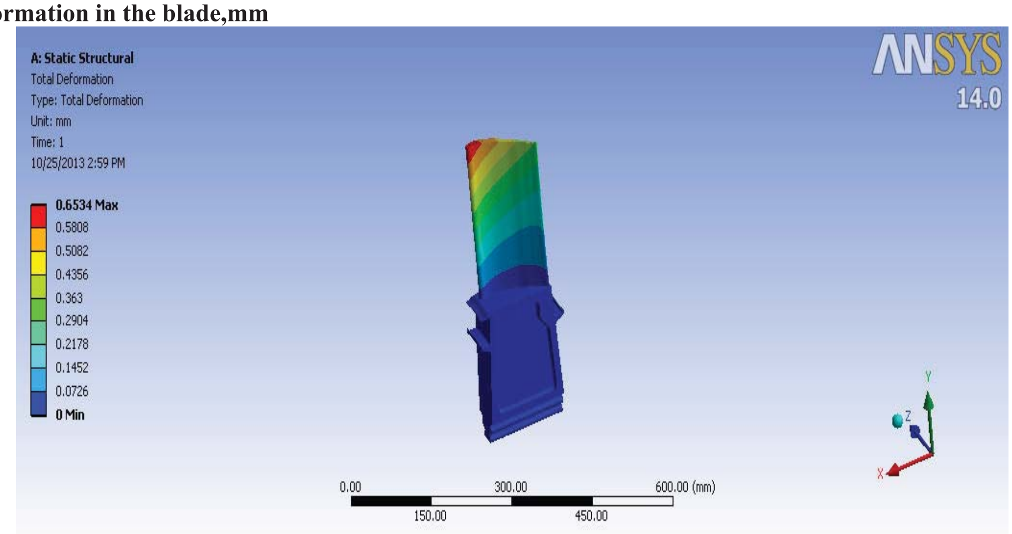
Deformation in the blade,mm



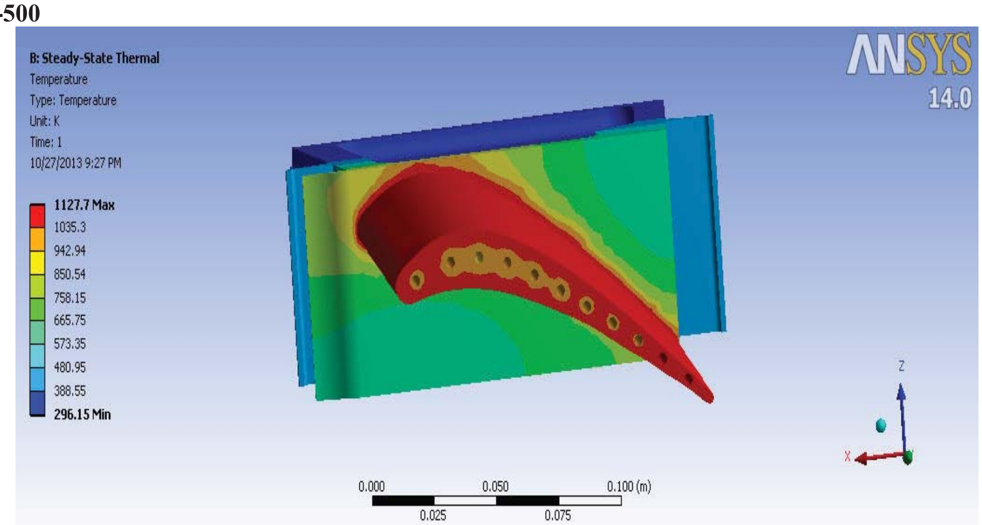
For GTD-111
Stress induced in the blade/mm^2



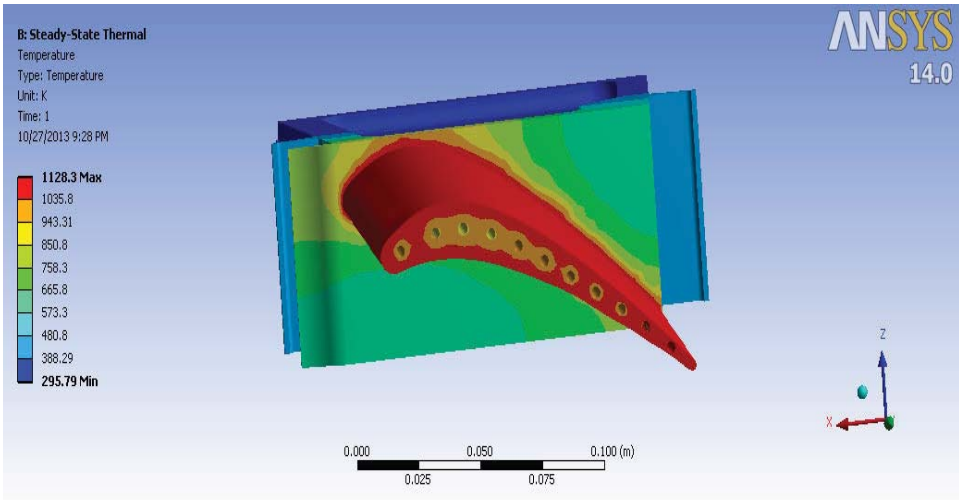
Deformation in the blade,mm



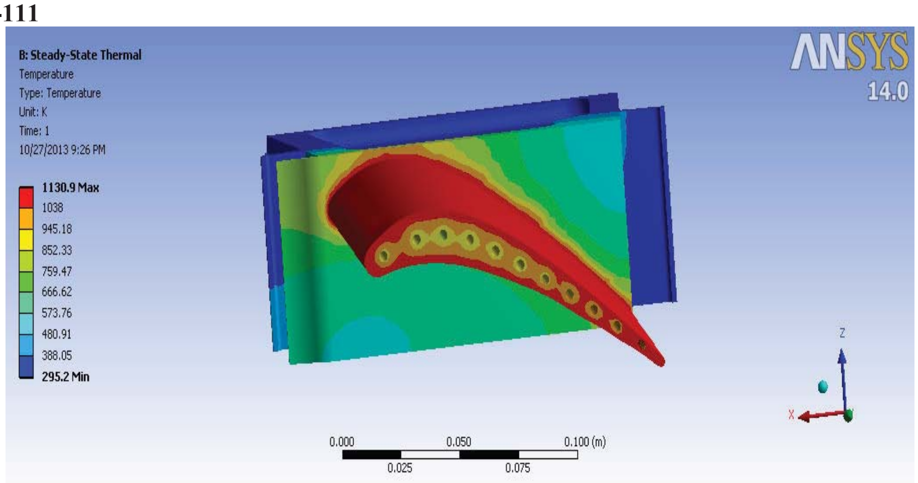
Thermal Analysis Result:
For U-500



For INCONEL-738



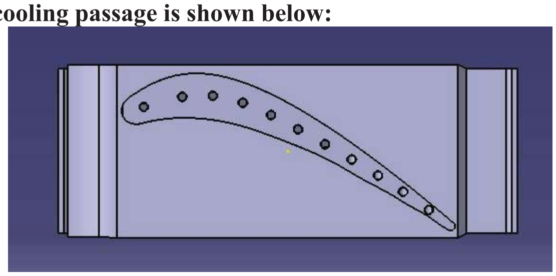
For GTD-111



VII. MODIFICATION ON COOLING PASSAGE OF THE TURBINE BLADE MADE OF GTD-111 ALLOY

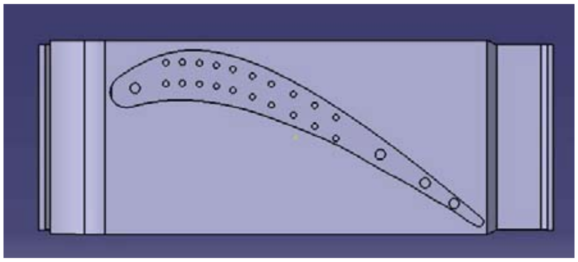
From the structural and thermal analysis report of different turbine blade material GTD-111 has better structural and thermal properties compared to other two materials. So for the modification purpose the physical properties of the GTD-111 super alloy are selected.

The existing design of the cooling passage is shown below:

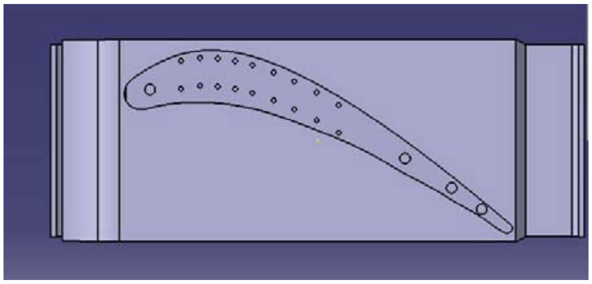


The different modifications are shown below:

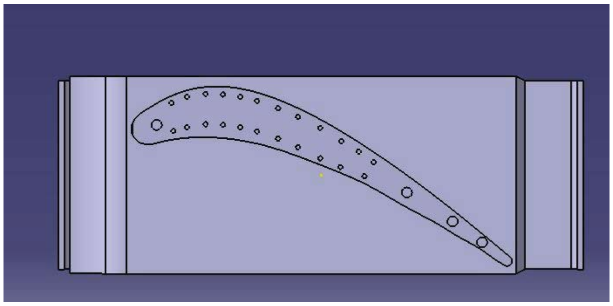
1. Reducing the size of hole from 3.5mm to 2.5mm and increasing the number of holes.



2. Reducing the gap between the holes and wall into 2.5mm from 3.5mm and the number of holes is same as above modification



3. Increasing the number of holes the size of hole and the gap between wall and the holes is same as the above modification



4. Changing the cooling passage design into serpentine one

VIII. RESULTS AND DISCUSSIONS

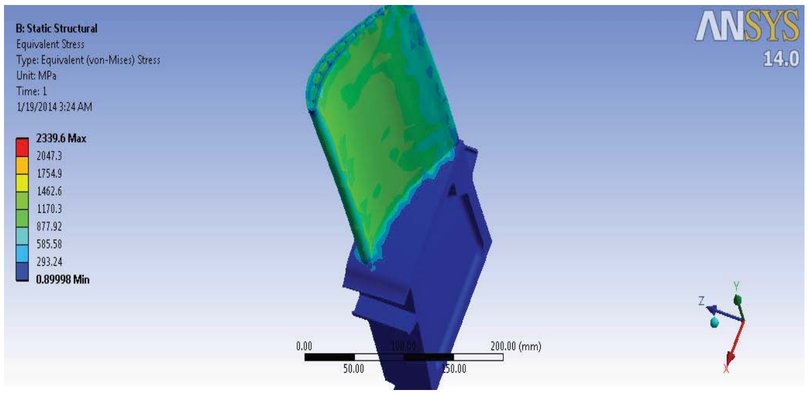
Modification	Stress (MPa)	Deformation (mm)	Temperature (K)
Existing Design	2339.6	1.9444	1250
Modification 1	2492.9	4.2037	1232.3
Modification 2	2974.2	4.1861	1255

Modification 3	1727.8	2.7295	1191.6

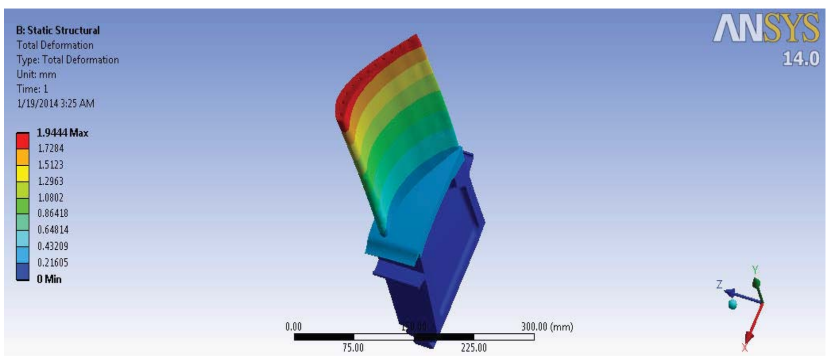
In the serpentine design cooling passage the temperature effect on the surface of the holes is low than the normal design and proper cooling is taken place. From the result data's it can be easily understand. The result plots are shown below:

Existing design (with normal and straight holes pattern)

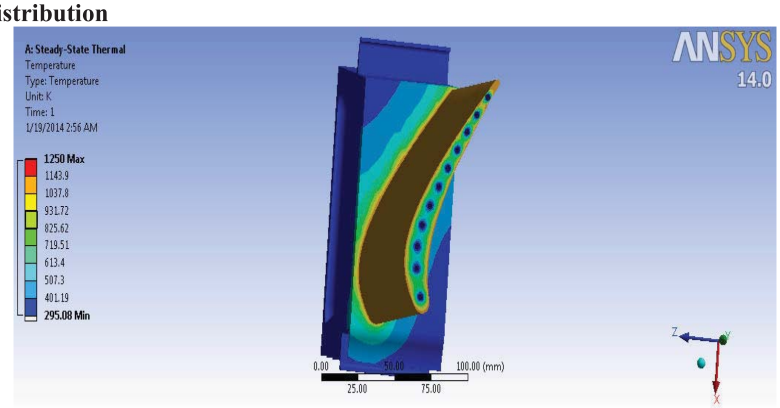
Stress



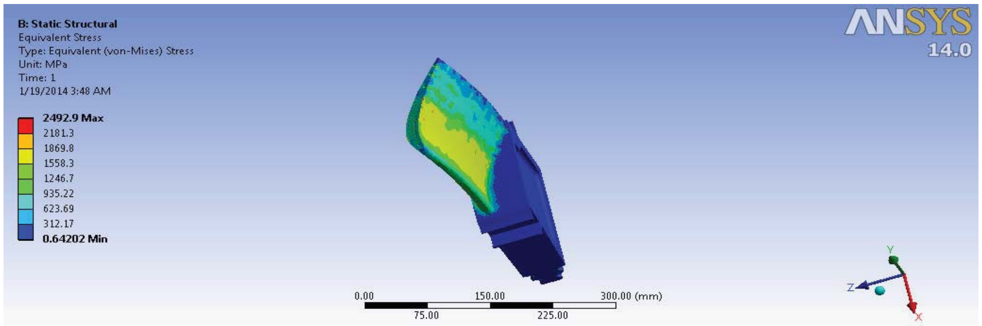
Deformation



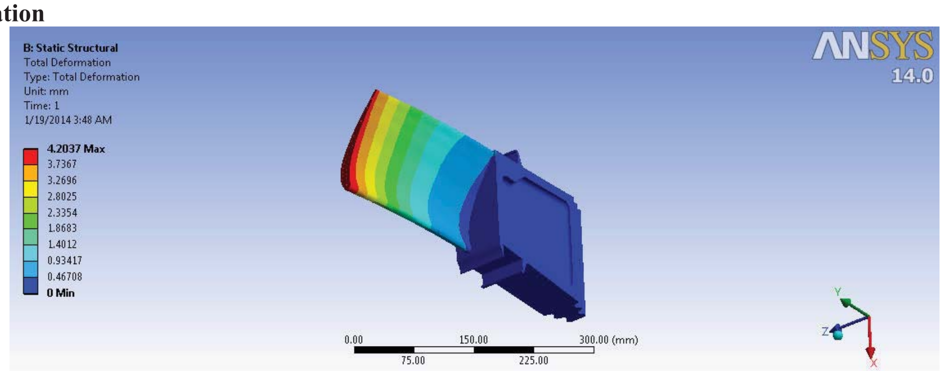
Temperature Distribution



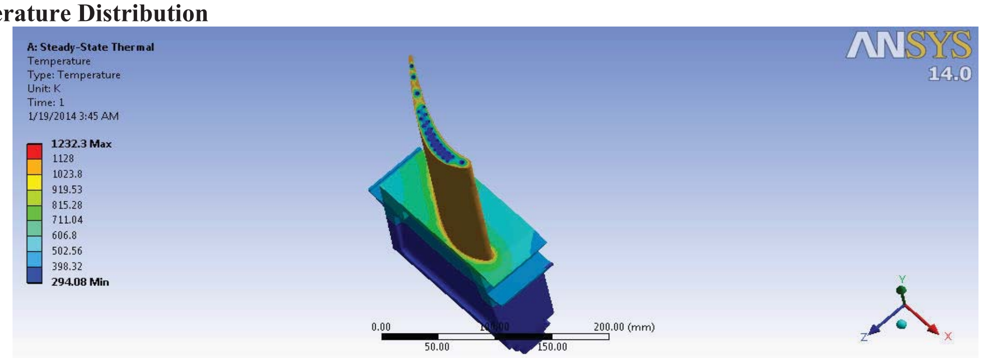
Modification 1
Reducing the size of hole from 3.5mm to 2.5mm and increasing the number of holes.
Stress



Deformation



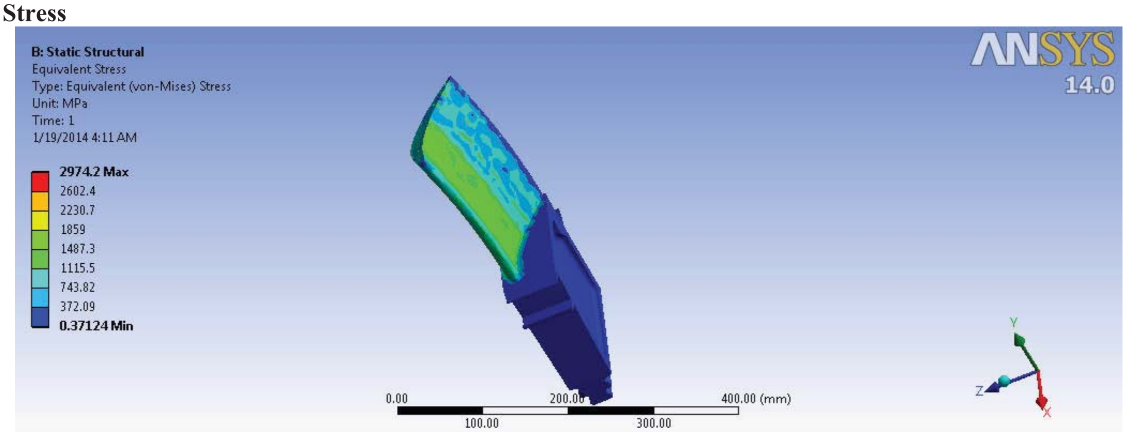
Temperature Distribution



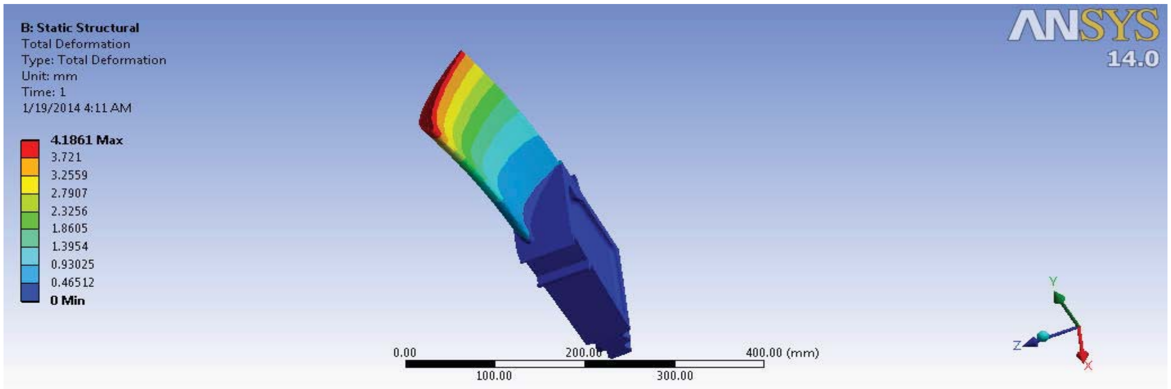
Modification 2

Reducing the gap between the holes and wall into 2.5mm from 3.5mm and the number of holes is same as above modification.

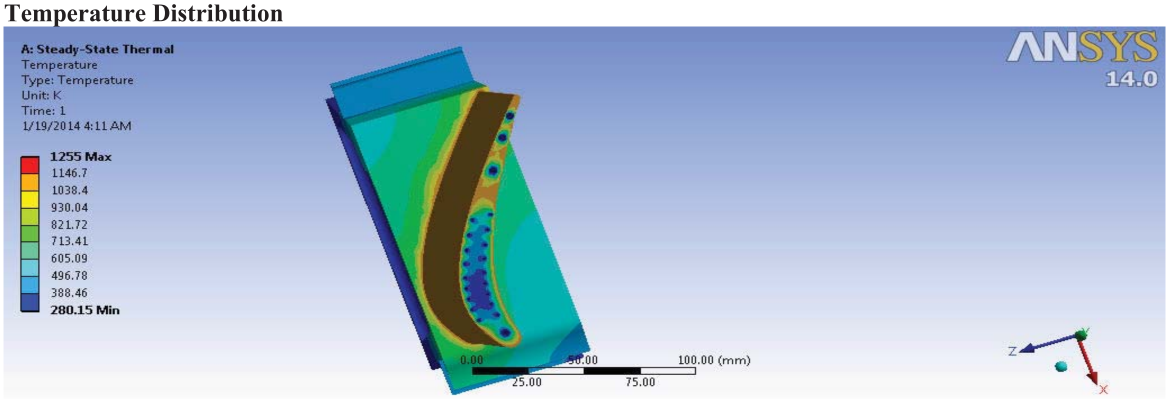
Stress



Deformation



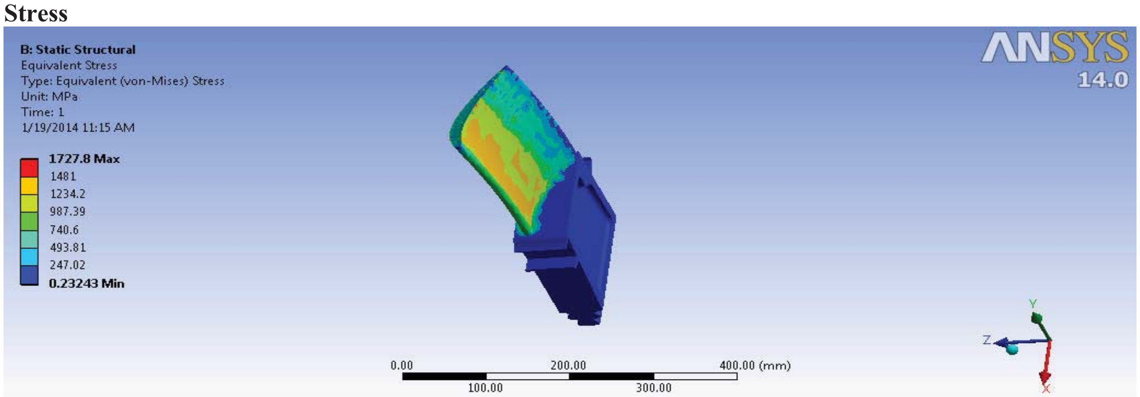
Temperature Distribution



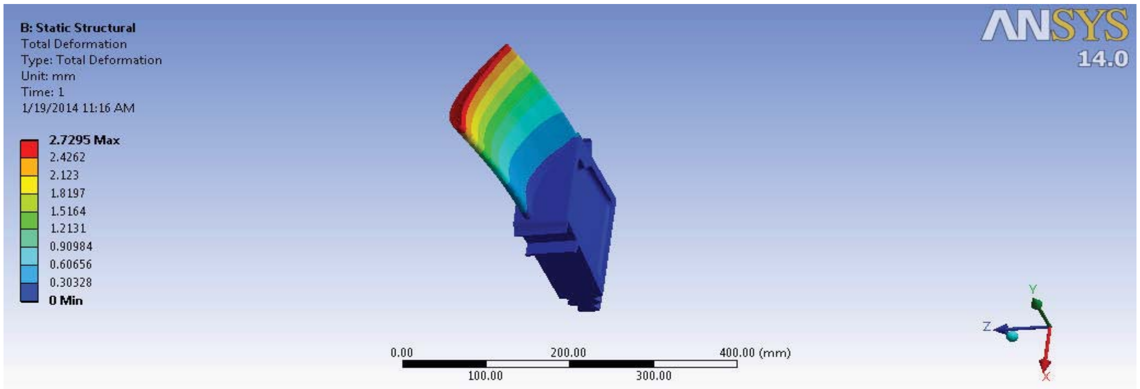
Modification 3

Increasing the number of holes the size of hole and the gap between wall and the holes is same as the above modification

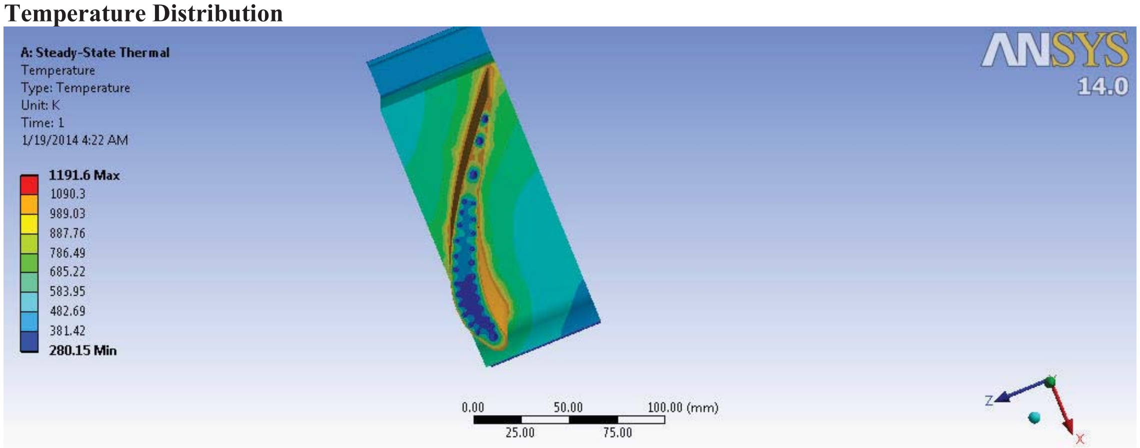
Stress



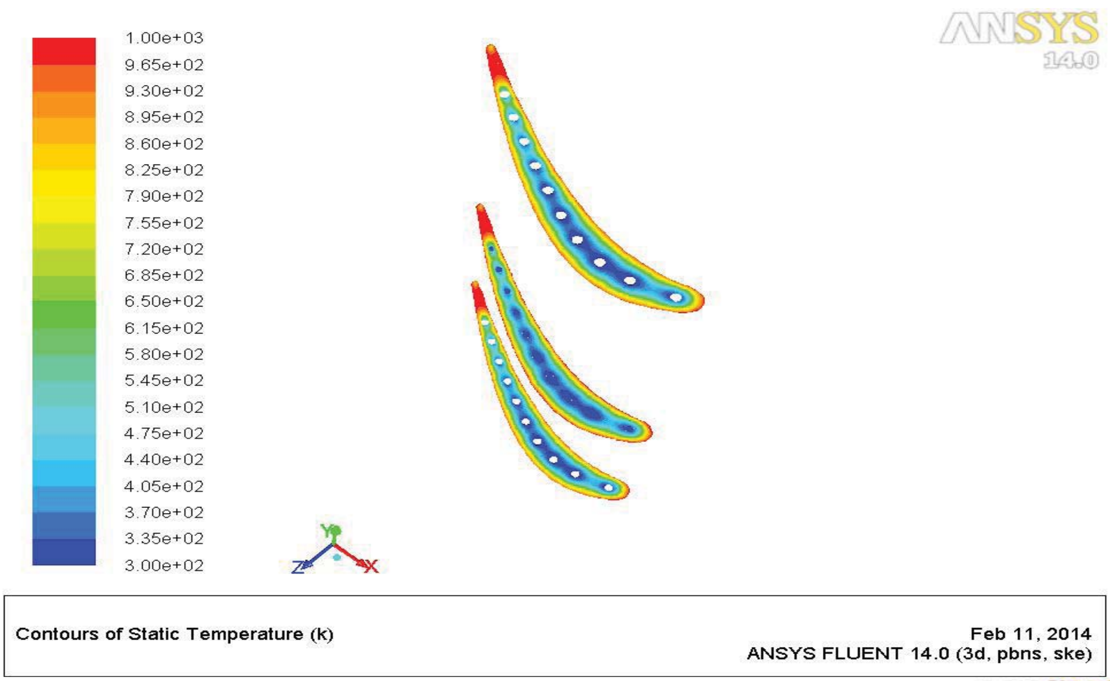
Deformation

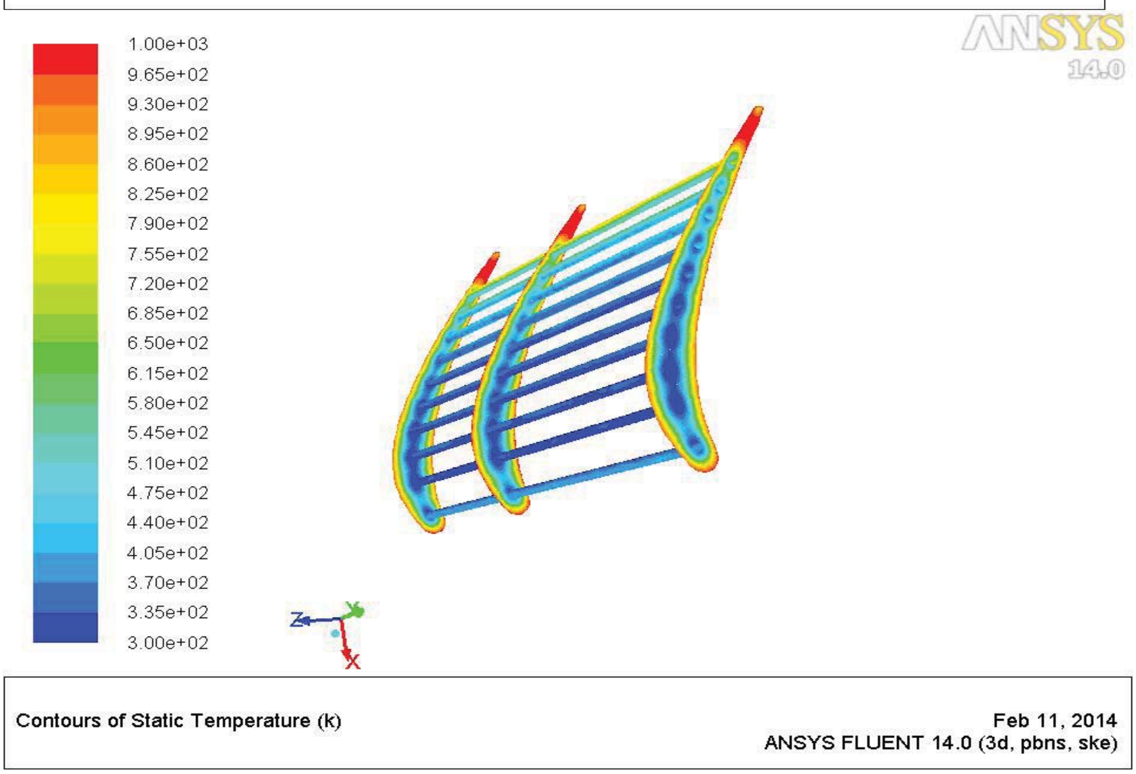


Temperature Distribution

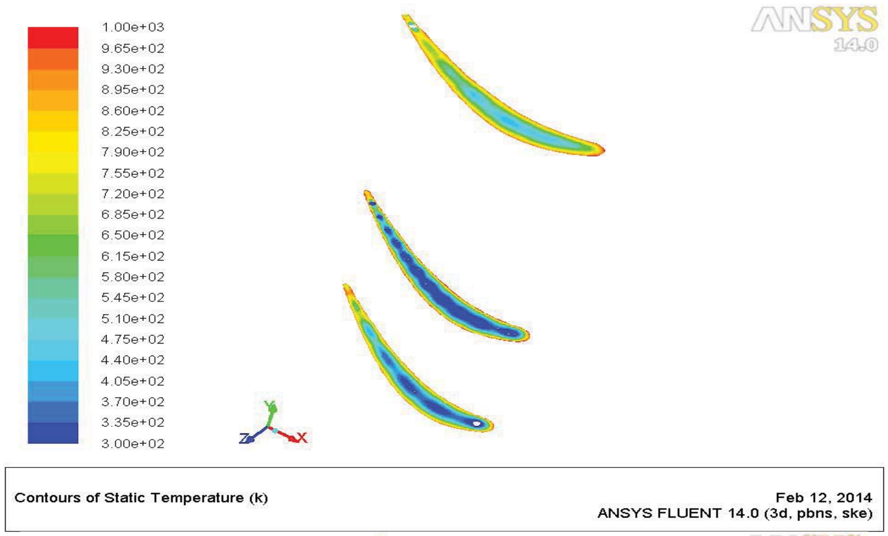


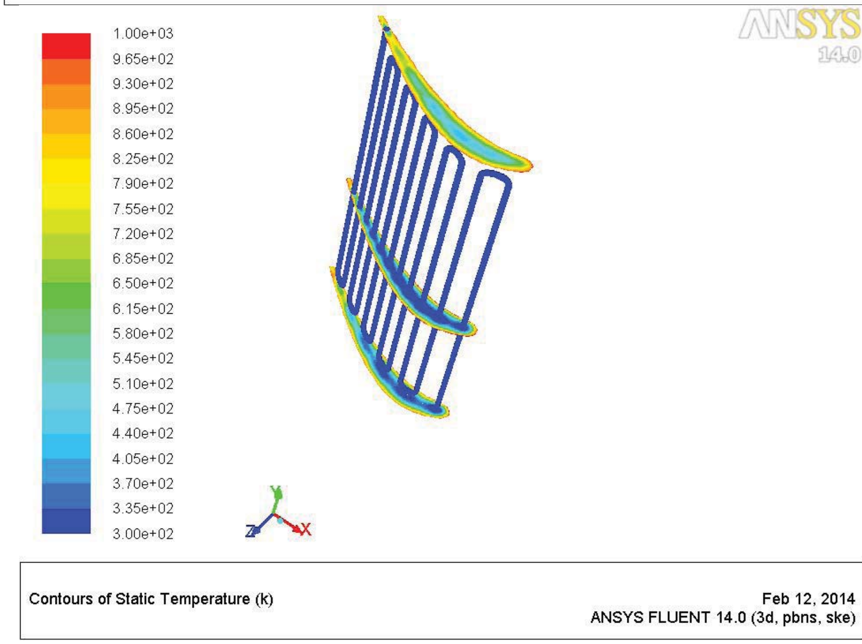
Modification 4
Changing the cooling passage design into serpentine one by flow visualization
Temperature change of normal design





Temperature variation with modification on cooling passage as serpentine one





IX.. CONCLUSION

The finite element analysis for structural and thermal analysis of gas turbine rotor blade is carried out using ANSYS 14.0.the temperature has a significant effect on the overall turbine blades. Maximum elongations and temperature are observed at the tip section and minimum elongation and temperature variation at the root of the blade.

The structural analysis shows that the variation of stress and strain for different materials along with the deformation for the three materials. The strain graphs are obtained as shown in the figure .it is observed that the **maximum strain is 0.003605 for GTD-11, 0.0030318 for IN-738 and for U-500 the strain value is 0.002169**. The deformations are obtained as shown in the figure, it is observed that the maximum deformation is 0.6534mm,0.54952mm and 0.39314mm for GTD-11,IN-738 and U-500 alloy respectively By comparing the above results the Maximum Stress and deformation is high for GTD-111.

The variation in the temperature is plotted and by analyzing the plots of the three different materials the material GTD-111 shows high withstanding in temperature around **857^0C (1130.9K**) which can withstand without causing any damage to the blade But by comparing the other two materials the temperature capability is **for U-500 it is 1127.7K and for IN-738 it is 1128.3K** so the material GTD-111 gives better results than the other materials .In order to withstand high temperature at the inlet of the turbine blade the most suited and best material is GTD-111

From the above analysis report the best material for the making of the first stage gas turbine blade is GTD-111 because it has high melting point and the strength is comparably better than the other two materials.

Based on the modification result the materials choose for modification is GTD-111.Due to its high melting point and strength. By analysing the modification results the best design are increasing the number of holes and reducing the size of holes and also reduce the gap between the holes and wall and the serpentine design.

The temperature plot of the existing design is **1250K** and the temperature plot of the modified design with increasing the number of holes is about **1191.6K**.Therefore the temperature variation between the existing design and modified design is about **58.4K**. It shows a deep variation in the temperature distribution over the turbine blade. The two modifications showing better results but for the serpentine design the manufacturing difficulty is more as compared to the other design. The number of holes can be increased by drilling method so the difficulty to manufacture the blade material with increase in number of holes is less. If we are neglecting the manufacturing difficulty both modification method are best way to increase the cooling of the turbine blade.

Therefore the overall efficiency and performance of the gas turbine blade will increasing and it also increase the number of operating cycles and it reduce the cost due periodic maintenance. These statements can be stated by analyzing the results in the report.

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