STRUCTURAL AND THERMAL ANALAYSIS OF GAS TURBINE BLADE AT VARIOUS OPERATING CONDITIONS

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CERTIFICATE

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ABSTRACT

Gas turbines play a major role in Aviation, land-based Power generation and marine applications owing to their high power-to –weight ratios and compactness when to compare to other conventional power generating units and as the demands for power increase, the power output and thermal efficiency of gas turbines must also increase. One method of increasing both the power output and thermal efficiency of the engine is to increase the temperature of the gas entering the turbine. In the advanced gas turbines of today, the turbine inlet temperature can be as high as 1500^0C, however, this temperature exceeds the melting temperature of the metal aerofoils. Therefore, it is imperative that the blades are cooled, so that they can withstand these extreme temperatures.

Cooling of gas turbine blades is a major consideration to improve their efficiency. Several methods have been suggested for the cooling of blades and one such technique is to have radial holes to pass high velocity cooling air along the blade span. The forced convection heat transfer from the blade to the cooling air will reduce the temperature of the blade to allowable limits. In the present work, Finite element analysis is used extensively to examine steady state thermal & structural performance of blades fabricated with N-155 nickel-chromium alloy. Their suitability to withstand high temperature in the series of 800^0C, 900^0C, 1000^0C, 1100^0C and 1200^0C is studied. Further the effect of cooling on the thermal and structural behaviour of the blade materials is also evaluated. Two different models consisting of solid blade and blade with 5 number of holes was analysed.

In this project, an attempt has been made to analyse the cooling of a gas turbine blade made of Nickel based Super alloy through Mechanical analysis. The turbine rotor blade was analysed for Total Heat Flux, Equivalent stresses, Thermal strain, Total deformation and temperatures distribution at different temperatures.

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NOMENCLATURE

SYMBOL	DISCRIPTION
P	Load
Fa	Axial force
Fc	Centrifugal force
Ft	Tangential force
α	Coefficient of thermal expansion
E	Young's Modulus
δ	Deflection
μ	Poisson's ratio
σ	Stress
L	Length
D	Diameter of shaft
N	RPM of turbine
E	strain
T	Torque transmitted by shaft
V1	approach Velocity
V2	theoretical exit velocity
A1	absolute air velocity
Vb	Blade speed
Vw	tangential component
P	Power developed
K	Thermal conductivity
h	Convective heat transfer coefficient
M	total mass of rotor blade
ρ	density of gases
Re	Reynolds Number
Nu	Nusselt number
Pr	Prandtl number
V_a	Velocity of air
V_b	Velocity of blade
d	Diameter of hole

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CHAPTER – 1
INTRODUCTION

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1.1 INTRODUCTION:

The increased awareness that the world's energy resources are limited has caused many countries to re-examine their energy policies and take drastic measures in eliminating waste. It has also sparked interest in the scientific community to take a closer look at the energy conversion devices and to develop new techniques to better utilize the existing limited resources.

1.2 Development of gas turbines

The gas turbine has experienced phenomenal progress and growth since its first successful development in the 1930s. The early gas turbines built in the 1940s and even 1950s had simple-cycle efficiencies of about 17 percent because of the low compressor and turbine efficiencies and low turbine inlet temperatures due to metallurgical limitations of those times. Therefore, gas turbines found only limited use despite their versatility and their ability to burn a variety of fuels. The efforts to improve the cycle efficiency concentrated in three areas:

1.2.1 Increasing the turbine inlet (or firing) temperatures

This has been the primary approach taken to improve gas-turbine efficiency. The turbine inlet temperatures have increased steadily from about 540^0C in the 1940s to 1425^0C and even higher today. These increases were made possible by the development of new materials and the innovative cooling techniques for the critical components such as coating the turbine blades with ceramic layers and cooling the blades with the discharge air from the compressor. Maintaining high turbine inlet temperatures with an air-cooling technique requires the combustion temperatures to be higher to compensate for the cooling effect of the cooling air. However, higher combustion temperatures increase the amount of nitrogen oxides (NO_x), which are responsible for the formation of ozone at ground level and smog. Using steam as the coolant allowed an increase in the turbine inlet temperatures

by 100^0C without an increase in the combustion temperature. Steam is also a much more effective heat transfer medium than air

1.2.2. Increasing the efficiencies of turbo machinery components

The performance of early turbines suffered greatly form the inefficiencies of turbines and compressors. However, the advent of computers and advanced techniques for computer-aided design made it possible to design these components aerodynamically with minimal losses. The increased efficiencies of the turbines and compressors resulted in a significant increase in the cycle efficiency.

1.2.3. Adding modifications to the basic cycle

The simple-cycle efficiencies of early gas turbines were practically doubled by incorporating intercooling regeneration (or recuperation), and reheating. These improvements, of course, come at the expense of increased initial and operation costs, and they cannot be justified unless the decrease in fuel costs offsets the increase in other costs. The relatively low fuel prices, the general desire in the industry to minimize installation costs, and the tremendous increase in the simple-cycle efficiency to about 40 percent left little desire for opting for these modifications.

The first gas turbine for an electric utility was installed in 1949 in Oklahoma as part of a combined-cycle power plant. It was built by general electric and produced 3.5 MW of power. Gas turbines installed until the mid-1970s suffered from low efficiency and poor reliability. In the past, the base-load electric power generation was dominated by large coal and nuclear power plants. However there had been an historic shift toward natural gas-fired gas turbines because of their higher efficiencies, lower capital costs, shorter installation times, and better emission characteristics, and the abundance of natural gas supplies, more and more electric utilities are using gas turbines for base-load power production as well as for peaking. The construction costs for gas-turbine power plants are roughly half that of comparable conventional fossil-fuel steam power plants, which were the primary base-load power plants until the early 1980s.More than half of all power plants to be installed in the foreseeable future, are forecast to be gas turbine or combined cycle gas-turbine types.

A gas turbine manufactured by General electric in the early 1990s had a pressure ratio of 13.5 and generated 135.7 MW of net power at a thermal efficiency of 33 percent in simple-cycle operation. A more recent gas turbine manufactured by general electric uses a turbine inlet temperature of 1425^0C and produces up to 282 MW while achieving a thermal efficiency of 39.5 percent in the simple-cycle mode. A 1.3-ton small-scale gas turbine labelled OP-16 built by the Dutch firm Opra Optimal Radial Turbine can run on gas or liquid fuel and can replace a 16-ton diesel engine. It has a pressure ratio of 6.5 and produces up to 2 MW of power. Its efficiency is 26 percent in the simple-cycle operation, which rises to 37 percent when equipped with a regenerator.

1.3 Applications of Gas Turbine

Land applications:

1) Locomotive propulsions.

2) Central power stations.

   a) Standby plants for hydro installations.

   b) Fully automatic booster stations at end of transmission lines.

   c) Standby and peak load plants for small system.

   d) Bomb proof power plants.

   e) At location where water is not available.

3) Industrial.

   a) Pumping stations.

   b) Space applications-

   Turbo jet, Turbo propulsion, marine applications.

1.4 Brayton Cycle: The Ideal cycle for gas – turbine engines

The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil-burning engine that he developed around 1870. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating

machinery. Gas turbines usually operate on an open cycle, as shown in fig 1.1. Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high-temperature gases then enter the turbine. Where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out (not re circulated). Causing the cycle to be classified as an open cycle.

The open gas turbine cycle described above can be modelled as a closed cycle, as shown in fig 1.2. by utilizing the air-standard assumptions. Here the compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant pressure heat-rejection process to the ambient air. The ideal cycle that the working fluid undergoes in this closed loop is the Brayton cycle.

Which is made up of four internally reversible processes:

1-2 Isentropic compression (in a compressor)

2-3 Constant-pressure heat addition

3-4 Isentropic expansion (in a turbine)

4-1 Constant-pressure heat rejection

An Open – cycle gas turbine engine

A Closed – cycle gas – turbine engine

Fig 1.1   Fig 1.2

Fig 1.3

Fig 1.4

Typical pressure ratios for gas turbine engines
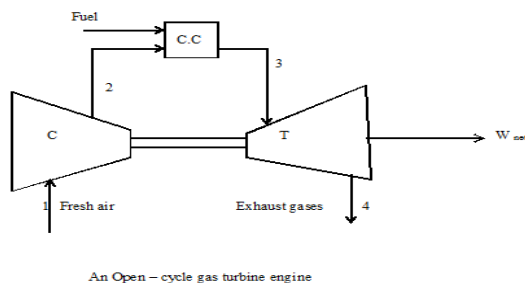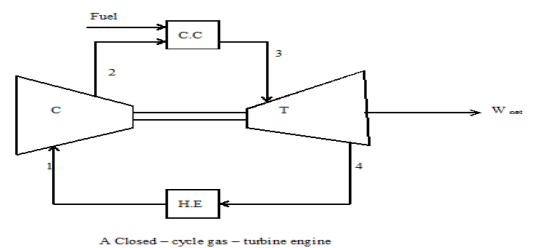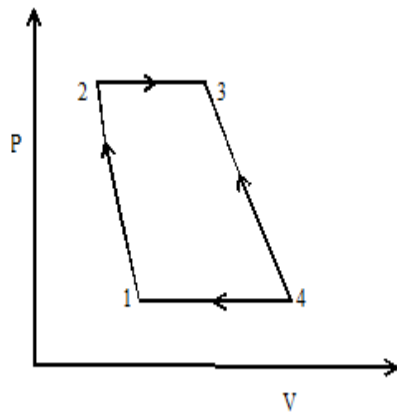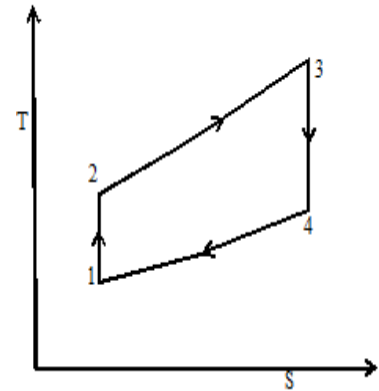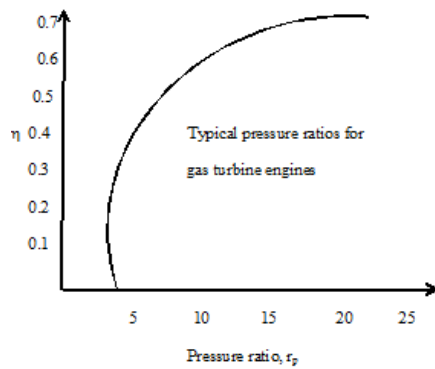
Fig 1.5

Fig1.6

Fig 1.5

Fig 1.6

The T-s and P-v diagrams of an ideal Brayton cycle are shown in fig 1.3 &1. 4.   All four processes of the Brayton cycle are executed in steady flow devices; thus, they should be analysed as steady-flow processes. When the changes in kinetic and potential energies are neglected, the energy balance for a steady-flow process can be expressed, on a unit-mass basis, as

$$(q_{in} - q_{out}) + (w_{in} - w_{out}) = h_{exit} - h_{inlet} \qquad \text{------ (1)}$$

Therefore,   heat   transfers   to   and   from   the   working   fluid   are

$$q_{in} = h_3 - h_2 = C_p (T_3 - T_2) \qquad \text{------ (2)}$$

$$Q_{out} = h_4 - h_1 = C_p (T_4 - T_1) \qquad \text{------ (3)}$$

$$n_{th\ Brayton} = 1 - 1/r_p^{(\gamma-1)/\gamma} \qquad \text{------ (4)}$$

Equation (4) shows that under the cold-air-standard assumptions, the thermal efficiency of an ideal Brayton cycle depends on the pressure ratio of the gas turbine and the specific heat ratio of the working fluid. The thermal efficiency increases with both parameters, which is also the case for actual gas turbines. A plot of thermal efficiency versus the pressure ratio is given in fig 1.5 for γ =1.4, which is the specific-heat-ratio value of air at room temperature.

The highest temperature in the cycle occurs at the end of the combustion process (state 3), and it is limited by the maximum temperature that the turbine blades can withstand. This also limits the pressure ratios that can be used in the cycle. For a fixed turbine inlet temperature T_3, the network output per cycle increases with the pressure ratio, reaches a maximum, and then starts to decrease, as shown in fig 1.6. Therefore, there should be compromise between the pressure ratio and the network output. With less work output per cycle, a larger mass flow rate is needed to maintain the same power output, which may not be economical. In most common designs, the pressure ratio of gas turbines ranges from about 11 to 16.

The air in gas turbines performs two important functions: It supplies the necessary oxidant for the combustion of the fuel, and it serves as a coolant to keep the temperature of various components within safe limits. The second function is accomplished by drawing in more air than is needed for the complete combustion of the fuel. In gas turbines, an air-fuel mass ratio of 50 or above is not uncommon.

The two major application areas of gas-turbine engines are aircraft propulsion and electric power generation. When it is used for aircraft propulsion, the gas turbine produces just enough power to drive the compressor and a small generator to power the auxiliary equipment. The high-velocity exhaust gases are responsible for producing the necessary thrust to propel the air craft. Gas turbines also used as stationary power plants to generate electricity as stand-alone units or in conjunction with steam power plants on the high-temperature side. In these plants, the exhaust gases of the gas turbine serve as the heat source for the steam. The gas-turbine cycle can also be executed as a closed cycle for use in nuclear power plants. This time the working fluid is not limited to air, and a gas with more desirable characteristics can be used.

The rotor blades of the turbo machine are very critical components and reliable operation of the turbo machine depends on their repayable operation. The major cause of break down in turbo machine is the failure of rotor blade. The failure of the rotor blade may lead to catastrophic consequences both physically and economically. Hence, the proper design of the turbo machine blade plays a vital role in the proper functioning of the turbo machine.

A good design of the turbo machine rotor blading involves the following

1) Determination of geometric characteristics from gas dynamic analysis.

2) Determination of steady loads acting on the blade and stressing due to them.

3) Determination of natural frequencies and mode shapes.

4) Determination of unsteady forces due to stage flow interaction.

5) Determination of dynamic forces and life estimation based on the cumulative damage fatigue theories.

The stress analysis of the rotor blade being the key phase of the turbo machine design requires much attention and careful determination of the blade loading to get realistic results. The stress analysis is performed to determine the critical section as well as the stressing pattern. As the blade vibration is also a cause of failure in many cases, the determination of natural frequencies and mode shapes is also of paramount importance. The designer should take care of dynamic forces such that the frequencies of these must be away from those of the rotor blades to avoid resonance, which is an undesirable phenomenon.

1.5 Cooling of Turbine blades

Gas turbines are used extensively for aircraft propulsion, land-based power generation, and industrial applications. Developments in turbine cooling technology play a critical role in increasing the thermal efficiency and power output of advanced gas turbines. Gas turbine blades are cooled internally by passing the coolant through several rib-enhanced serpentine passages to remove heat conducted from the outside surface. Cooler air from the internal coolant passages out of the blade surface to form a protective layer between the blade surface and hot gas-path flow.
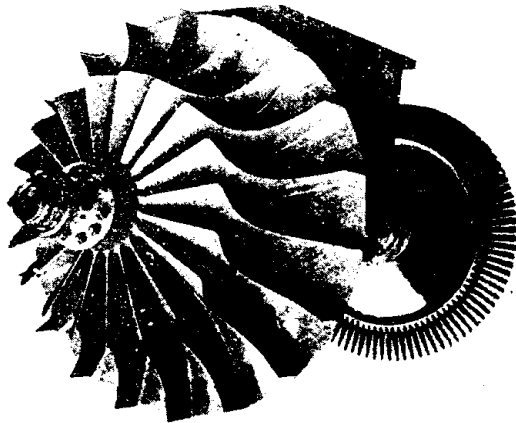
Fig1.7. Turbine blade coupled to centrifugal compressor

Advanced gas turbine engines operate at high temperatures (1200–1500C) to improve thermal efficiency and power output. The turbine inlet temperature increases, the heat transferred to the turbine blade also increases. The level and variation in the temperature within the blade material, which cause thermal stresses, must be limited to achieve reasonable durability goals. The operating temperatures are far above the permissible metal temperatures. Therefore, there is a critical need to cool the blades for safe operation.

The blades are cooled with extracted air from the compressor of the engine. Since this extraction incurs a penalty on the thermal efficiency and power output of the engine, it is important to understand and optimize the cooling technology for a given turbine blade geometry under engine operating conditions. Gas turbine cooling technology is complex and varies between engine manufacturers. The common cooling technology with three major internal cooling zones in a turbine blade with strategic film cooling in the leading edge, pressure and suction surfaces, and blade tip region. The leading edge is cooled by jet impingement with film cooling; the middle portion is cooled by serpentine rib-roughened passages with local film cooling the following three types of cooling methods have been adopted to varying degree of success

1. Convection cooling

2. Film cooling

3. Transpiration cooling

While all three methods have their difference, they all work by using cooler air (bled from the compressor) to remove heat from the turbine blade.

Convection cooling works by passing cooling air though passages internal to the blade. Heat is transferred by conduction to the blade and then by convection into the air flowing inside of the blade. A large internal surface area is desirable for this method, so the cooling passages are generally provided with small fins.

Impingement cooling which is a variation of convection cooling, works by hitting the inside surface of the blade with high velocity air. This allows more heat transfer by convection then regular convection cooling. Impingement cooling is often used on certain areas of the turbine blade, like the leading edge with standard convection cooling used in the rest of the blade.

The second type of cooling is film cooling. This type of cooling works by pumping cool air out of the blade through small holes in the blade. This air creates a thin layer of cool air on the surface of the blade, protecting it from the high temperature gases. The air holes are most often located along the leading edge. One consideration with film cooling is that injecting the cooler air into the gas flow reduces turbine efficiency. The drop in the efficiency increases as the amount of cooling flow increases. The drop-in efficiency however is usually compensated by the increasing overall performance produced by the higher turbine temperature.

Transpiration cooling is the third major type of cooling and is like film cooling as it creates a thin film of cooling air on the blade, but it is different in that that air is lead though a porous shell rather than injected through holes. This type of cooling is effective at high temperature as it uniformly covers the entire blade with cool air.

The purpose of turbine technology is to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time. Gas turbines have been constructed to work on variety of fuel: -oil, natural gas, coal gas, producer gas, blast furnace and pulverized coal.

1.6 Production of Blades

Blades may be the heart of turbine and all other member exist for the sake of the blades. Without blading there would be no power and the slightest fault in blading would mean a reduction in efficiency and costly repairs. The following are some of the methods adopted for production of blades.

1) Rolling: - Sections are rolled to the finished size and used in conjunction with packing pieces. Blades manufactured by this method do not fail under combined bending and centrifugal force.

2) Machining: - Blades are also machined from rectangular bars. This method has had the same advantage as that of first. Impulse blading is manufactured by this technique.

3) Forging: - Blade and vane sections having aerofoil sections are manufactured by specialist techniques. The simplest way is to determine the profile required at the hub and tip and join then by straight ruled lines. Once the geometry of the ruled line is established they may be machined by a milling machine, rest carefully by each line to generate the shape required in a master block from which the forging die may be copy machined. This method ensures the accurate forging of blades to their finished size, requiring only finishing. Broaching often does the machining of the fir-tree root and electrochemical machining may be used in some parts to avoid the conventional cutting processes.

In advance methods, computers are used to determine the blade shape required by aerodynamic and stress criteria. The computer may then instruct a numerically controlled milling machine to prepare the dies.

4) Extrusion: - Blades are sometimes extruded and the roots are left on the subsequent machining. This method is not reliable as rolled sections, because of narrow limits imposed on the composition of blade material.

1.7 Blade Materials

Proper selection of blade material plays a key role in blade design. The factors that influence the selection of blade materials are: -

1) Method of manufacture

2) Ease of machining

3) The ability to produce blade sections free from flaws.

4) Ductility both allow of rolling of shapes.

5) The capacity for being welded.

6) Ease of forging easily.

7) Condition of operations.

8) Suitable tensile strength at elevated temperature.

9) Resistance to creep.

10) Cost.

The commonly used blade materials are: -

Brass: - Brass (70 to 72 % Cu and 28 to 30 % Zn) is suitable for temperature up to 230 deg. This is rarely used now days.

Copper Nickel: - This is an alloy containing about 80 % Cu, 19 % Ni and fraction of iron and magnesium.

Nickel Brass: - It is suitable for temperature range up to 230 and contains 50 % Cu, 40 % Zn and 10 % Ni. It may be cold drawn.

Manganese copper: - Its composition is 95 to 96 % Cu, 4 to 5 % Mn and lesser amounts of iron, carbon and leads. It is not suitable for high stress and temperature. It may be cold drawn and cold rolled.

Phosphor Bronze: - This is copper tin alloy with a small amount of phosphorous. Its composition is 86 % Cu, 14 % tin and 1 % phosphorous for hard bronze.

Monel Metal: - The composition of Monel metal is 67 % Ni and 28 % Cu with a small amount of iron, carbon, manganese. It is resistant to corrosion and is suitable for elevated temperature. It is used for marine work.

Stainless steel: - It is an alloy of iron, chromium and carbon containing 12 to 14 % chromium and normal percentage of carbon. It is very resistant to corrosion and erosion. It is also very hard. It may be rolled, easily machined and welded.

Modern Alloys: -A modern turbine blade alloy is complex in that it contains up to ten significant alloying elements, but its microstructure is very simple. The structure is

analogous to an `Inca wall', which consists of rectangular blocks of stone stacked in a regular array with narrow bands of cement to hold them together. In the alloy case the `blocks are an intermetallic compound with the approximate composition Ni_3 (Al, Ta), whereas the `cement' is a nickel solid solution containing chromium, tungsten and rhenium.

Super alloys: The titanium in the original intermetallic has been replaced by tantalum. This change gave improved high temperature strength, and improved oxidation resistance. However, the biggest change has occurred in the nickel, where high levels of tungsten and rhenium are present. These elements are very effective in solution strengthening.

Since the 1950's, the evolution from wrought to conventionally cast to directionally solidified to single crystal turbine blades has yielded a 250°C increase in allowable metal temperatures, and cooling developments have nearly doubled this in terms of turbine entry gas temperature. An important recent contribution has come from the alignment of the alloy grain in the single crystal blade, which has allowed the elastic properties of the material to be controlled more closely. These properties in turn control the natural vibration frequencies of the blade.

If metallurgical development can be exploited by reducing the cooling air quantity this is a potentially important performance enhancer, as for example, the Rolls-Royce Trent 800 engine uses 5% of compressor air to cool its row of high pressure turbine blades. The single crystal alloy, RR3000, can run about 35°C hotter than its predecessor. This may seem a small increase, but it has allowed the Trent intermediate pressure turbine blade to remain uncooled.

CHAPTER – 2
LITERATURE REVIEW

B. Deepanraj et.al [1] Gas turbine is an important functional part of many applications. Cooling of blades has been a major concern since they are in a high temperature environment. Various techniques have been proposed for the cooling of blade sand one such technique is to have axial holes along the blade span. Finite element analysis is used to analyse thermal and structural performance due to the loading condition, with material properties of Titanium- Aluminium Alloy. Six different models with different number of holes (7, 8, 9, 10, 11, and 12) were analysed in this paper to find out the optimum number of holes for good performance. In Finite element analysis, first thermal analysis followed by structural analysis is carried out. Graphs are plotted for temperature distribution for existing design (12 holes) and for 8 holes against time. 2D and 3D model of the blade with cooling passages are shown. Using ANSYS, bending stress, deflection, temperature distribution for number of holes are analysed. It is found that when the numbers of holes are increased in the blade, the temperature distribution falls. For the blade configuration with 8 holes, the temperature near to the required value i.e., 800°C is obtained. Thus, a turbine blade with 8 holes configuration is found to be the optimum solution.

Je-Chin Han et.al [2] Film cooling is widely used to protect modern gas turbine blades and vanes from the ever-increasing inlet temperatures. Film cooling involves a very complex turbulent flow-field, the characterization of which is necessary for reliable and economical design. Several experimental studies have focused on gas turbine blade, vane and end-wall film cooling over the past few decades. Measurements of heat transfer coefficients, film cooling effectiveness values and heat flux ratios using several different experimental methods have been reported. The emphasis of this current review is on the Pressure Sensitive Paint (PSP) mass transfer analogy to determine the film cooling effectiveness. The theoretical basis of the method is presented in detail. Important results in the open literature obtained using the PSP method are presented, discussing parametric effects of blowing ratio, momentum ratio, density ratio, hole shape, surface geometry, free-stream turbulence on flat plates, turbine blades, vanes and end-walls. The PSP method provides very high-resolution contours of film cooling effectiveness, without being subject to the conduction error in high thermal gradient regions near the hole.

Lalit Dhamecha et.al [3] Gas turbine play a vital role in the today's industrialized society, and as the demand for power increase, the power output and thermal efficiency of gas turbine must also increase. One method of increasing both the power output and thermal efficiency of the engine is to increase the temperature of the gas entering the turbine. In the advanced gas turbine, the inlet temperature of around 1500°C is used; however, this temperature exceeds the melting temperature of the metal aerofoils. Therefore, along with high temperature material development, a refined cooling system must be developed for continuous safe operation of gas turbines with high performance. Gas turbine blades are cool internally and externally. This paper is mainly focus on

external cooling of the turbine i.e. film cooling. In film cooling, relatively cool air is injected from the inside of the blade which travels through the entire blade length and form a protective film around the blade-surface. In present work attempt has been made to analyse the failure of the gas turbine blade through structural analysis. The analysis is conducted for two different blade configurations one is the base line configuration with film cooling cylindrical holes along the entire length and in another configuration the holes along the leading edge are branched together for anti-vortex considerations. The two configurations are further study for two different pitches to diameter ratio(y/d) of the cooling holes.

WIN LAI HTWE et.al [4] Gas turbines have an important role in electric power generation. Gas turbine technology is used in a variety of configurations for electric power generation. Turbine rotor blades are the most important components in a gas turbine power plant. Turbine blades are mainly affected due to static loads. Also, the temperature has significant effect on the gas turbine rotor blades. This paper summarizes the design and steady state thermal analysis of gas turbine rotor blade, on which Cosmo software is used for design of solid model of the turbine blade. ANSYS14.5 software is used for analysis of finite element model generated by meshing of the blade and design calculation is computed by using MATLAB software. The materials of the gas turbine rotor blade are chosen as copper, titanium and nickel. The existing turbine blade material is copper. The gas turbine rotor blade height is 0.0826m, rotor blade chord is 0.0645m, rotor blade thickness is 0.0129m and the numbers of gas turbine rotor blade are 92 blades. The gas turbine rotor blade inlet temperature is 1622°C and rotor blade outlet temperatures 1478°C. Total thermal heat flux of theoretical result for copper is 2.6453MW/, for titanium is 0.9927MW/m2 and for nickel is 1.9559MW/m2. Simulation result of total thermal heat flux for copper is 3.0060MW/m2, for titanium is1.1503MW/m2 and for nickel material is 2.1810MW/m2. According to the comparison of the theoretical result and Simulation result, titanium material has the least heat flux. So, this material is better than the two other materials

L.Umamaheswararao et.al [5] the first stage rotor blade of a gas turbine has been analysed for structural, thermal analysis using ANSYS (Finite Element Analysis Software). The material of the blade was specified as INCONEL 718. The thermal boundary conditions on the rotor blade are taken from the reference. The temperature distribution across the blade is obtained. The maximum stress up to which the blade can withstand is known and the stress distributions across the blade are obtained accordingly. The obtained results are compared with N-155, Mild Steel and the most suitable material is discussed. In final the actual fir tree model blade root compared with I-section model blade root, results are tabulated, and it is observed that stress distribution less in fir tree model that the I-section model.

Amjed Ahmed Jasim AL-Luhaibi et.al [6] Performance of a gas turbine is mainly depending on various

parameters e.g. ambient temperature, compressor pressure ratio, turbine inlet temperature etc. The most important parameter to increase the life of the turbine blade is the cooling of the blade, which is necessary after reaching a certain temperature of the gases passing through the blades. Various types of cooling models are available for a turbine blade cooling. The power output of a gas turbine depends on the mass flow rate through it. This is precisely the reason why on hot days, when air is less dense, power output falls off. This paper is to analyse the film cooling technique that was developed to cool gases in the initial stages of the turbine blades, where temperature is very high (>1122 K). It is found that the thermal efficiency of a cooled gas turbine is less as compare to the uncooled gas turbine for the same input conditions. The reason is that the temperature at the inlet of the turbine is decreased due to cooling and the work produced by the turbine is slightly decreased. It is also found that the power consumption of the cool inlet air is of considerable concern since it decreases the net power output of gas turbine. In addition, net power decreases on increasing the overall pressure ratio. Furthermore, the reviewed works revealed that the efficiency of the cooled gas turbine largely depends on the inlet temperature of the turbine and previous research said that the temperature above 1123K, require cooling of the blade.

P.R. Surve et.al [7] Blades of gas turbine are responsible for extracting energy from the high temperature and high-pressure gases. Gas turbine blade operated at high temperature provides better efficiency and maximum work output. The present paper deals with structural analysis of gas turbine blade. The analysis was carried out to know the mechanical stresses and deformation experienced by the gas turbine rotor blade. Solid model of turbine blade is created by using SOLIDWORKS20 software. The turbine blade is analysed for its' structural performance due to the loading condition using ANSYS 16.2 software to study the variation of stresses on gas turbine blade for aluminium alloy, titanium alloy and magnesium alloy material. Among this three materials Titanium alloy has maximum equivalent stress 7.53×105 N/m2 and minimum deformation of $2.33 \times 10\text{-}5$ m.

Hussain Mahamed Sahed Mostafa Mazarbhuiya et.al [8] in gas turbines the major portion of performance dependency lies upon turbine blade Design. Turbine blades experience very high centrifugal, axial and tangential force during power Generation. While withstanding these forces blades undergo elongation. Different methods have proposed for better enhancement of the mechanical properties of blade to withstand in extreme Condition. Present paper describes the stress and elongation for blades having properties of Different materials. Steady state structural analysis has performed in the present work for Different materials (In 625, In 718, In 738, In 738 LC, MAR M246, Ni-Cr, Ti-alloy, Ti-Al, Ti-T6, U500). Remarkable finding is that the root of the blade is subjected to maximum stress for all Blade materials and the blade made of MAR M246 has less stress and deformation among all other blade materials which can be selected as a suitable material for gas turbine blade.

Pedaprolu Venkata Vinod et.al [9] this project summarizes the design and analysis of Gas turbine blade, CATIA is used for design of solid model and ANSYS Software for analysis for F.E. model generated, by applying boundary condition, this project also includes specific post processing and

life assessment of blade. How the program makes effective use of the ANSYS pre-processor to mesh complex Turbine blade geometries and apply boundary conditions. Here under we presented how Designing of a turbine blade is done In CATIA with the help of co-ordinate generated on CMM. And to demonstrate the pre-processing capabilities, static and dynamic stress analyses results, generation of Campbell and Interference diagrams and life assessment. The principal aim of this project is to get the natural frequencies and mode shape of the turbine blade.

CHAPTER – 3

TURBINES

Turbine: A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. A turbine is a turbo machine with at least one moving part called a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades so that they move and impart rotational energy to the rotor. A working fluid contains potential energy (pressure head) and kinetic energy (velocity head). The fluid may be compressible or incompressible. Several physical principles are employed by turbines to collect this
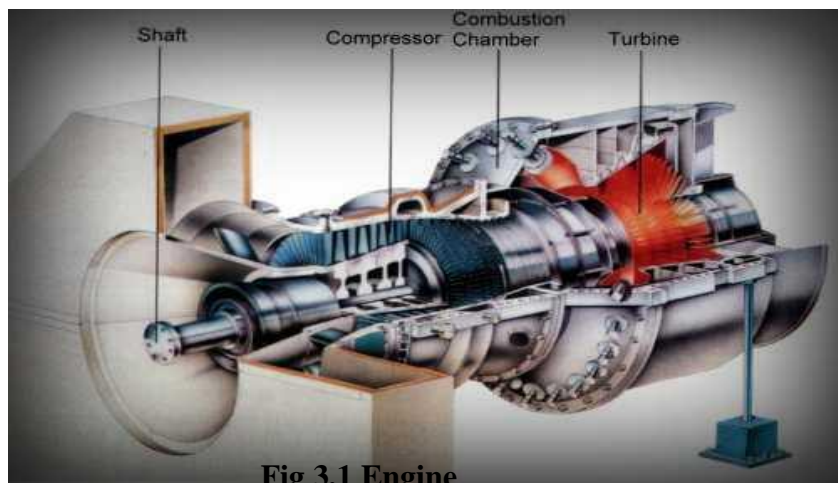
Fig 3.1 Engine

3.1 GAS TURBINES:

The gas turbine in its most common form is a rotary heat operating by means of series of processes consisting of air taken from the atmosphere, increase of gas temperature by constant pressure combustion of the fuel in the whole process being continuous. It is like petrol and diesel engines in working medium and internal combustion but is akin to the steam turbines in its aspect of the steady flow of the working medium. Today the steam turbine is preeminent as an aircraft power plant with outputs ranging from a few hundreds of Newton if thrust to over 1000 KN. As a shaft unit the smallest in regular service is 5H.P. The outstanding characteristics of gas turbines, which make them eminent of all turbines, are as follows:

1. It has a very simple mechanism.

2. It runs at higher speed.

3. It is very compact engine compared to other requiring less weight and space.

4. It requires less maintenance cost.

5. Cheaper liquid fuel can be used, as phenomenon of detonation does not exist.

6. It is highly situated for peak load and standby power generation and aircraft propulsion.

7. It works at high operating pressures

8. It has greater power to weight ration than other engines.

9. It requires less manpower.

Gas turbines also used in marine application for power generation and propelling. For these applications the gas turbine must work under high pressure, temperature and critical forces (tangential force, axial force, centrifugal force). The main part of the gas turbine is blades which must withstand these forces.

3.1.1 GAS TURBINE OPERATION:

The gas turbine is an internal combustion engine that uses air as the working fluid.

The engine extracts chemical energy from fuel and converts it to mechanical energy using the gaseous energy of the working fluid (air) to drive the engine and propeller, which, in turn, propel the airplane and marine ships. Gas turbine works under Brayton cycle.

3.1.2 BRAYTON CYCLE: THE IDEAL CYCLE FOR GAS-TURBINE ENGINES

The Brayton cycle was first proposed by George Brayton for use in the reciprocating oil-burning engine that he developed around 1870. Today, it is used for gas turbines only where both the compression and expansion processes take place in rotating machinery. Gas turbines usually operate on an *open cycle,* as shown in Fig. 1. Fresh air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high-pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The resulting high temperature gases then enter the turbine, where they expand to the atmospheric pressure while producing power. The exhaust gases leaving the turbine are thrown out (not recirculated), causing the cycle to be classified as an open cycle. The open gas-turbine cycle described above can be modelled as a closed cycle, as shown in Fig 2, by utilizing the air-standard assumptions. Here the compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat-addition process from an external source, and the exhaust process is replaced by a constant pressure heat-rejection process to the ambient air. The ideal cycle that the working fluid undergoes in this closed loop is the Brayton cycle, which is made up of four internally reversible processes:

1-2 Isentropic compression (in a compressor)

2-3 Constant-pressure heat addition

3-4 Isentropic expansion (in a turbine)

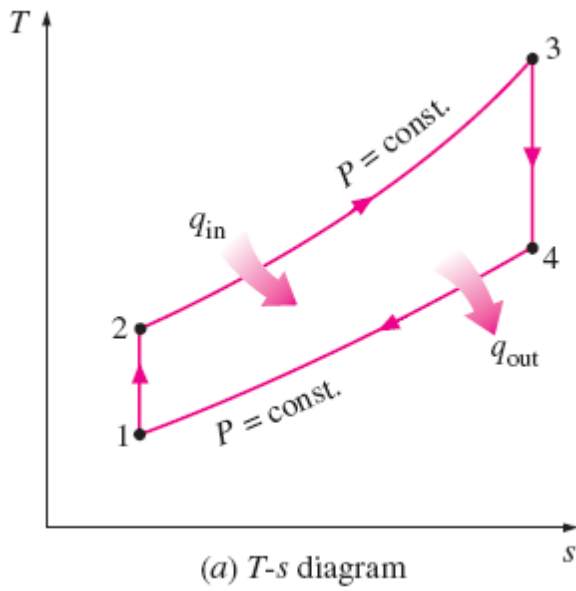4-1 Constant-pressure heat rejection

Fig 3.2   Fig 3.3

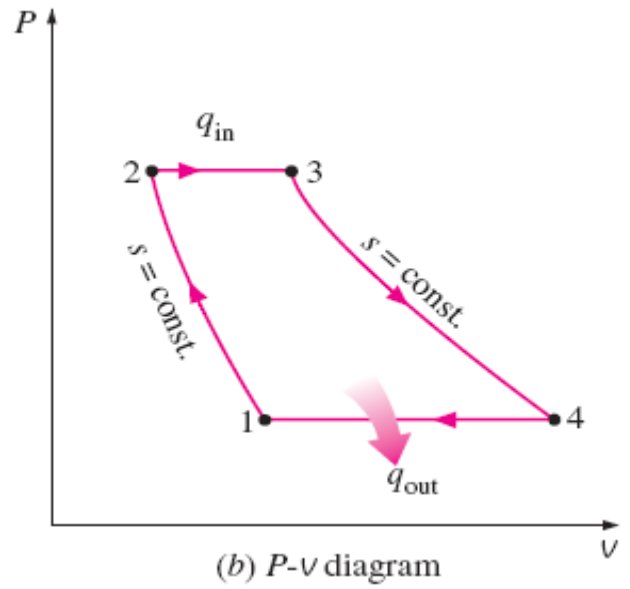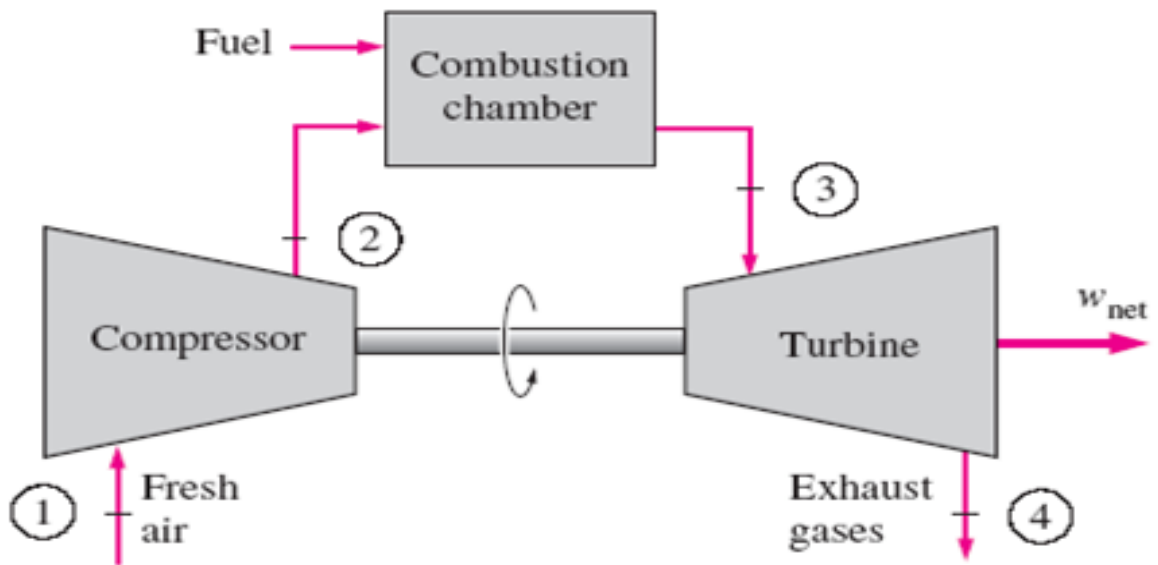(a) T-s diagram   (b) P-v diagram

Fig 3.4

FIGURE 1
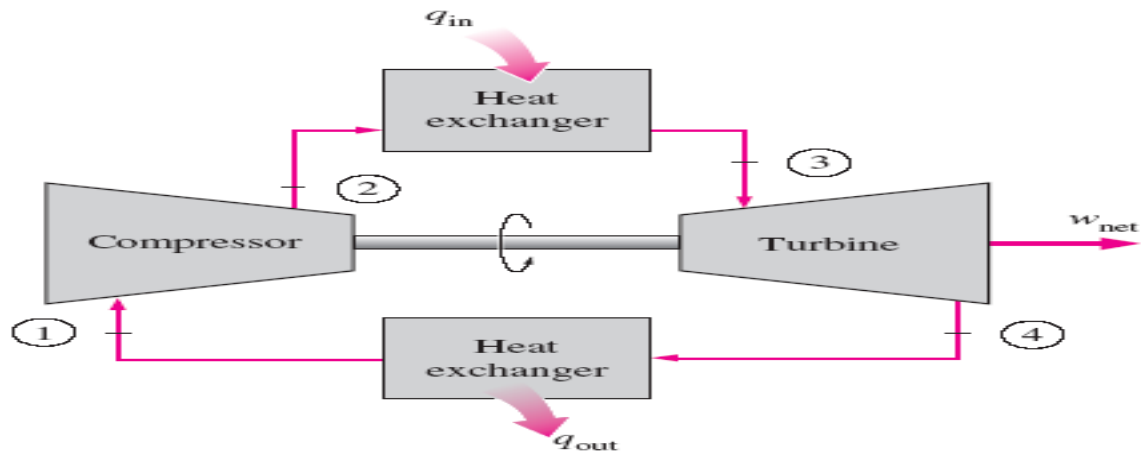
An open-cycle gas-turbine engine.

FIGURE 2

A closed-cycle gas-turbine engine.

Fig 3.5

The highest temperature in the cycle occurs at the end of the combustion process (state 3), and it is limited by the maximum temperature that the turbine blades can withstand. This also limits the pressure ratios that can be used in the cycle. There should be a compromise between the pressure ratio (thus the thermal efficiency) and the network output. With less work output per cycle, a larger mass flow rate (thus a larger system) is needed to maintain the same power output, which may not be economical. In most common designs, the pressure ratio of gas turbines ranges from about 11 to 16. The air in gas turbines performs two important functions: It supplies the necessary oxidant for the combustion of the fuel, and it serves as a coolant to keep the temperature of various components within safe limits. The second function is accomplished by drawing in more air than is needed for the complete combustion of the fuel. In gas turbines, an air–fuel mass ratio of 50 or above is not uncommon. Therefore, in a cycle analysis, treating the combustion gases as air does not cause any appreciable error. Also, the mass flow rate through the turbine is greater than that through the compressor, the difference being equal to the mass flow rate of the fuel. Thus, assuming a constant mass flow rate throughout the cycle yields conservative results for open-loop gas-turbine engines.

3.1.3 USES:

1. Almost all electrical power on Earth is produced with a turbine of some type. Very high efficiency steam turbines harness about 40% of the thermal energy, with the rest exhausted as waste heat.

2. Most jet engines rely on turbines to supply mechanical work from their working fluid and fuel as do all nuclear ships and power plants.

3. Turbines are often part of a larger machine. A gas turbine, for example, may refer to an internal combustion machine that contains a turbine, ducts, compressor, combustor, heat-exchanger, fan and (in the case of one designed to produce electricity) an alternator. Combustion turbines and

steam turbines may be connected to machinery such as pumps and compressors, or may be used for propulsion of ships, usually through an intermediate gearbox to reduce rotary speed.

4. Reciprocating piston engines such as aircraft engines can use a turbine powered by their exhaust to drive an intake air compressor, a configuration known as a turbocharger (turbine supercharger) or, colloquially, a "turbo".

5. Turbines can have very high-power density (i.e. the ratio of power to weight, or power to volume). This is because of their ability to operate at very high speeds. The Space Shuttle's main engines used turbo pumps (machines consisting of a pump driven by a turbine engine) to feed the propellants (liquid oxygen and liquid hydrogen) into the engine's combustion chamber. The liquid hydrogen turbo pump is slightly larger than an automobile engine (weighing approximately 700 lb) and produces nearly 70,000 HP (52.2 MW).

6.Turboexpanders are widely used as sources of refrigeration in industrial processes.

7. Military jet engines, as a branch of gas turbines, have recently been used as primary flight controller in post-stall flight using jet deflections that are also called thrust vectoring. The U.S. FAA has also conducted a study about civilizing such thrust vectoring systems to recover jetliners from catastrophes.

3.1.4 ADVANTAGES:

- Very high power-to-weight ratio, compared to reciprocating engines;
- Smaller than most reciprocating engines of the same power rating.
- Moves in one direction only, with far less vibration than a reciprocating engine.
- Fewer moving parts than reciprocating engines.
- Greater reliability, particularly in applications where sustained high-power output is required
- Waste heat is dissipated almost entirely in the exhaust. This results in a high temperature exhaust stream
- that is very usable for boiling water in a combined cycle, or for cogeneration.
- Low operating pressures.
- High operation speeds.
- Low lubricating oil cost and consumption.
- Can run on a wide variety of fuels.
- Very low toxic emissions of CO and HC due to excess air, complete combustion and no "quench" of the flame on cold surfaces.

3.1.5 DISADVANTAGES:

- Cost is very high.

- Less efficient than reciprocating engines at idle speed.

- Longer start up than reciprocating engines.

- Less responsive to changes in power demand compared with reciprocating engines.

- Characteristic whine can be hard to suppress.

3.1.6 APPLICATIONS:

A) Land applications

1) Locomotive propulsions.

2) Central power stations.

   a) Standby plants for hydro installations.

   b) Fully automatic booster stations at end of transmission lines.

   c) Standby and peak load plants for small system.

   d) Bomb proof power plants.

   e) At location where water is not available.

3) Industrial.

   a) Pumping stations.

   b) Space Applications-Turbo jet, Turbo propulsion, marine applications

3.2 TURBINE BLADE:

A turbine blade is the individual component which makes up the turbine section of a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like super alloys and many different methods of cooling, such as internal air channels, boundary layer cooling, and thermal barrier coatings. So, for this application the gas turbine blade must be casted with a material which has high chemical and physical properties. One of such type of materials is superalloy. Superalloy is combination some materials to increase the material properties.

3.2.1 BLADE MATERIALS:

Proper selection of blade material plays an important role in blade design. The factors that influence the selection of blade materials are: -

1) Method of manufacture

2) Ease of machining

3) The ability to produce blade sections free from flaws.

4) Ductility both allow of rolling of shapes.

5) The capacity for being welded.

6) Ease of forging easily.

7) Condition of operations.

8) Suitable tensile strength at high temperature.

9) Resistance to creep.

10) Cost.

3.2.2 Super alloy: Super alloys had been made to satisfy all physical and chemical properties.

Superalloys are heat-resisting alloys based on nickel, nickel-iron, or cobalt that exhibit a combination of mechanical strength and resistance to surface degradation.

Superalloys are primarily used in gas turbines, coal conversion plants, and chemical process industries, and for other specialized applications requiring heat and/or corrosion resistance.

A noteworthy feature of nickel-base alloys is their use in load-bearing applications at temperatures more than 80% of their incipient melting temperatures, a fraction that is higher than for any other class of engineering alloys.

Applications of superalloys are categorized below; the bulk of tonnage is used in gas turbines:

• Aircraft gas turbines: disks, combustion chambers, bolts, casings, shafts, exhaust systems, cases, blades, vanes, burner cans, afterburners, thrust reversers.

• Steam turbine power plants: bolts, blades, stack gas re-heaters

• Reciprocating engines: turbochargers exhaust valves, hot plugs, valve seat Inserts.

• Metal processing: hot-work tools and dies, casting dies

• Medical applications: dentistry uses, prosthetic devices

• Space vehicles: aerodynamically heated skins, rocket engine parts

• Heat-treating equipment: trays, fixtures, conveyor belts, baskets, fans, Furnace mufflers.

• Nuclear power systems: control rod drive mechanisms, valve stems, springs, Ducting

• Chemical and petrochemical industries: bolts, fans, valves, reaction vessels, Piping, pumps

• Pollution control equipment: scrubbers

• Metals processing mills: ovens, afterburners, exhaust fans

• Coal gasification and liquefaction systems: heat exchangers, re-heaters, piping.

3.2.3 Nickel Base Superalloys:

Nickel-base superalloys are the most complex, the most widely used for the hottest parts, and, to many metallurgists, the most interesting of all superalloys. They currently constitute over 50% of the weight of advanced aircraft engines. The principal characteristics of nickel as an alloy base are the high phase stability of the face-centred cubic (FCC) nickel matrix and the capability to be strengthened by a variety of direct and indirect means. Further, the surface stability of nickel is readily improved by alloying with chromium and/or aluminium.

3.2.4 Alloying materials for super alloys:

NICKEL: It increases the strength and toughness. Nickel contributes great Strength and hardness with elastic limit, good ductility and good resistance to corrosion .an alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature.

CHROMIUM: It combines hardness with high strength and high elastic limit. It also imparts corrosive –resisting properties.

TUNGSTEN: It prohibits grain growth, increases the depth of hardness of quenched steel and confers the property of remaining hard even when heated to red colour.

VANADIUM: It aids in obtaining a fine grain structure in tool steel. The addition of very small

amount of vanadium produces a marked increase in tensile strength and elastic limit.

MANGANESE: It improves the strength in both the hot rolled and heat-treated Conditions.

COBALT: It gives red hardness by retention of hard carbides at high temperature. It tends to decarburize during heat treatment. It increases hardness and strength and residual magnetism and coercive magnetic forces.

MOLYBDENUM: A very small quantity of molybdenum is generally used with Chromium and manganese to make molybdenum steel. These steels possess extra Tensile strength.

MILD STEEL: - In the past, it was used in many turbines but now it is rarely used. It corrodes very soon with wet steam, but it is very inexpensive.

NICKEL STEEL: - This alloy is more resistant to corrosion than is mild steel. It may be forged or machined but not welded. Generally, steel with 3 to 5 % Ni is used. It is used in many turbines.

CHAPTER 4

INTRODUCTION TO CATIA AND ANSYS SOFTWARES

4.1 CATIA

Catia-v5 is the industry's de facto standard 3D mechanical design suit. It is the world's leading

CAD/CAM/CAE software, gives a broad range of integrated solutions to cover all aspects of product design and manufacturing. Much of its success can be attributed to its technology which spurs its costumer's to more quickly and consistently innovate a new robust, parametric, feature based model. Because that CATIA-V5 is unmatched in this field, in all processes, in all countries, in all kind of companies along the supply chains. Catia-v5 is also the perfect solution for manufacturing enterprise, with associative applications, robust responsiveness and web connectivity that make it the ideal flexible engineering solution to accelerate innovations.

Catia-v5 provides easy to use solution tailored to needs of small medium sized enterprises as well as large industrial corporations in all industries, consumer goods, fabrications and assembly. Electrical and electronics goods, automotive, aerospace, shipbuilding and plant design. It is user friendly solid and surface modelling can be done easily.

4.1.1 ADVANTAGES OF CATIA-V5:

1. It is much faster and more accurate.

2. once a design is completed. 2D and 3D views are readily obtainable.

The ability to changes in late design process is possible.

3. It provides a very accurate representation of model specifying all

other dimensions hidden geometry etc.

4. It is user friendly both solid and surface modelling can be done.

5. It provides a greater flexibility for change. For example, if we like to change the dimensions of our model, all the related dimensions in design assembly, manufacturing etc. will automatically change.

4.1.2 DIFFERENT MODULES IN CATIA:

There are different modules in CATIA using which different tasks can be performed.

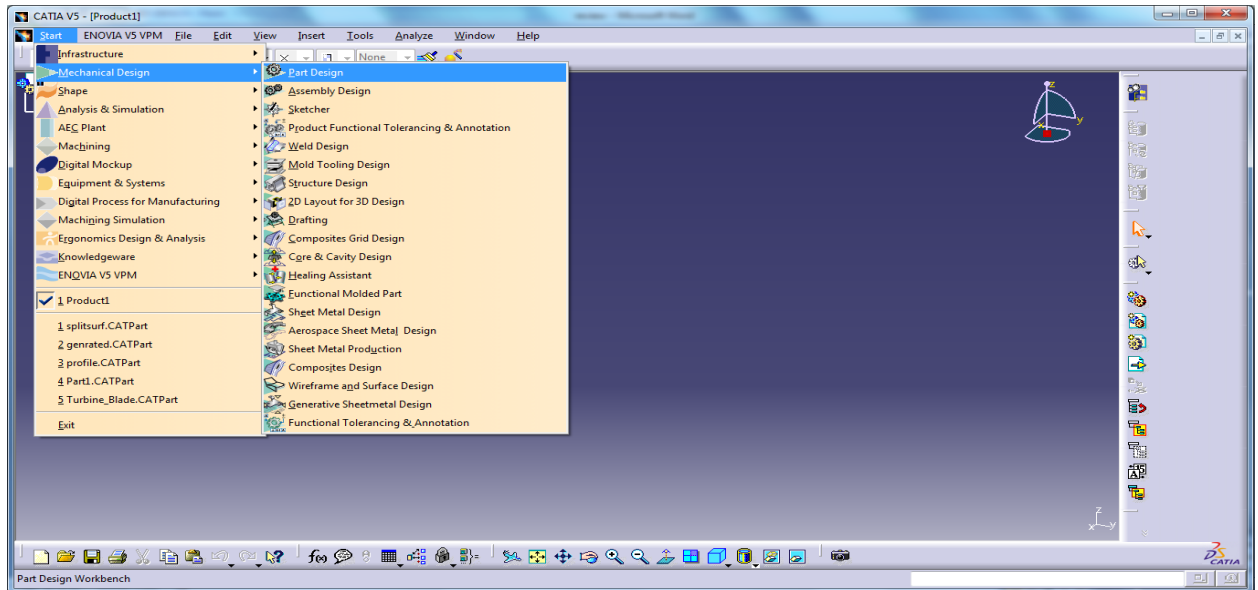The main window and modules of CATIA shown in figure:

Fig.4.1

The main modules are

1. Part design

2. Assembly

3. Drafting

4. Wire frame and Surface Design

5. Core & Cavity Design.

4.1.3 PART DESIGN

The version 5-part design application makes it possible to design precise 3D mechanical parts with an intuitive and flexible user interface, from sketching in an assembly context to iterative detailed. Version 5-part design application will be enable you to accommodate design requirements for parts of various complexities, from simple to advanced.

This application, which combines the power of feature– based design with the flexibility of a Boolean approach, offers a highly productive and intuitive design environment with multiple design methodologies, such as post-design and local 3D parameterization.

Select START -> Mechanical Design ->Part Design from the menu bar

OPTIONS USED TO CREATE SOLIDS:

Pad– pad is a method of defining three-dimensional geometry by projecting a two-dimensional section at specified distance normal to the sketching plane.

Pocket - pocket is a method of extruding a profile or a surface and removing the material resulting from the extrusion.

Shaft– The shaft tool creates a feature by revolving a sketched section around a centreline.

Fillet– A fillet is a curved face of a constant or variable radius that is tan-gent to, and that joins, two surfaces. Together, these three surfaces from either an inside corner or outside corner. Chamfer - chamfering consists in removing or adding a flat section from a selected edge to create a bevelled surface between the two original faces common to that edge.

Draft– Drafts are defined on modelled parts to make them easier to re-move from moulds.

Mirror– Mirroring a body or a list of features consists in duplicating these elements using a symmetry by selecting a face or plane as reference.

Pattern– To duplicate the whole geometry of one or more features and position this geometry on a part.

4.1.4 ASSEMBLY:

Bottom up assembly:

Parts of the assembly are created in respective part files and assembled in assembly file.

Used for components having lesser parts.

Top down assembly:

Parts are created in the assembly file itself. Used for components having more parts.

Assembly procedure:

To assemble the already created components, select product name in specification tree– right click—select components– select new part or select component or new product to create a sub assembly.

Apply constraints to the components to assemble.

4.1.5 GENERATIVE DRAFTING: Generative Drafting is a new generation product that provides users with powerful functionalities to generate drawings from 3D parts and assembly definitions. The generative drafting has been designed to show you how to generate drawings of varying levels of complexity, as well as apply dimensions, annotations and dress-up elements to these drawing.

Start– Mechanical Design– Drafting

Views:

Front view- a front view is a projection view obtained by drawing perpendicular from all points on edges of the part to the plane of projection. The plane of projections upon which the front view is projected is called the frontal plane.

Projection view– projection view are views conceived to be drawn or projected onto planes known as projection planes. A transparent plane or plane of glass representing a projection plane is located parallel to

the front surfaces of the part.

Isometric view– The isometric view command enables to create a 2D view with any orientation, this orientation being the same as the one in the 3D viewer. Among other results and depending on how the 3D viewer is oriented when created the view, can obtain a regular X-Y-Z is isometric view.

4.1.6 DIMENSIONING:

Generative dimensioning– To generate dimensions in one shot from the constraints of a 3D part. Only the following constraints can be generated: distance, length, angle, radius and diameter.

Dimensions– To create and modify dimensions, these dimensions will be associative to the elements created from a part or an assembly. When created, these elements are associated with a view.

Generative Balloons– To generate balloons automatically to the components of an assembly which are previously generated in assembly.

text– To create a text with possible line wrapping.

4.1.7 WIREFRAME & SURFACE DESIGN:

A surface is a geometric feature with no defined thickness. The wall of surface feature does not have defined thickness. Surface tools are used to create geometric shapes with complex contours and relations.

A quilt is a combination of one or more surface features. To enter surface design work bench

Start—Mechanical design– Wireframe and surface design.

Surface operations:

The surface operations are: join, healing, disassemble, split, trim, boundary, extract, and extrapolate.

Join - To join surfaces or curves

Healing - To join surfaces with some gap.

Disassemble - To unjoin single surfaces.

Split - To cut a curve by using a point, curve, surface and Plane.

Trim - To cut two surfaces

4.2 INTRODUCTION TO ANSYS:

ANSYS is an engineering simulation software provider founded by software engineer John Swanson. It develops general– purpose finite element analysis and computational fluid dynamics software. While ANSYS has developed a range of computer– aided engineering (CAE) products, it is perhaps best known for its ANSYS Mechanical and ANSYS Multiple physics products. ANSYS Mechanical and ANSYS

Multiple physics software are non-exportable analysis tools incorporating pre-processing (geometry creation, meshing), solver and post-processing modules in a graphical user interface. These are general—purpose finite element modelling packages for numerically solving mechanical problems, including static/dynamic structural analysis (both liner and non-liner), heat transfer and fluid problems, as well as acoustic and electro-magnetic problems. ANSYS Mechanical technology incorporates both structural and material non-linearities. ANSYS Multi physics software includes solvers for thermal, structural, CFD, electromagnetics, and acoustics and sometimes couple these separate physics together to address multidisciplinary applications. ANSYS software can also be used in civil engineering, electrical engineering, physics and chemistry.

ANSYS, Inc. acquired the CFX computational fluid dynamics code in 2003 and fluent, Inc. in 2006. The CFX packages from ANSYS are used for engineering simulations. In 2008, ANSYS acquired Ansoft Corporation, a leading developer of high– performance Electronic Design Automation (EDA) SOFTWARE and added a suite of products designed to simulate high-performance electronics designs found in mobile communication and interest devices, broadband networking components and systems, integrated circuits, printed circuits boards, and electromechanical systems. The acquisition allowed ANSYS to address the continuing convergence of the mechanical and electrical worlds across a whole range of industry sectors.

4.2.1 ANSYS WORK BENCH:

ANSYS Work bench is a new– generation solution from ANSYS that provides powerful methods for interacting with the ANSYS solver functionally. This environment provides a unique integration with CAD systems, and your design process, enabling the best CAE results. ANSYS Work bench is comprised of five modules:

1. simulation for performing structural and thermal analyses using the ANSYS solver.

2.CFX-Mesh for generating a CFX– Pre-mesh for the CFX-5 Solver

3. Design Modeler for generating a CFX-Pre-mesh for the CFX-5 Solver.

4. Design Xplorer and Xplorer VT for investigating the effect of

variations input to the response of the system.

5. FE Modeler for translating a Nastran mesh for use in ANSYS.

Every analysis involves four main steps:

A. Preliminary Decisions

1. what type of analysis: static, model, etc.?

2.what to model: part or assembly?

3. which elements: surface or solid bodies?

B. pre-processing

1. attach the model geometry.

2. define and assign material properties to parts.

3. mesh the geometry.

4. apply loads and supports.

5. request results.

C. solve the model

D. post processing

1. review results.

2. check the validity of the solution.

4.2.2 ANSYS WORK BENCH ANALYSIS:

The ANSYS Work bench platform is the frame work upon the industry's broadcast and deepest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user through even complex metaphysics analyses with drag– and–drop simplicity. With bi-directional CAD connectivity, powerful highly– automated meshing, a project–level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Work bench platform delivers unprecedented productivity, enabling simulation

The Work bench environment allows you to solve

much more complex analyses, including (as of ANSYS 8.0):

1. Multi-part assemblies.

2. 3-D solid elements, shell elements, and shell-solid assemblies.

3. Nonlinear contact with or without friction.

4. Small-displacement and large– displacement static analyses.

5. Modal, harmonic, and eigen value bucking analyses.

6. steady –state thermal analysis, including temperature–Dependent material properties and thermal contact.

4.2.3 STEP BY STEP PROCEDURE ANALYSIS IN ANSYS WORK BENCH:

1. Open ANSYS work bench analysis version 13.0

2. ANSYS work bench environment will be seen. Then assembled part in CATIA is imported in (. igs) format to ANSYS by going through this step.

Static structural —> geometry —> import

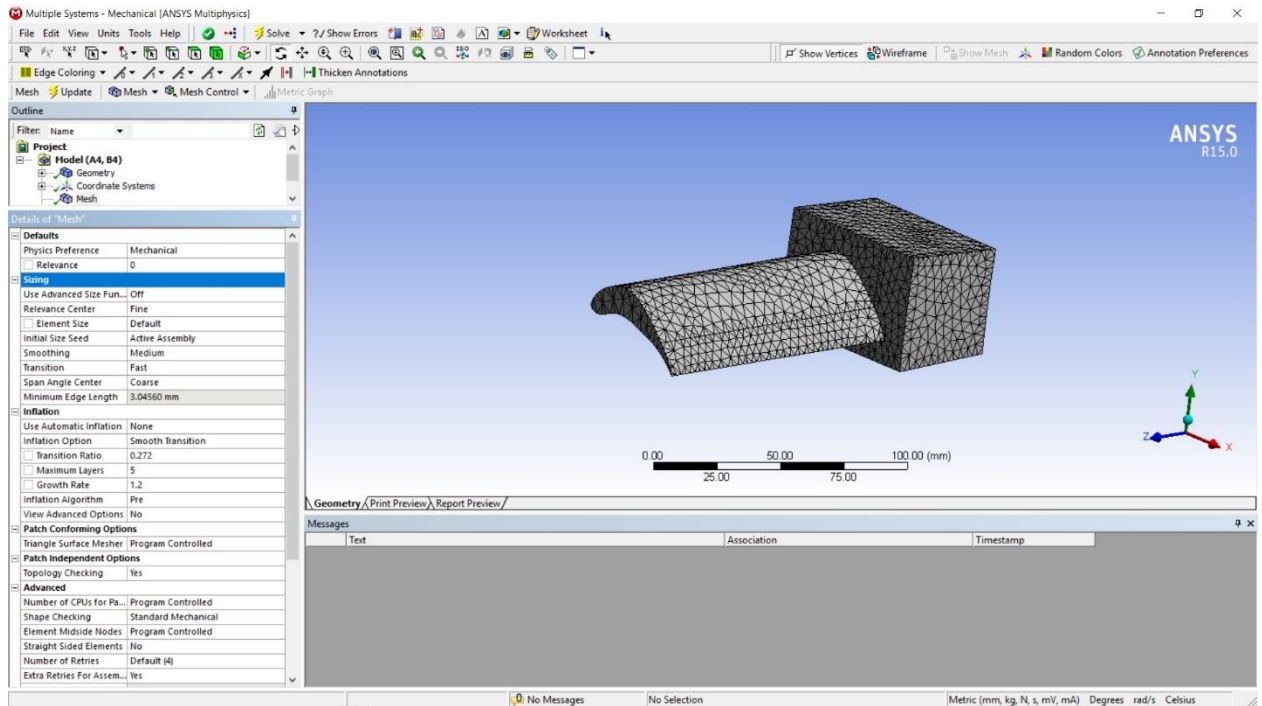2. ANSYS work bench environment will be seen like this.

Fig.4.2

4. select the static structural analysis type from top menu bar by clicking new analysis tab as shown below.
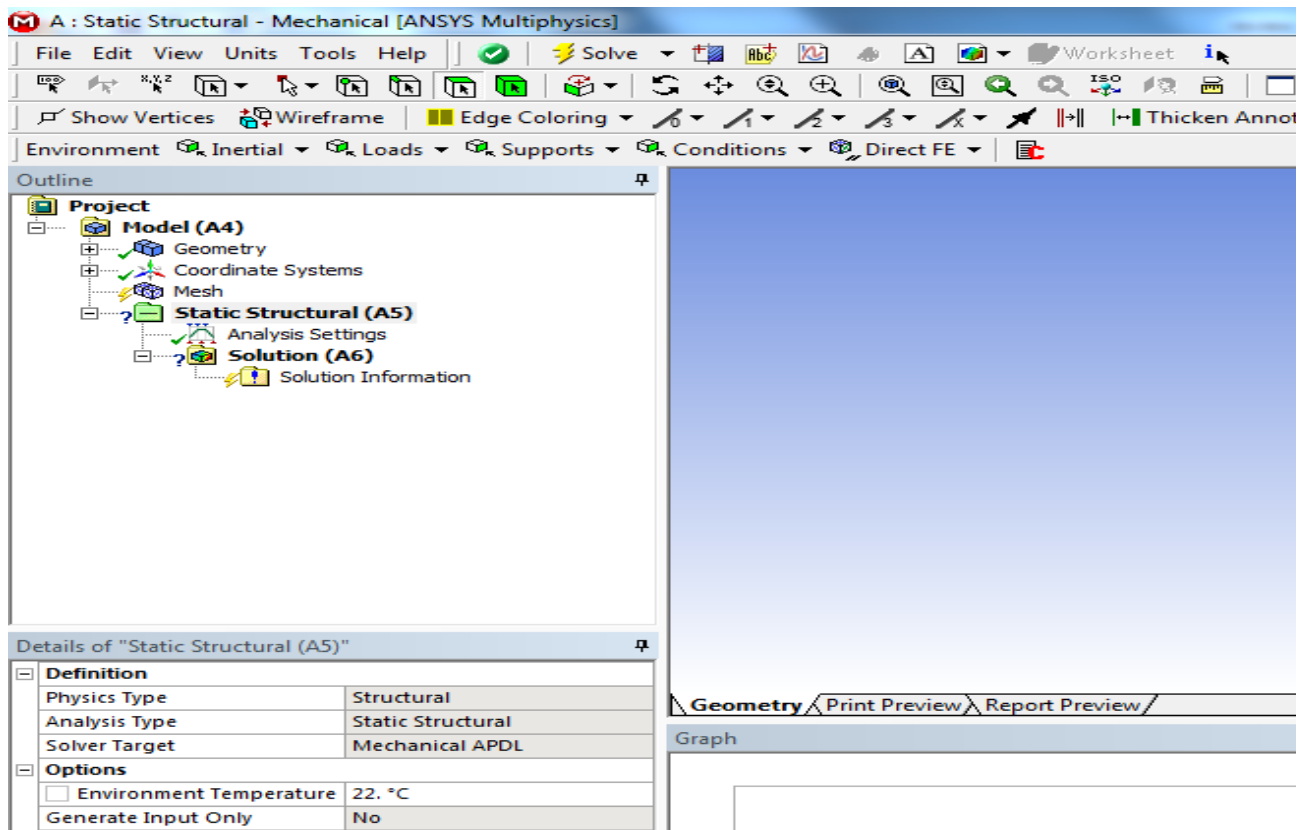
Fig.4.3

5. The next step will be assignment of material properties to the solid model. Default material will be structural steel in ANSYS, materials ap-plying on the element whose analysis is to be done will be changed by varying its mechanical properties like young's modulus, density.
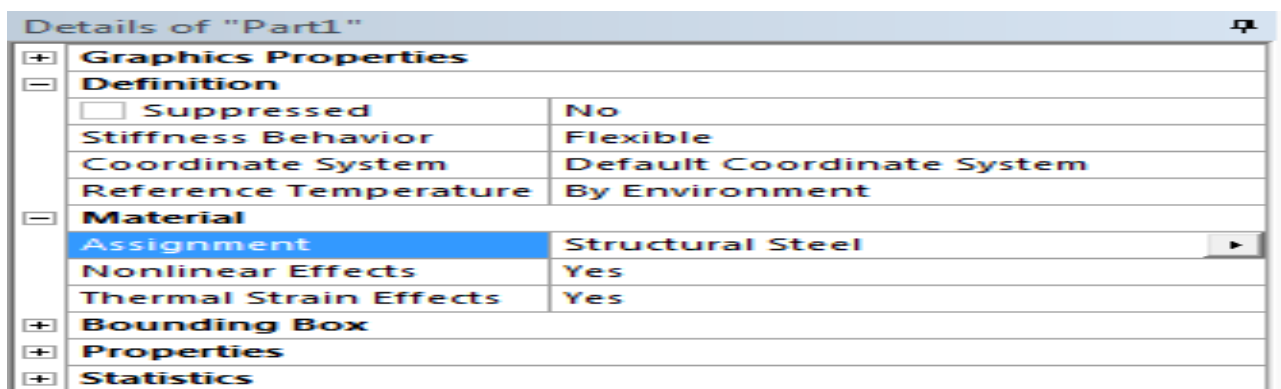

Fig.4.4

6. at the left side of the page, click MODEL —> EDIT then mechanical window will open. Select mesh on left side of the screen and select sizing at the bottom of the page then you can select the relevance centre of mesh you are desired

7. Right click to static structural on left side of the page and then click to INSERT option and provide then

click FORCE and these forces are provided in all 3 directions
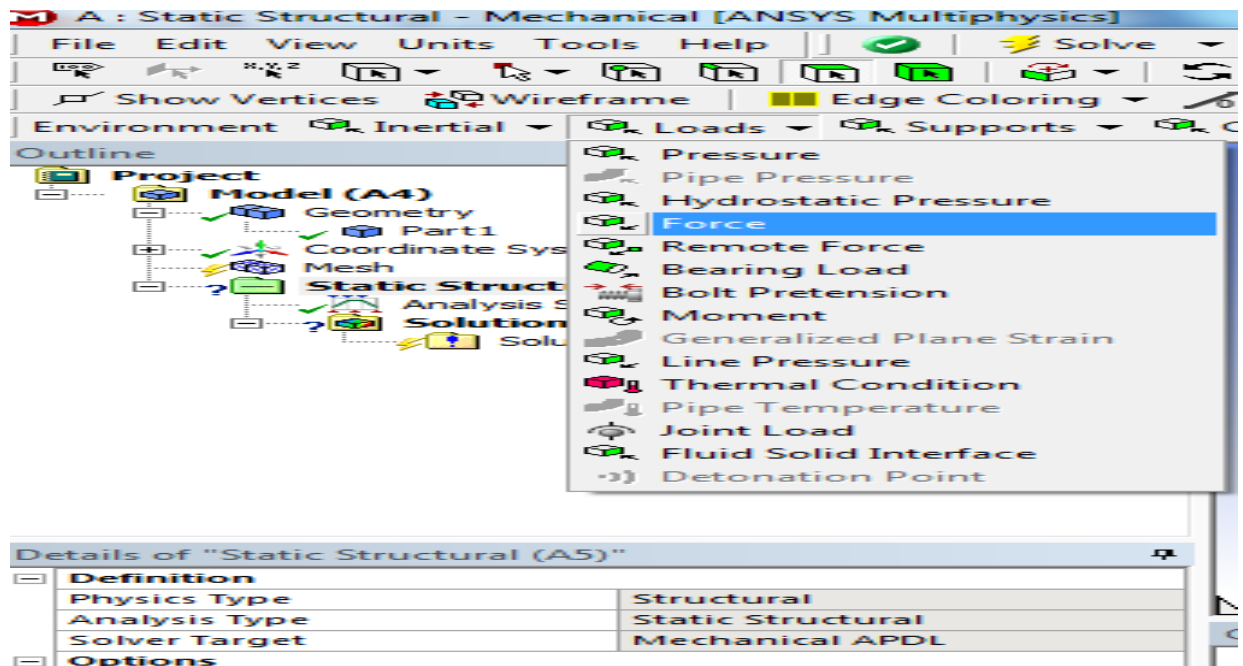
Fig.4.5

8. select the points where forces are to be applied and its magnitude with its direction.

9. click to apply on bottom left portion of the page.

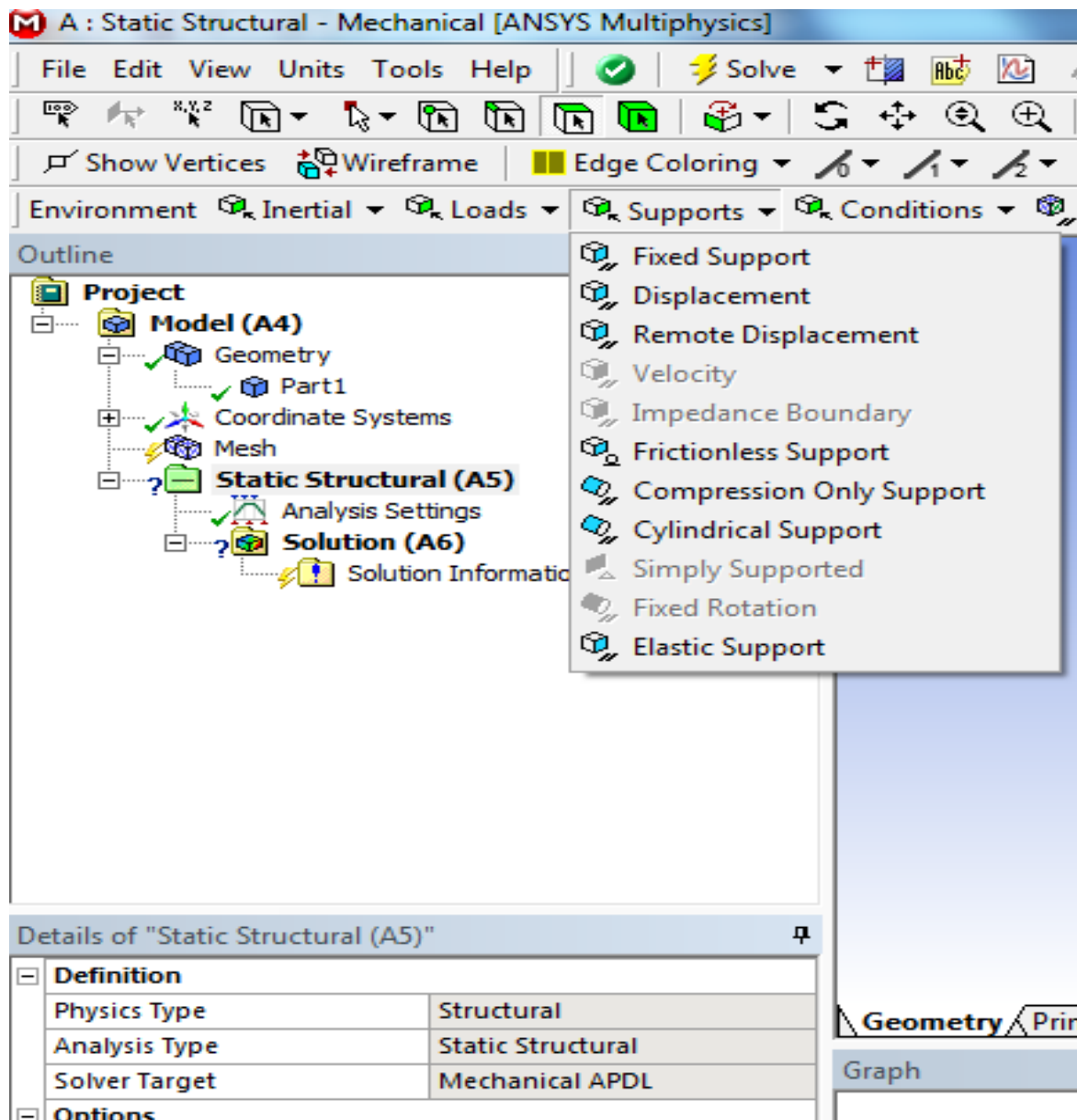10. similarly click STATIC STRUCTURAL —> INSERT—>fixed supports (constraints)

Fig.4.6

11. select the points where constraints are to be applied.

12. right click to solution option on top left portion of the page and then select what are outputs to be obtained in this present project of the page and then select what are outputs to be obtained in this present Project we required Deformation and Equivalent Stress (Von-misses)
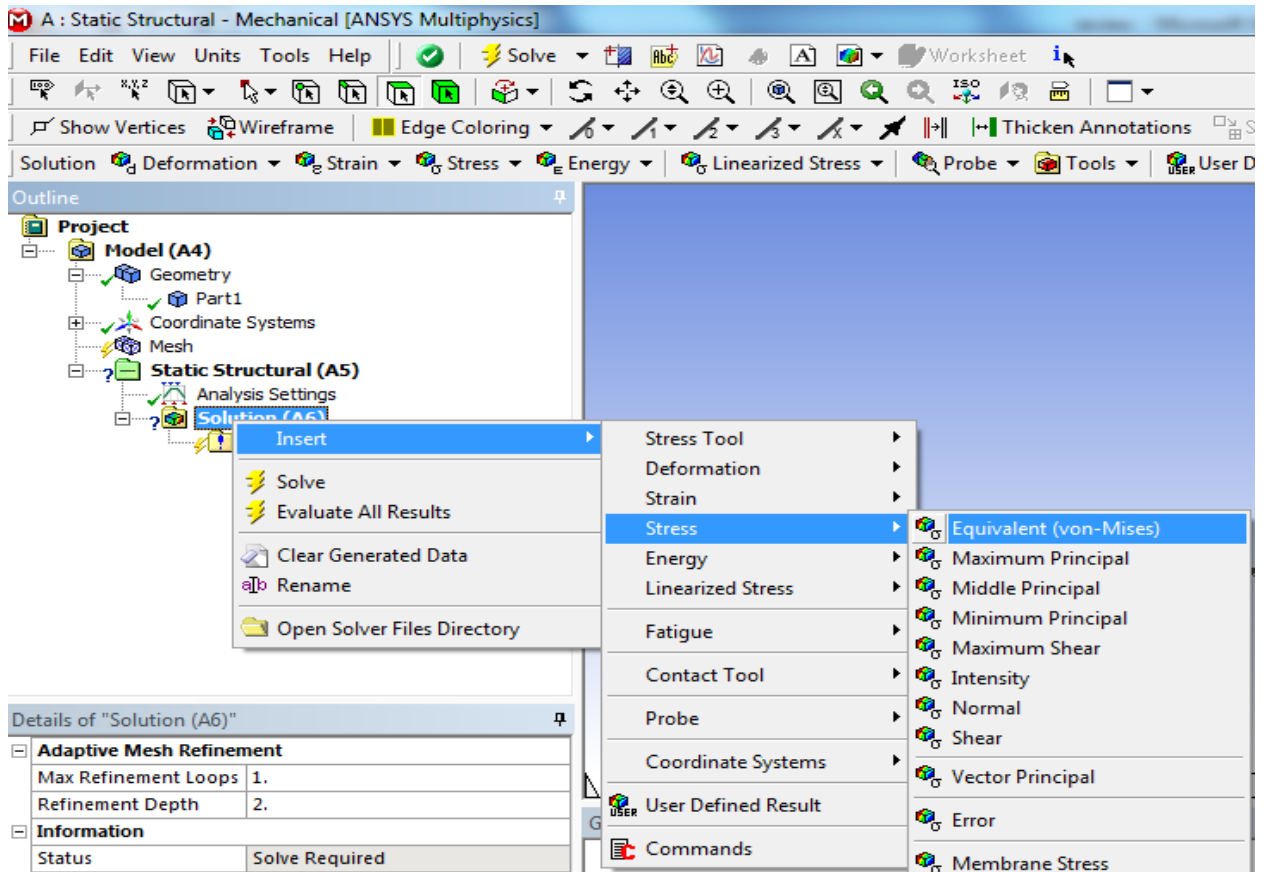
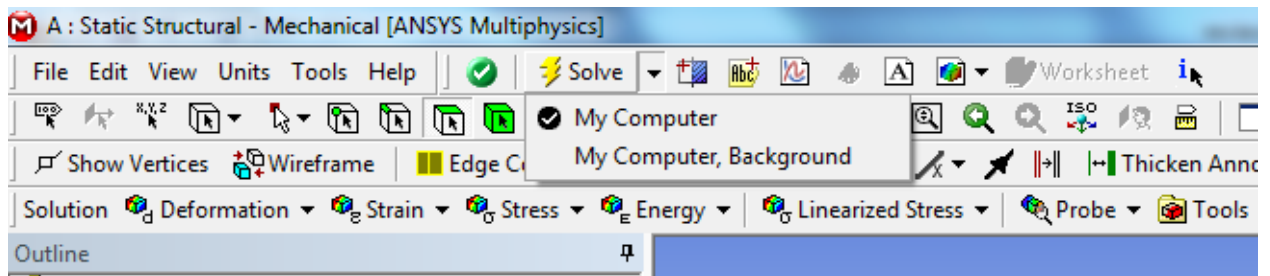Fig.4.7

13. click on SOLVE icon on Top menu as shown below

Fig.4.8

14. ANSYS reports are generated.

15. click to report preview and print preview.

16. You can get the reports in the word format by using the SEND TO button on the pallet.

CHAPTER-5
THEORETICAL ANALYSIS

5.1 Modelling & Design of Turbine blade

A Turbine rotor blade consists of 120 blades each blade height is 117 mm. The blade model profile is generated by using CATIA software. Key points are created along the profile in the working plane. The points are joined by drawing B spline curves to obtain a smooth contour. The contour (2D model) is then converted into area and then volume (3D model) was generated by extrusion. The hub is also generated similarly. These two volumes are then combined into single volume. This model of turbine blade is then imported into ANSYS software. The blade is then analysed sequentially with thermal analysis preceding structural analysis. The model is discretized using 10 noded tetrahedral solid element (Solid 87). The surface of the blade is applied with Surface element (Surf 152) for applying the convection loads. The temperatures of blade are then determined by thermal analysis. Followed by this, the structural analysis is carried out by importing the temperatures determined in thermal analysis. 10 noded tetrahedral solid element (Solid 187) was used for structural analysis. The loads considered for structural analysis are centrifugal, axial & tangential forces.

5.2 Evaluation of heat transfer coefficient (h)

The convective heat transfer coefficients are evaluated on suction side and pressure side separately. The blade suction has been divided into 5 parts and heat transfer coefficients are evaluated for all the 5 parts separately the procedure followed is given as under.

An iterative procedure has been adopted to determine the value of heat transfer coefficients to start with first iteration the properties of the air are evaluated at the average temperature of gasses from inlet to exit and the heat transfer coefficient is determining proper correlation by applying preliminary values on the blade model, thermal analysis carried out.

To determine the temperature of the surface of the blade. To improve the accuracy, the heat transfer coefficients are now evaluated at the film temperature which is the average of bulk fluid temperature and the temperature of the surface. The heat transfer coefficients are again applied on the blade model on the temperature exiting on the surface of the blade are found out the procedure is again repeated by using the new values of surface temperature to determine the heat transfer coefficients.

This process is carried out to determine the exert values of heat transfer coefficients. The procedure followed is mentioned as under.

5.3 Heat transfer coefficient over a blade surface

Reynolds's number $(Re) = (v D)/\mu$ ----   (1)

$Nu = 0.664 \, Re^{0.5} \, Pr^{\,0.333}$ -----   (2)

$Nu = hL/k$ -----   (3)

$h = Nu \, k/L$ ----- (4)

Then get exact values of h and T. In this way completed the study state thermal analysis. Next, to perform the structural analysis on the body so that finds out stresses on the body. Similarly, to the above process solid blade stresses were calculated with respect to temperature but there is a chance that at the high temperature due to more stresses the material might fail. So, to overcome this problem we have adopted the turbine blade cooling system. Here, first by taking series of solid, 5 holes and 9 holes and changing the material find out the optimum cooling blade material & holes.

5.4 Evaluation of Gas Forces on the Rotor Blades

Gas forces acting on the blades of the rotor in general have two components namely tangential (Ft) and axial (Fa). These forces result from the gas momentum changes and from pressure differences across the blades. These gas forces are evaluated by constructing velocity triangles at inlet and outlet of the rotor blades. The rotor blades considered for analysis are untwisted and same profile is taken throughout the length of the blade. If the gas forces are assumed to be distributed evenly then the resultant acts through the centroid of the area.

At the inlet of the Gas turbine rotor blades,

Absolute flow angle $\alpha_2 = 23.85^0$

Absolute velocity $V_2 = 462.21$ m/s

The velocity triangles at inlet of Gas turbine rotor blades were constructed as shown.
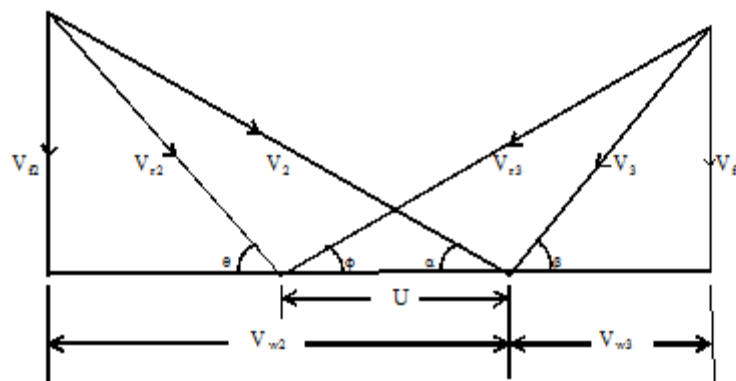
Figure 5.1 Inlet & Exit velocity triangles of Gas turbine rotor blades

Diameter of blade midspan D = 1.3085 m.

Design speed of turbine N = 3426 r.p.m.

Peripheral speed of rotor blade at its midspan U = πDN/60   ------------------ (1)

From the velocity triangles in figure we get,

Whirl velocity V_{w2} = 422.74 m/s

Flow Velocity V_{f2} = 186.89 m/s

Relative velocity $\quad\quad\quad\quad V_{r2}$ = 265.09 m/s

Blade angle at inlet $\quad\quad\quad \theta_2$ = 135.017 ^{0}

At the exit of Gas turbine rotor blades,

Flow velocity $\quad\quad\quad\quad V_{r3}$ = 180.42 m/s

Relative flow angle $\quad\quad\quad \theta_2$ = 37.88 ^{0}

From the velocity triangles (Figure), we get

Whirl velocity at exit $\quad\quad V_{w3}$ = 2.805 m/s

Relative velocity at exit $\quad\quad V_{r3}$ = 293.83 m/s

Finding tangential Force (Ft) and Axial force (Fa) on each rotor

Tangential force

In Newtons $\quad\quad\quad F_t = M (V_{w2} - (+V_{w3})]$ ………….. (2)

Axial Force

In Newtons $\quad\quad\quad F_A = M (V_{f2} - (+V_{f3})]$. ………… (3)

Where 'M' represents mass flow rate of gases through the turbine in kg / sec.
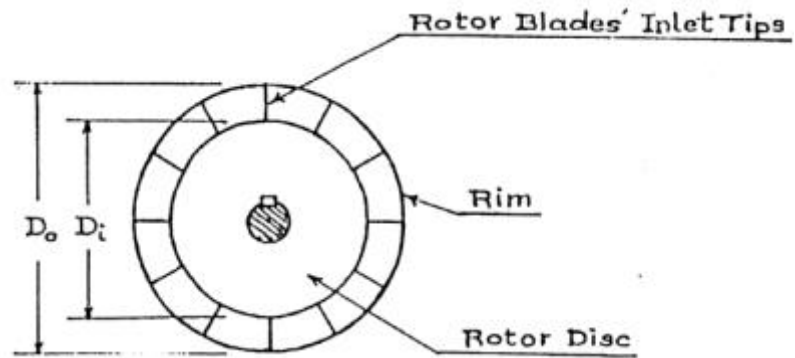
Figure 5.2   Rotor

Blade tip diameter, Do = 1416 mm, Blade root diameter, D_i = 1191 mm

Referring to Figure

$$M = \rho_2 \times \pi \, (D_0 - D_i)/4 \times V \, f_2. \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (4)$$

Where ρ_2 is the density of gases at the entry of Gas turbine rotor

$\rho_2 = 0.6104 \; kg/m^3$

Using equation (4),

M = 52.55 kgs /sec

Using equations (2) and (3)

Total tangential force on Gas turbine rotor

Ft = 22362.38 Newtons.

Total axial force on Gas turbine rotor

Fa = 339.98 Newtons.

Number of blade passages in Gas turbine rotor = 120

Tangential force on each rotor blade

$$Ft = \frac{FT}{\text{No. of blade passages}} \qquad \dots\dots\dots\dots\dots\dots (5)$$

Axial forced on each rotor blade

$$Fa = \frac{FA}{\text{No. of blade passages}} \qquad \dots\dots\dots\dots\dots\dots (6)$$

Using equation (5)

Ft = 186.35 Newtons

Using equation (6)

Fa = 2.833 Newtons

Power developed (p) in the Gas turbine rotor

From Euler's energy equation,

$$P = M\{Vw_2\ U - (+Vw_3\ U)\}. \qquad \dots\dots\dots\dots\dots\dots\dots\dots (7)$$

Using equation (7)

P = 5.199 Mega Watts

We get,

Tangential force F_t = 186.35 Newtons

Axial force F_a = 2.833 Newtons

Power developed P = 5.199 Mega Watts

5.5 Centrifugal Forces Experienced by the Rotor Blades
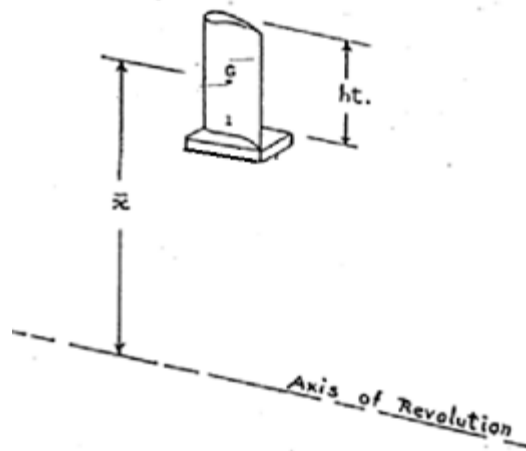
Figure 5.3. 3-D view of rotor blades showing position of centroid 'G'

Centrifugal force Fc:

$$Fc = M \times \{2 \pi N/60\}^2 \times (\underline{x}) \dots\dots\dots\dots\dots\dots\dots\dots (9)$$

Where M = Total mass of rotor blade

N = 3426 r.p.m.

($\underline{x}$) = Distance of centroid from the axis of revolution

= 112.5mm

Using equation (9)

Fc = 5517.37 N.

5.6 Convective Heat Transfer Coefficients over the Blade Surfaces
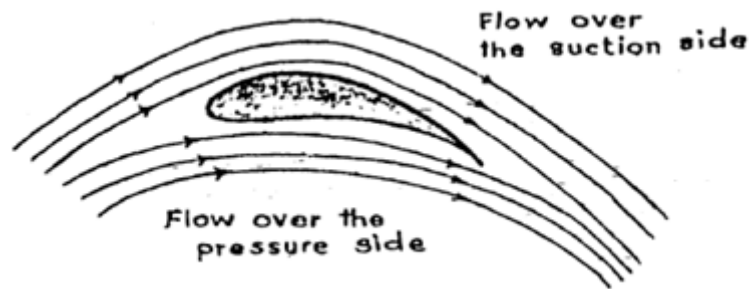
Figure 5.4. gas flow over suction and pressure side of rotor blade

A) Evaluation of Convective Heat Transfer Coefficient on Suction Side (C surface)

Temperature of gases at inlet Ti = 1227^0C

Temperature of gases at exit Te = 1100^0 C

Mean fluid temperature

$$Tmf = \underline{Ti + Te} \qquad (10)$$

2

The flowing properties of air at Tmf were noted.

On suction side the flow is approximated to the flow across a cylinder whose diameter (D) is equal to the chord length (l) of the aerofoil.

Reynolds number

$$Re = 69422.31 \quad \ldots\ldots\ldots \underline{Vr * D} \ldots\ldots\ldots\ldots\ldots\ldots \quad (11)$$

$$v$$

Average relative velocity

$$Vr = 265.09 + 293.83/2 = 279.46 \text{ m/sec} \ldots \quad \underline{Vr2 + Vr3} \ldots\ldots\ldots \quad (12)$$

$$2$$

Using equation (11)

$$Re = 69422.31$$

The Nusselt number (Nu) is calculated using the empirical relation for flow across cylinders.

The generalized equation is

$$NuD = C \, ReD.^m \, Pr^{0.333} \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

The values of C and M are selected from the table below.

Table No 5.1

Red	C	M
0.4 – 4.0	0.989	0.330
4.0 – 4.0	0.911	0.385
40.0 – 4000	0.683	0.4666
4000 – 40000	0.193	0.618
40000 – 4000000	0.0266	0.805

Using equation (13)

NuD = 188.26

NuD = ……$\underline{h_s * D}$………………. (14)
              K

Using equation (14)

Hs = 331 w/m^2 k

B) Heat Transfer Coefficient on The Pressure Side (B surface).

For Gas turbine rotor blades,

Ti = 1227^0 c

Te = 1100^0 c

Tmf = $\underline{Ti + Te}$ (11)

              2

Kinematic viscosity (v), Prandtl number (Pr) and thermal conductivity (k) of air at Tmf are noted down form air tables.

On pressure side, the flow is approximated to the flow over a flat plate whose length (L) along the flow direction is equal to chord length (l) of the aerofoil blade.

Reynolds number

Re = 69797.56 ………$\underline{Vr * L}$……………………. (11)

                    v

Using equation (16), Re = 69797.56

Since Re< 5 * 10 ^{5} flow is laminar on pressure side. Following is the empirical relation for laminar flow over a flat plat.

$$Nu = 0.664 \, Pr^{1/3} \, Re^{1/2} \quad \cdots\cdots\cdots\cdots\cdots \quad (17)$$

Using equation (17) Nu =

For flat plate,

$$Nu = 157.18 \cdots\cdots\cdots \underline{hp * L} \cdots\cdots\cdots\cdots \quad (18)$$
$$K$$

Hp = 276 w/m^2 K

C) Heat transfer coefficient on leading edge surface (A surface)

The average of heat transfer coefficient on suction side (hs) and heat transfer coefficient on pressure side (hp)

= $(h_s + h_p)/2$ = 300 w/m^{2}K and Temperature of leading edge (T) = 1227^{0}C

D) Heat transfer coefficient at trailing edge (E surface)

h = 276 w/m^{2}k, t = 1100^{0}C

E) Heat transfer coefficient on trailing edge (F surface)

h = 331 w/m^{2}k, t = 1100^{0}C

F) Heat transfer coefficient on the surface of hub (D surface)

For Gas turbine rotor blades,

Ti = 1227^0 c

Te = 1100^0 c

Tmf = $\underline{Ti + Te}$ (11)

2

Kinematic viscosity (v), Prandtl number (Pr) and thermal conductivity (k) of air at Tmf are noted down form air tables.

the flow is approximated to the flow over a flat plate whose length (L) along the flow direction is equal to chord length (l) of the aerofoil blade.

Reynolds number

$$Re == 129186.413 \ldots\ldots\ldots \underline{Vr * L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

$$v$$

Using equation (16), Re = = 129186.413

Since Re< $5 * 10^5$ flow is laminar on pressure side. Following is the empirical relation for laminar flow over a flat plat.

$$Nu = 0.664 \, Pr^{1/3} \, Re^{1/2} \quad \cdots\cdots\cdots\cdots (17)$$

Using equation (17) Nu =

For flat plate,

$$Nu = 213.66 \ldots\ldots\ldots \underline{h * L} \ldots\ldots\ldots\ldots\ldots (18)$$

$$K$$

$$h = 375.4 \, w/m^2 \, K$$

5.7 Determination of Heat transfer coefficient for flow through circular cooling passages

Unlike steam turbine blading, gas turbine blading need cooling. The objective of the blade cooling is to keep the metal temperature at a safe level to ensure a long life. Although it is possible to cool the blades by air cooling. Radially for passage of cooling air internally as shown in fig 1.
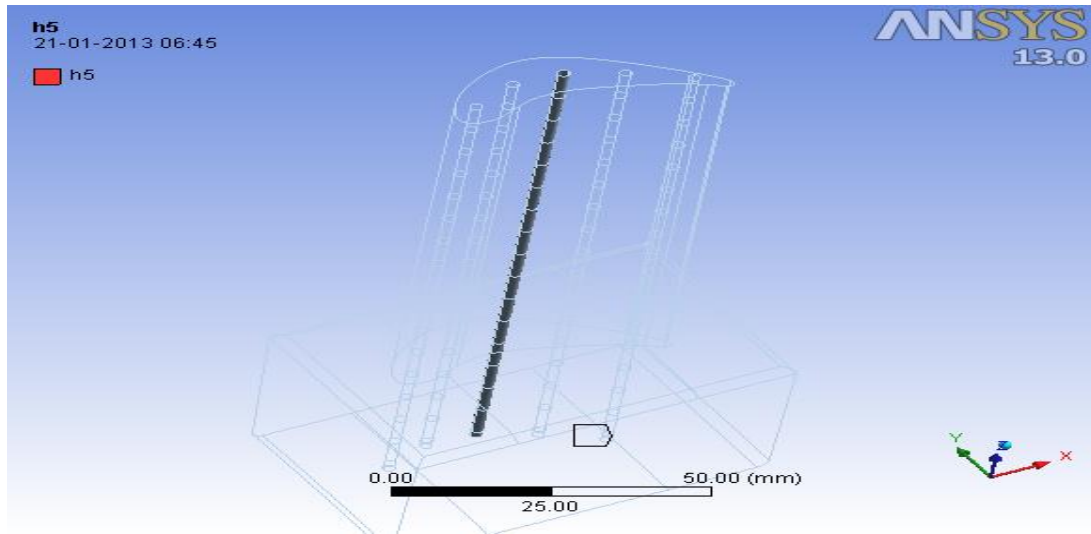
Fig 5.5 Heat transfer coefficient for flow through circular cooling passages

Properties are intially at $T_m = T_i+T_s/2$, Where $T_i = 300^0C$ and T_s is taken from the thermal analysis of solid blade model h is priliminarily determined at this T_m

Relative velocity of air and blade is

$V_a = 230$ m/sec

$V_b = 234.7$ m/sec

$V_{a/b} = \sqrt{V^2_a + V^2_b}$ ----- (1)

$V_{a/b} = 330$ m/sec

Flow through pipes

Reynolds's number (Re) = 330 x (2E-03) / (1.099 E-04)

$\qquad\qquad$ = 5979. 98 ------- $(V_{a/b}\, d)/\mu$ --- (2)

$Nu = 0.023\ Re^{0.8}\ Pr^{\,0.4}$

= 20. 97 -------- hd/k ⁻⁻⁻⁻ (3)

h = 637 w/m²k. ------- Nu k/d   ----- (4)

The energy balance equation is

$h.\pi.D. L (T_s - (T_o+T_i/2)) = m. cp (T_o - T_i)$ --- (5)

From which T_o The properties are evaluated of the mean bulk temperature of $Tb = T_o+T_i/2$ at h determined from the steps mentioned above

$m = \rho.\pi/4.d^2.V_a$

= 0.374 x $\pi/4$ x(2E-03)² x 230

= 2.7E-04   -------- (3)

Substiting (4),(3) valuves in equation (5)

$T_o = 739^0C$

Same procure in reaming hole

Calculating hole segment (section) Heat transfer coefficients

$Y = a X^{1.4}+b$ ------ (4)

$T_i = a X^{1.4}+T_e$ (where a = $\underline{T_i - T_e)}$
$\phantom{T_i = a X^{1.4}+T_e (where a = }(L)^{1.4}$

$\underline{T_i - T_e}$ * $(X)^{1.4} +T_e$ (X = hole segment)

$(L)^{1.4}$

$300 - 739/ (117)^{1.4} *(X)^{1.4} + 739$

(Where X = 0, 10,20,30,40,50,60,70,80,90,100,110,117)

Substiting X valuves in equation (4)

Obtaining the following values

Table 5.2

X	T_o
0	739.00
10	724.97
20	701.97
30	673.68
40	641.29
50	605.46
60	566.64
70	525.12
80	481.16
90	434.93
100	386.61
110	336.30
117	299.99

5.8 Generation of Blade Model

The following material properties were defined in the material property table named as material N 155 and Inconel 718.

Table 5.3

Properties	Units	N 155	Inconel 718
E	Pa	143 E09	149 E09
ρ	Kg/cu m	8249	8220
K	W/m-K	20.0	25.0
μ	---	0.344	0.331
α	E-06/^{0}C	17.7	16.0
C_p	J/Kg K	435	586.2
Melting Point	^{0} C	1354	1344
Yield stress	MPa	550	1067

A Turbine rotor blade consists of 120 blades each blade height is 117 mm. The blade model profile is generated by using CATIA software. The aerofoil profile of the rotor blade was generated on the XY plane with the help of key points defined by the coordinates as given below. Key points are created along the profile in the working plane. A rectangle of dimensions 49*27 mm was generated
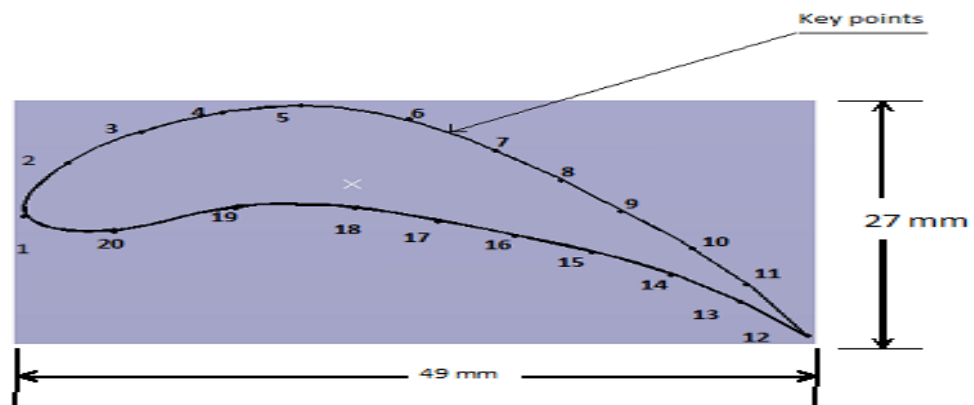
Figure 5.6 Boundary of aero foil section

List of Selected Key points

Table 5.4

Sl.No	X	Y(Z=0)		Sl.No	X	Y (Z = 0)
1	0	0		20	49	0
2	2.6	17.3		21	49	27
3	5.85	21		22	0	27
4	10	25		23	19.8	0
5	14.8	26.6		24	1	13.6
6	22.9	25.3		25	29.2	0
7	28	22.2		26	29.2	27
8	33.4	18.5		27	19.8	27
9	38	14.4		28	15.2	27
10	42	10.9		29	18.08	27
11	45.5	5.7		30	49	2.70E-02
12	49	0		31	48.9	2.88E-02
13	6.18	12.4		32	29.2	12.49
14	11.2	14.4		33	19.8	26.62
15	16.18	15.5		34	19.8	15.12
16	21.1	14.9		35	29.2	21.25
17	26	13.6		36	0	3.00E-02
18	38.2	8.77		37	19.8	3.00E-02
19	45	3.95		38	19.8	15.12

The points are joined by drawing B spline curves to obtain a smooth contour. The contour (2D model) is then converted into area and then volume (3D model) was generated by extrusion. The hub is also generated similarly. These two volumes are then combined into single volume. This model of turbine blade is then imported into ANSYS software. The blade is then analysed sequentially with thermal analysis preceding structural analysis. The model is discretized using 10 noded tetrahedral solid element (Solid 87).The surface of the blade is applied with Surface element (Surf 152) for applying the convection loads. The temperatures of blade are then determined by thermal analysis. Followed by this, the structural analysis is carried out by importing the temperatures determined in thermal analysis. 10 noded tetrahedral solid element (Solid 187) was used for structural analysis. The loads considered for structural analysis are centrifugal, axial & tangential forces.

Figure 5.7 Rotor blade with 3 –D, 10 Node elements

5.8.1 Element type description for thermal analysis (solid 87, surf 152)

SOLID87 Element

SOLID87 is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element has one degree of freedom, temperature, at each node.

The element is applicable to a 3-D, steady-state or transient thermal analysis. See SOLID87 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element. If the model containing this element is also to be

analysed structurally, the element should be replaced by the equivalent structural element (such as SOLID187). A 20-node thermal solid element, SOLID90, is also available.
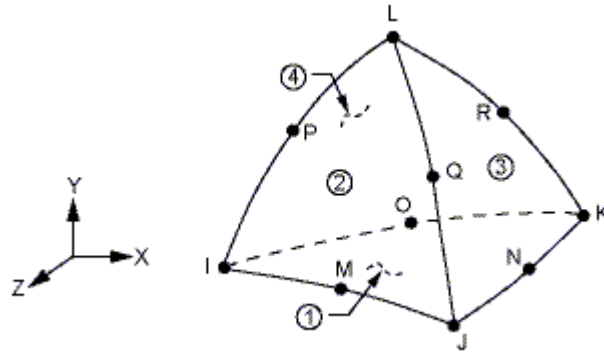
Fig 5.8 SOLID87, 3-D, steady-state

SOLID87

Nodes	I, J, K, L, M, N, O, P, Q, R
Degrees of Freedom	TEMP
Real Constants	None
Material Properties	KXX, KYY, KZZ, DENS, C, ENTH
Surface Loads	Convection or Heat Flux (but not both) and Radiation
Body Loads	Heat Generations

SURF152 Element Description

SURF152 may be used for various load and surface effect applications. It may be overlaid onto an area face of any 3-D thermal element. The element is applicable to 3-D thermal analyses. Various loads and surface effects may exist simultaneously. See SURF152 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element.
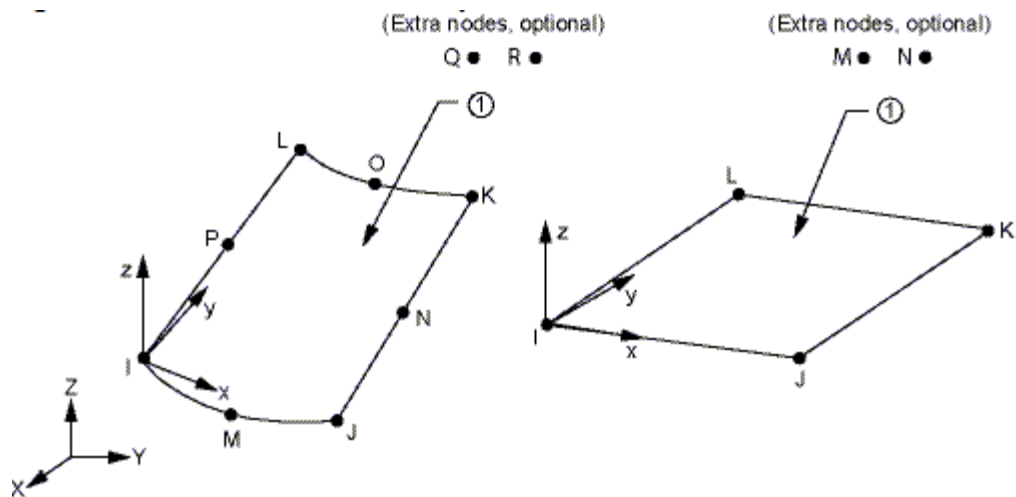
Fig 5.9 SURF152, 3-D thermal element

SURF152

Nodes	I, J, K, L, M, N, O, P, Q,
Degrees of Freedom	DOF for all nodes except extra node(s)
	DOF for extra node(s) (KEYOPT (5) = 1 or 2)

Real Constants	FORMF, SBCONST, (Blank), OMEG, NRF, VABS,
	TKI, TKJ, TKK, TKL, (Blank), (Blank), ENN, GC, JC

Surface Loads	Convections, Heat Fluxes

Body Loads	Heat Generation

5.8.2 Element type description for Structural Analysis (solid 187)

SOLID187 Element Description

SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behaviour and is well suited to modelling irregular meshes (such as those produced from various CAD/CAM systems).

The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials. See SOLID187 in the Theory Reference for the Mechanical APDL and Mechanical Applications for more details about this element.
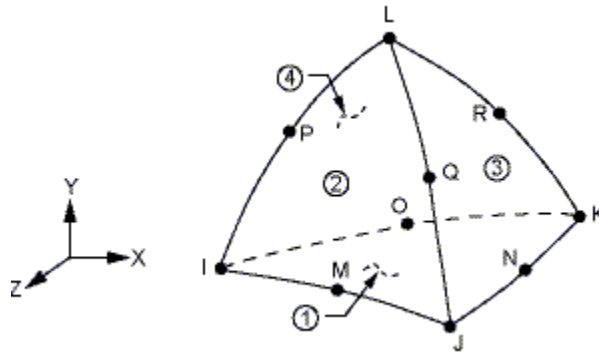
Fig 5.10 SOLID187, 3-D, 10-node element

SOLID187

Nodes	I, J, K, L, M, N, O, P, Q, R
Degrees of Freedom	UX, UY, UZ
Real Constants	None
Material Properties	EX, EY, EZ, ALPX, ALPY, ALPZ PRXY, PRYZ, PRXZ, DENS, GXY, GYZ, GXZ, DAMP.
Surface Loads	Pressures
Body Loads	Temperatures
Body force densities	the element values in the global X, Y, and Z directions.
Special Features	Plasticity, Viscoelasticity Viscoelasticity/Creep Hyper elasticity, Elasticity

5.9 Structural Boundary Conditions to be applied on the Rotor Blade Model

Two structural boundary conditions namely displacement and force were applied on the rotor blade model. The solution part of ANSYS was opened and the displacement constraints (U) were imposed on the areas shaded and numbered.
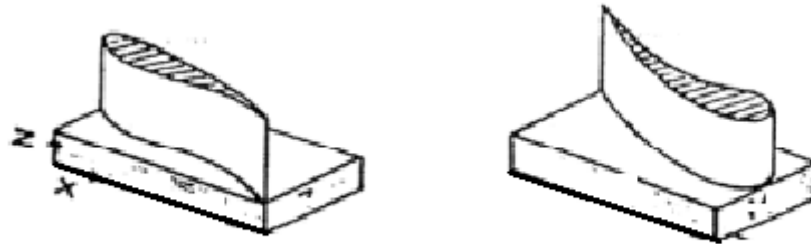
Figure 5.11 Structural boundary conditions on rotor blade

Fixed on the lateral surfaces of the hub Since the gas forces were assumed to be distributed evenly, the tangential and axial forces act throughout the centroid of the blade. The centrifugal force also acts through the centroid of the blade and in radial direction.

For Gas turbine rotor blades,

Tangential force ft =186.35N.

Axial force Fa = 2.833 N.

Centrifugal force Fc = 5517.37 N.

In the solution part of Ansys the blade forces namely tangential, axial and centrifugal were applied on the node located at the centroid of the blade as shown.
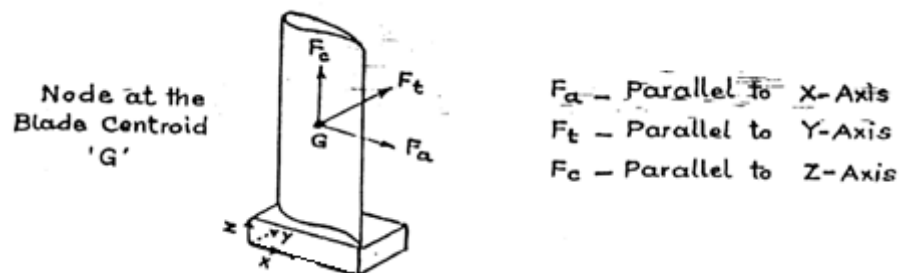
Figure 5.12 Static loading on rotor blade

5.10 Thermal Boundary Conditions Applied on the Rotor Blade Model

Two boundary conditions namely Heat flux and Convection were applied on the rotor blade model.

The solution part of ANSYS was opened and Heat flux = 0 was applied on the areas shaded and numbered in figure

Heat flux = 0

In the convective boundary condition, the convective heat transfer coefficient (h) and temperature of surrounding gases (T) must be specified on the areas subjected to convection.
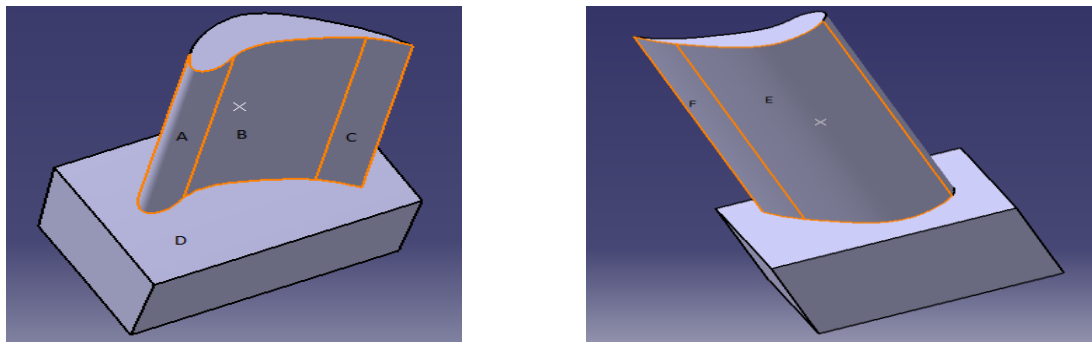
Figure 5.13 Thermal Boundary conditions

The following are the convective boundary conditions for the areas

For area A, h = (h_s + h_p)/2 = 300 w/m²K and T = 1227⁰C

For area A, $h = (h_s + h_p)/2 = 300$ w/m^{2}K and T = 1227^0C

For area B, $h = h_p = 276$ w/m^{2}K and T $= 1163.5^0$C

For area C, $h = h_s = 331$ w/m^2 K and T $= 1163.5^0$C

For area D, $h = 375.4$ w/m^2 K, T $= 1227^0$C, 1163.5^0C and 1100^0C

For area E, $h = 276$ w/m^2 K and T $= 1100^0$C

For area F, $h = 331$ w/m^2 K and T $= 1100^0$C

5.11 Analysis of Stresses and Deflections Taking Temperature Effect into Consideration

The thermal analysis file 'y' was reopened. The element type was switched from thermal to its equivalent structural element type. The structural boundary conditions namely displacements and forces were again applied on the model. In the thermal analysis the temperature distribution is stored in a. rth file. The temperature distribution was imposed on the blade by recalling it from .rth file file. The stresses and deflections were then analysed using software results were viewed in the post processor.

CHAPTER-6
Results & Discussion

The thermal & structural analysis of the blade is considered at for two different materials N 155 and Inconel 718 to determine their relative capability to withstand high temperatures of greater than 1200^0C that are generally encountered the gas that applications. The study involves the determination of temperatures at heat fluxes from thermal analysis. These temperatures are the impacted to structural analysis to evaluate the thermal stresses due to differential thermal expansion and the external forces applied on the blade. The Temperature distribution of the blade depends on the heat transfer coefficient for gases and the thermal conductivity of the material. The heat transfer coefficients are calculated by iterative process and the same were adopted. The analysis was carried out for steady state heat transfer conditions. It is observed that the maximum temperatures are prevailing at the leading edge of the blade due to the stagnation effects. N155 the maximum temperature is 1184.9^0C and minimum temperature is 1119.4^0C. For Inconel 718, the maximum temperature is 1184.7^0C and minimum temperature is 1120.1^0C at the trailing edge. The body temperature of the blade doesn't vary much in the radial direction. However, there is a temperature fall from the leading edge to the trailing edge of the blade as expected. It is observed for solid blade model from fig 6.1 (N - 155) and fig 6.2 (Inconel 718), that the blade temperatures attained for Inconel 718 are marginally lower. This can be attributed to the lower thermal conductivity of Inconel 718. The analysis is carried out initially on solid blade model of both materials. The results of which are discussed below.
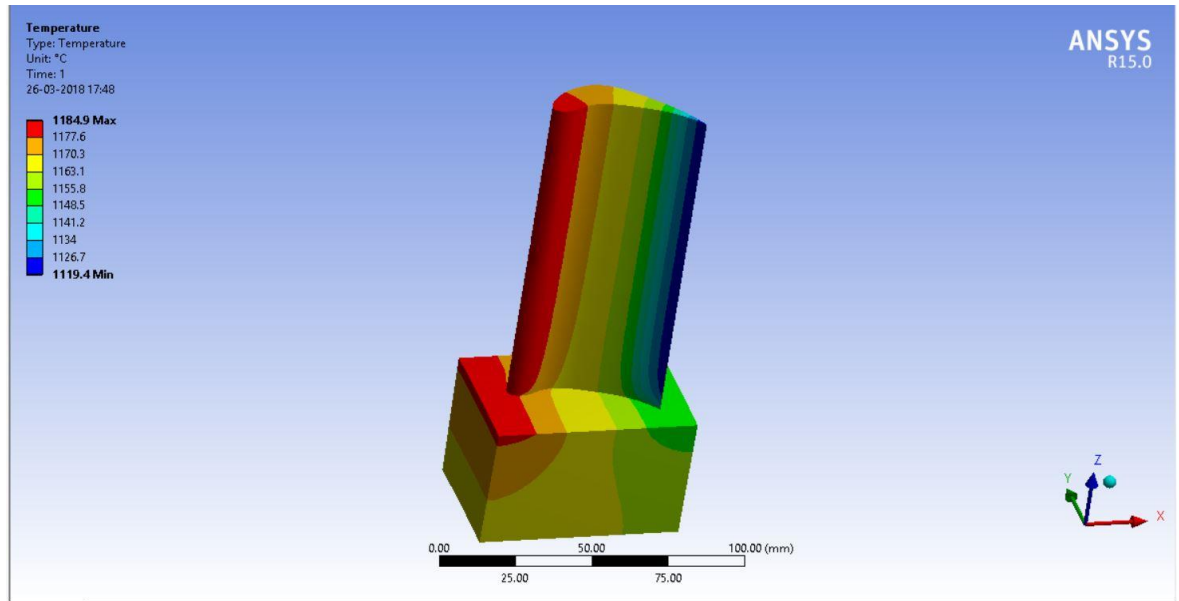
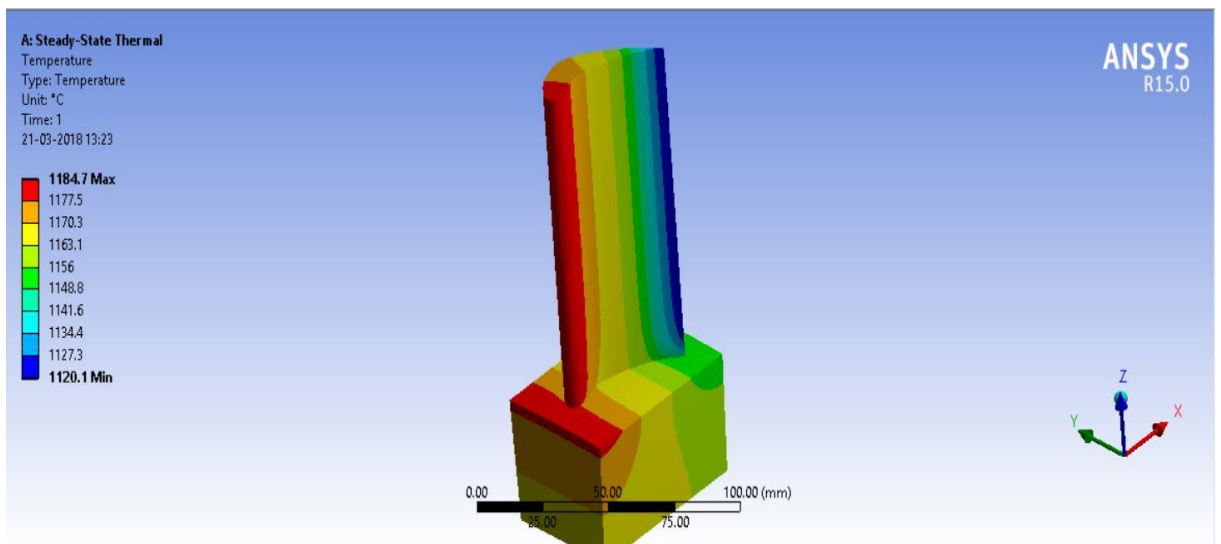**Fig 6. 1. Temperature distribution for solid (N155)**

Fig 6. 2. Temp distribution for solid (Inconel)

The study of directional heat flux plot from Ansys results shows that the heat flux is maximum in Y direction close to the leading edge and the value is 0.065 w/mm^2. The heat flux at the trailing edge is -0.001W/mm^2. The negative value suggest that the heat flow is from the blade to the gases which is however of very low order. This can be attributed to higher temperature of blade at the trailing edge compared to the gas temperature. This is due to conduction heat transfer with in the blade material from the leading edge to the trailing edge. This conclusion can also be drawn from the X directional heat flux plot fig 3

which shows that the heat flux in X direction is maximum close to the trailing edge 0.066384w/mm². The maximum total heat flux occurs at section close to the trailing edge. This value about 0.0138w/mm².
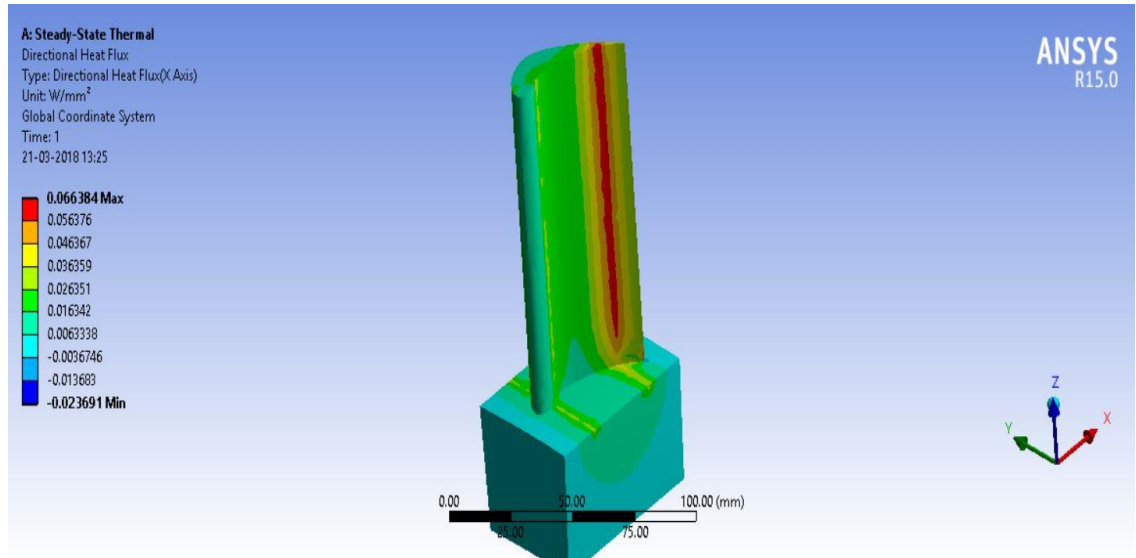
Fig 6.3 Directional Heat flux (X - axis) for solid (Inconel 718)
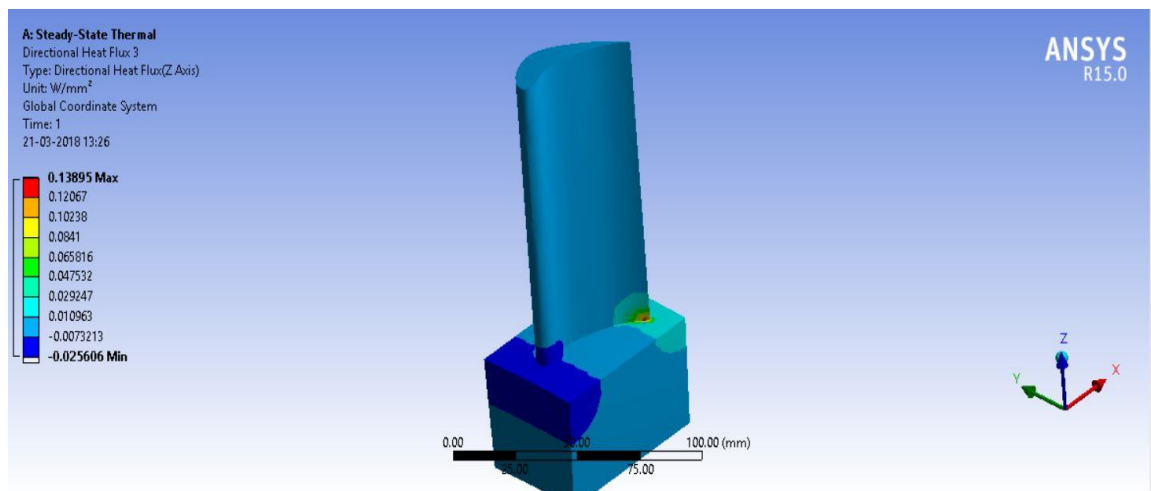
Fig 6.4 Directional Heat flux (Z - axis) for 5holes (Inconel 718)

To reduce the temperatures and heat fluxes, air passages are drilled along the length of the blade from tip to root. The diameters of holes are taken as 2 mm and the holes are evenly placed and drilled through the hub and blade.

When cooling passages are provided, there is an appreciable variation of temperature profile of the blade. Compared to solid blade it can be observed from the figs. 6.5& 6.6 (5 holes) that the temperature at the root of the blade is lower and it increases towards the tip

of the blade. This characteristic can be explained from the fact that the cooling air is at its lowest temperature (300^0 C) while flowing through the hub and root of the blade and it goes on increasing along the radial direction. The heat is conducted with in the blade from tip to root due to higher temperature prevailing at the tip. This is visible from the directional heat flux plot in Z – direction fig 6. 4. The maximum heat flux is 0.25606 in negative Z direction in the from the Y direction the heat flux plots it is a normal interpretation that the heat is flowing to the blade. Similar conclusion can be drawn the blade model with 9 holes. The maximum temperature falls further down to 900.57 from 902.82^0C with the increasing number of holes from 5 to 9 it can be observed from the figs. 6.7 & 6.8 (9 holes). The maximum temperature occurs at the leading edge due to its expansion to the gasses at their highest temperature and at the trailing edge section. This is due to lack of cooling effect at the trailing edge of cooling holes cannot be drilled at the smallest thickness of trailing edge. The similarities in heat flux variation between blade with 5 and 9 holes. The maximum heat flux is $0.0641w/mm^2$ in the negative Z direction that is heat flows from tip to root and in to hub of the root it can be observed from the figs.6.9 however this heat flux is lower compared that of 5 holes as more amount of heat is converted into the cooling air.
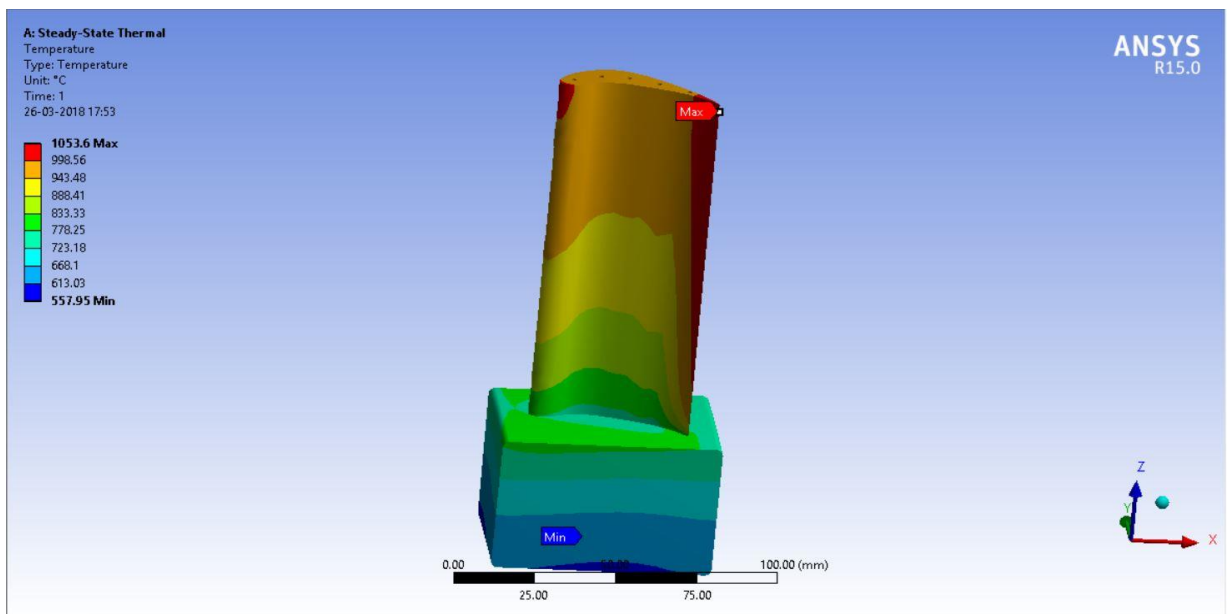
Fig 6.5.Temp. Distribution for 5 holes (N-155)
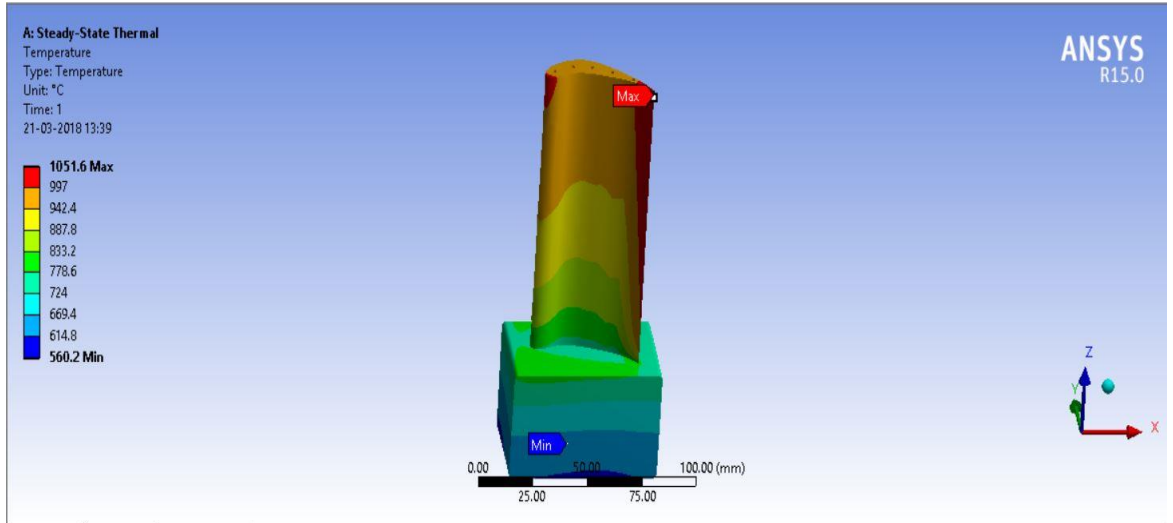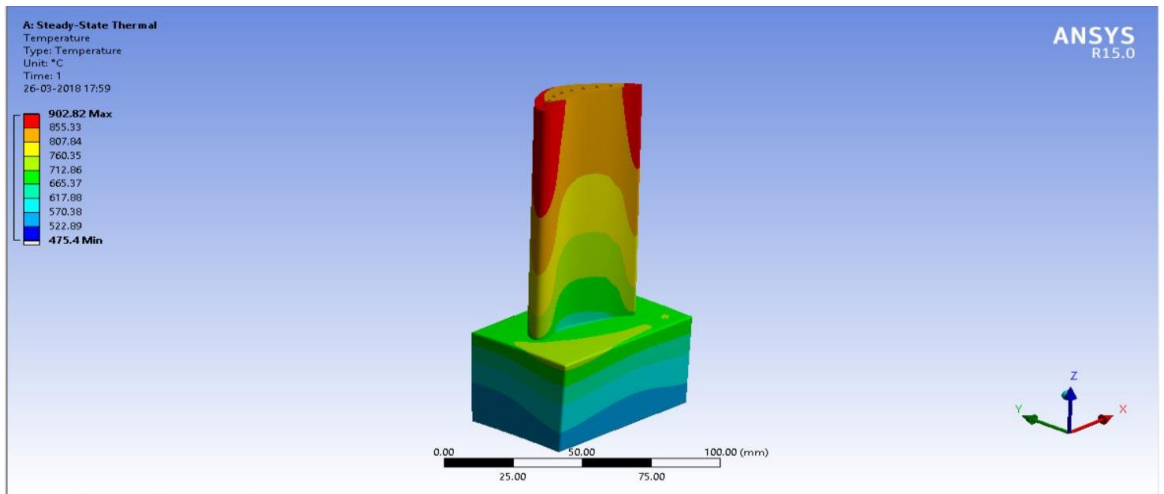
Fig6. 6. Temp. Distribution for 5holes (Inconel)

Fig 6. 7. Temperature distribution for 9holes (N-155)
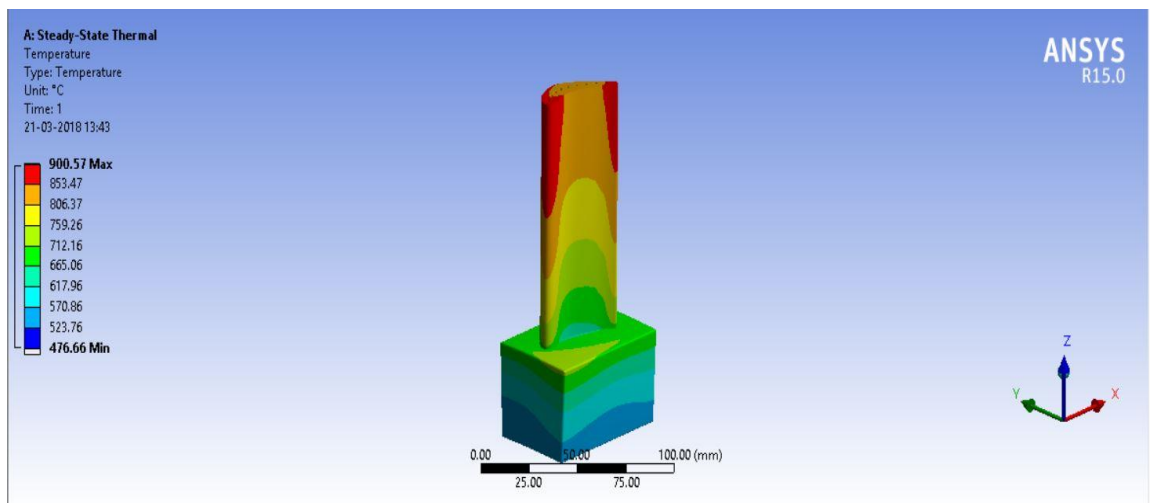

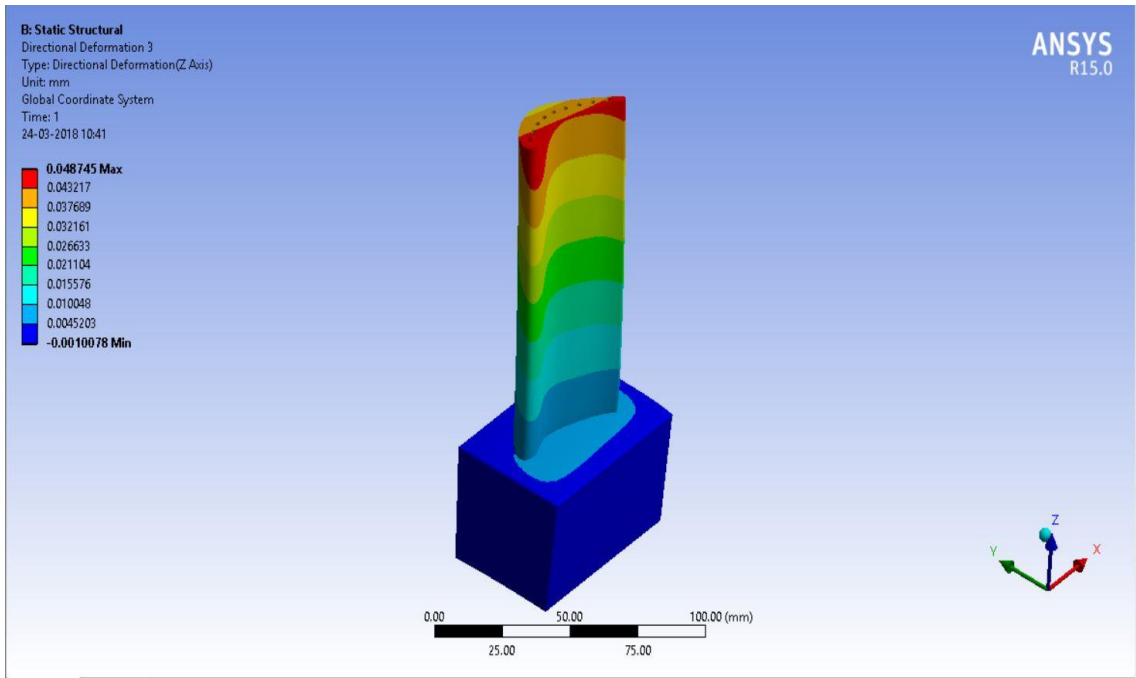**Fig 6. 8. Temperature distribution for 9holes (Inconel718)**

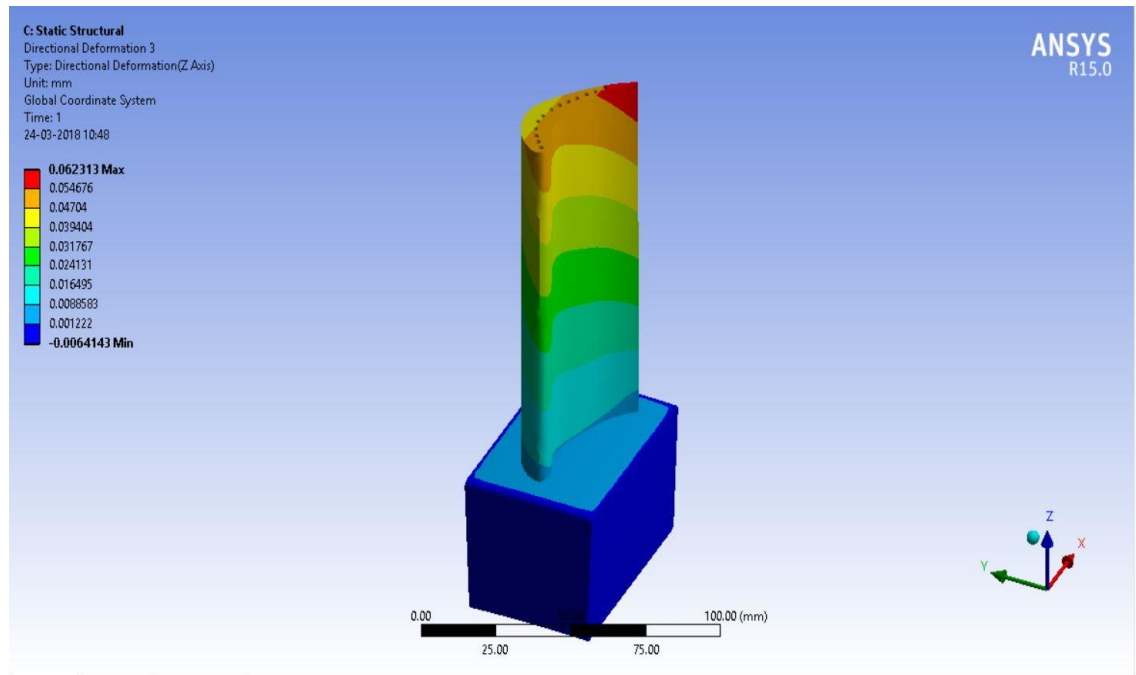**Fig 6. 9.Directional Heat flux (Z - axis) for 9holes (Inconel 718)**

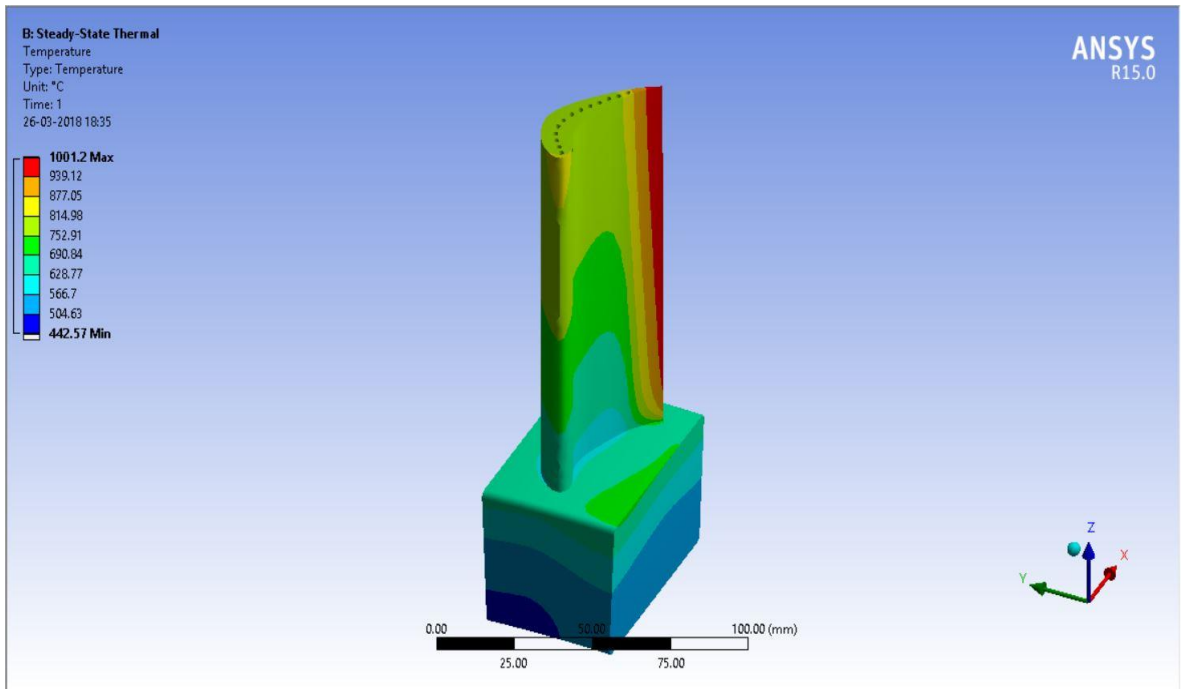**Fig6.10. Directional Heat flux (Z - axis) for 13holes (Inconel 718)**
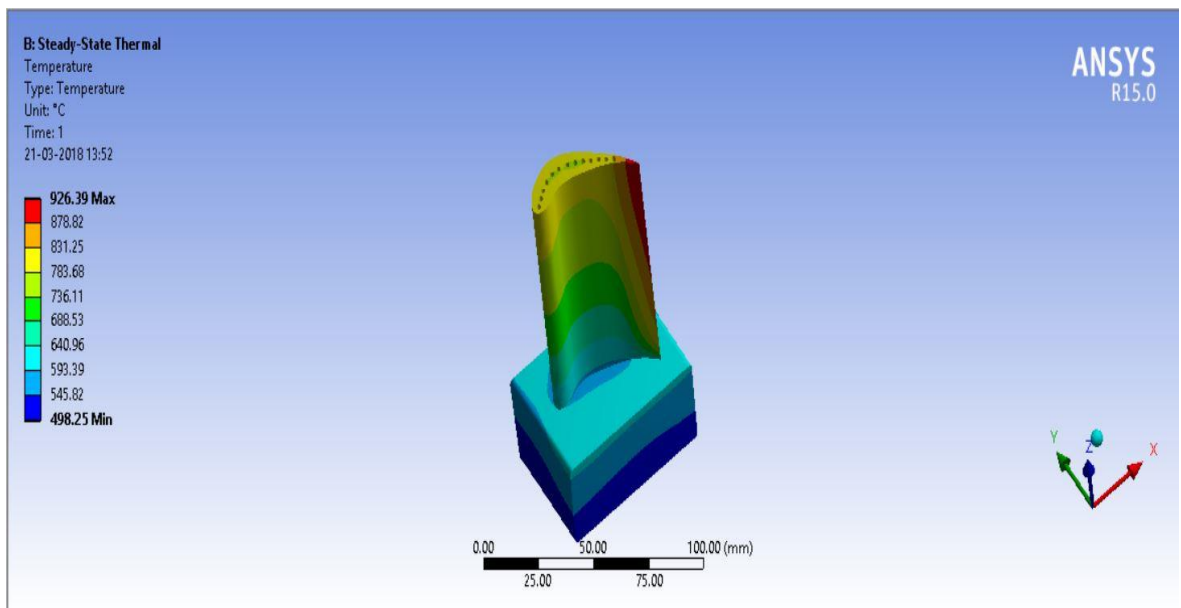
Fig 6. 11.Temperature distribution for 13holes (N-155)

Fig 6. 12.Temperature distribution for 13holes (Inconel718)

From the fig 6.25, the maximum temperature attained in the blade goes on decreasing with increasing number of holes. It is found that for 13 holes the maximum temperature attained is about 926.39^{0}C. It has been reported by Deepan raj [1] that a decreasing temperature will lead to lower thermal efficiency, as larger portion of air is utilised for cooling purpose

and reduced quantities of air flows into the combustor chamber of gas turbine plant. The reduced mass flow rate of the gas and the decreased temperature of the blade will reduce the power output and efficiency of the plant. Hence the number of holes is restricted to 13.

The temperatures obtained from the thermal analysis are imported to structural analysis to determine the thermal stresses. The Centrifugal, Axial and Tangential forces acting on the blade are considered as loads in structural analysis.
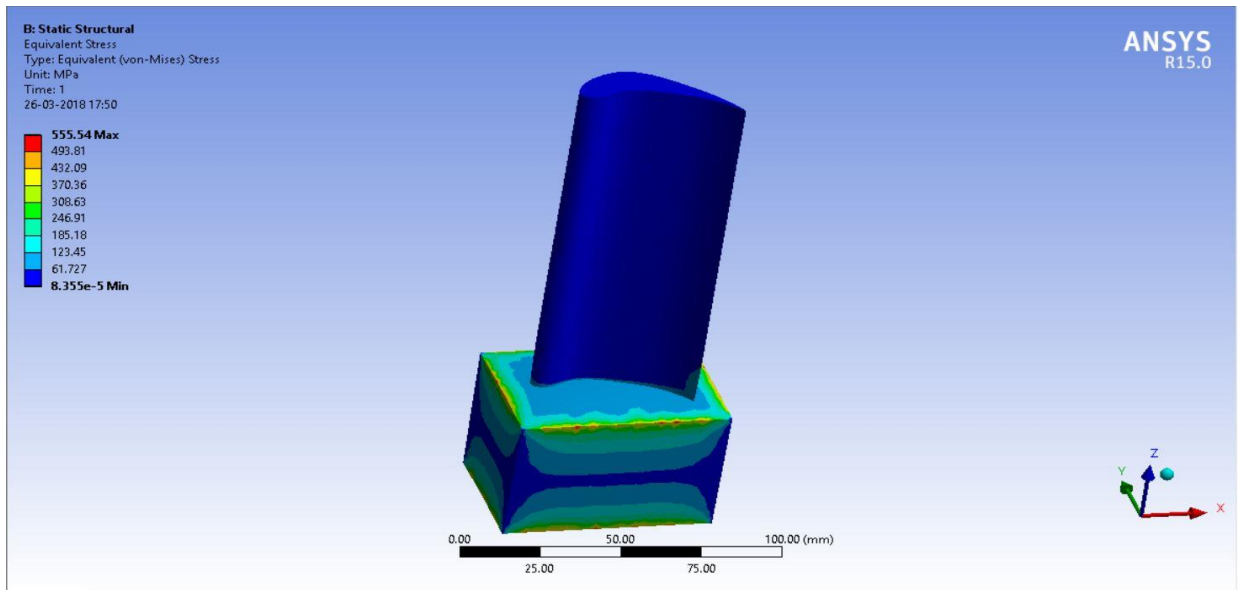

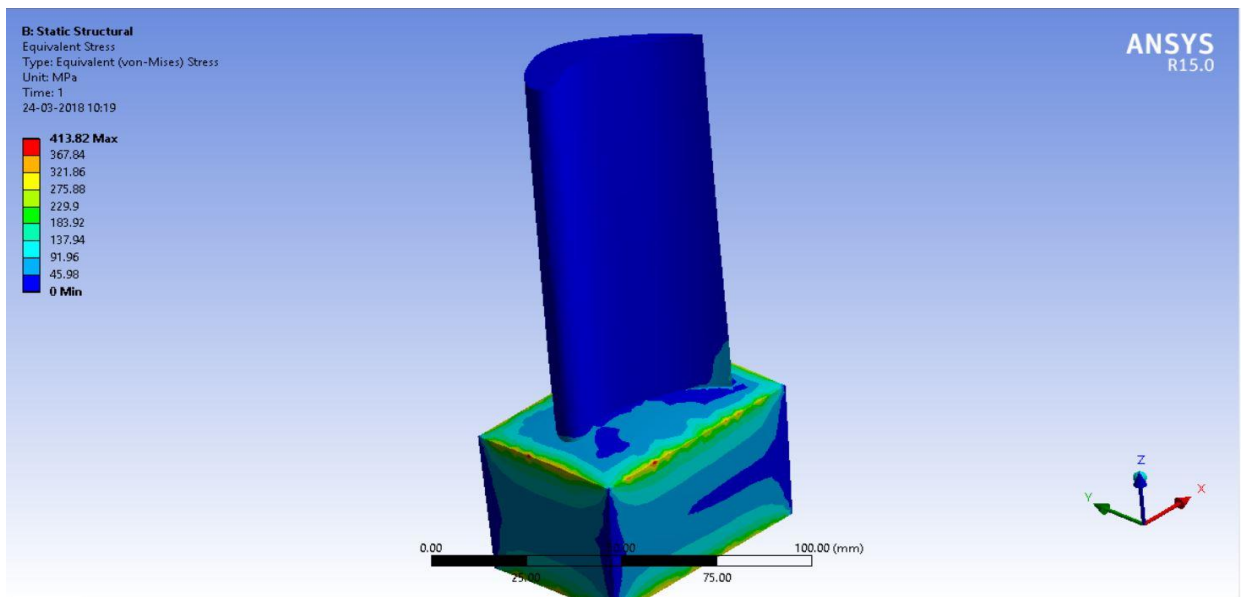**Fig6. 13.Stress distribution for solid (N-155)**

Fig6. 14.Stress distribution for solid (Inconel718)

From the structural analysis, of solid blade, it can be observed from the figures 6.13 & 6.14, that the stresses induced in the blade section are very low compared to the hub portion. The maximum stress value is 657.65 Mpa for Inconel 718 for N155 the stress is 158.77 Mpa. The induced stresses are well within yield limits for Inconel718, but it is marginally higher for N155. The factor of safety for Inconel 718 is around 2.0 and for N155 it is 1.09. This maximum stress occurs at corners of the hub and may be due to discontinuity in the hub. However, this discontinuity doesn't exist in the hub. But consideration should also be given to the temperatures of the blade section which are higher. To limit these temperatures, forced convection cooling is adopted through passages provided in the blade.
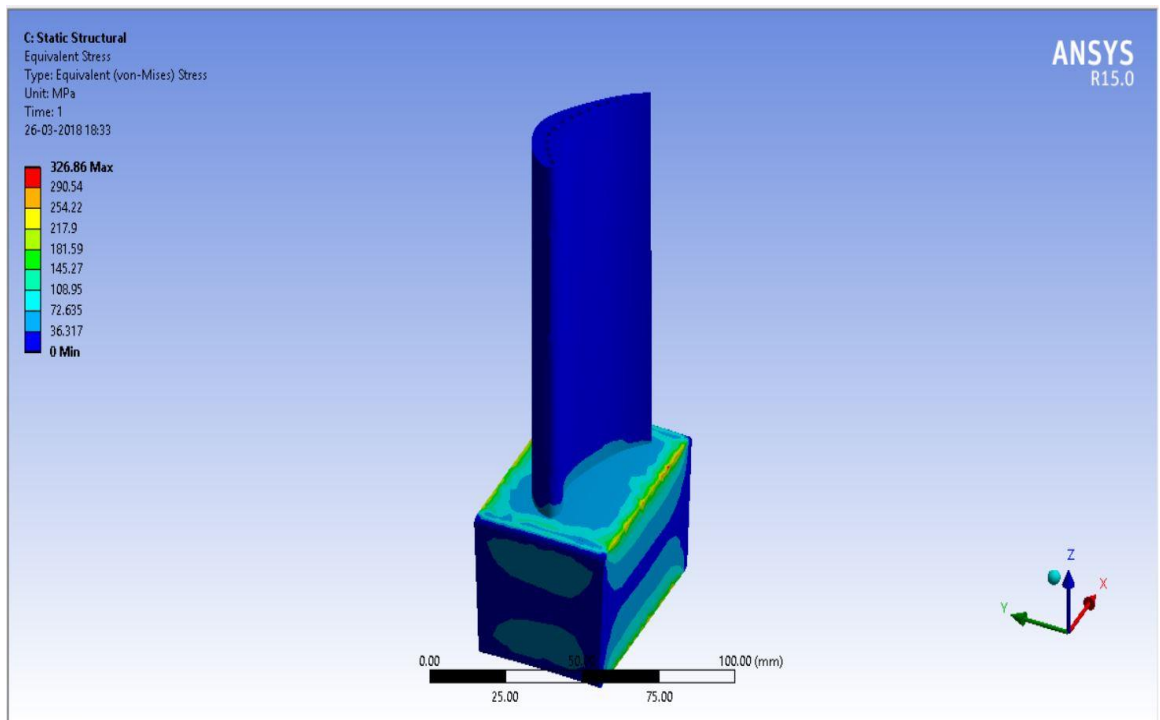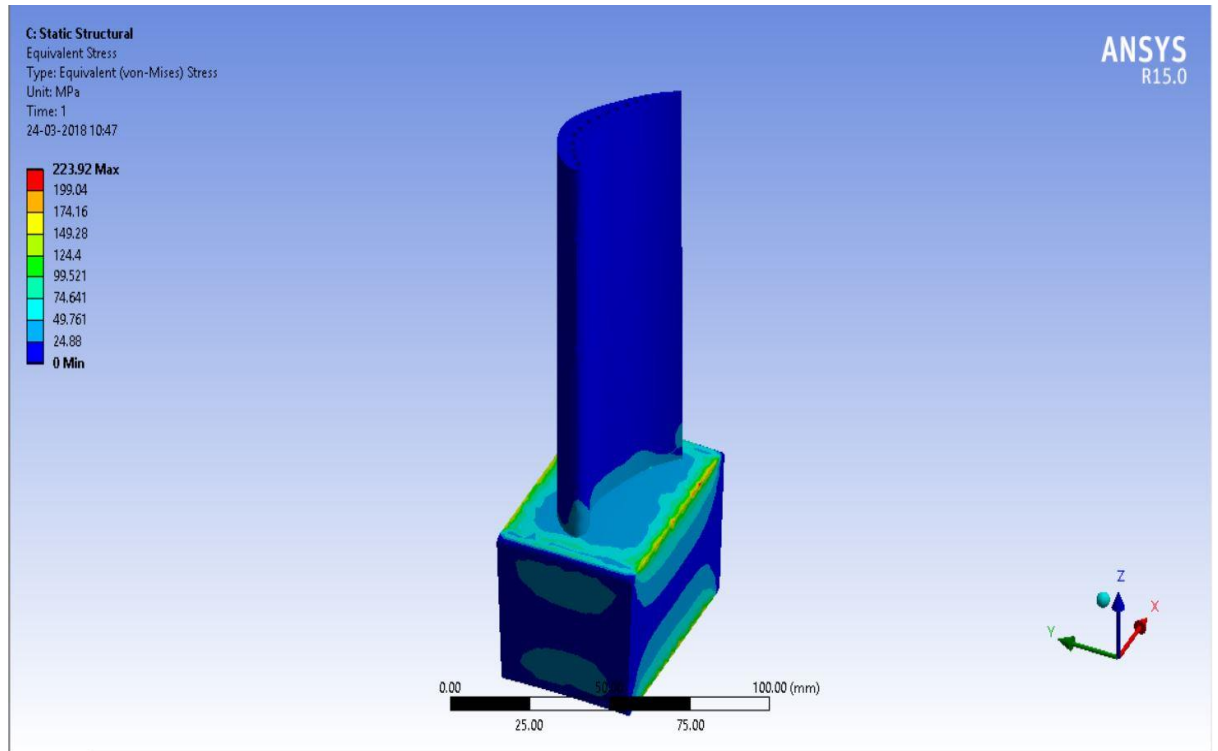
Fig 6.15. Stress distribution for 13 holes (N-155)

Fig 6. 16.Stress distribution for 13 holes (Inconel718)

The provision of cooling passages reduces the body temperature of the blade and hub and the temperature drops with the increase in number of holes. It is also observed that the stresses induced in the hub are higher compared to the blade portion, since it is fixed. The provision of cooling passages will decrease stresses induced in the hub while a slight increase in the stresses induced in the blade portion are observed. There is an appraisable decreasing in the induced stresses when holes are provided. This can be due to reduced thermal expansion of the blade which in turn can be attributed to drop in temperatures when holes are provided. The maximum stresses induced for 5 holes model are 348.75 Mpa and 117.85 Mpa for Inconel718 and N - 155 respectively. These values are within limits. The corresponding values for 9 holes are 609.46 Mpa and 211.53Mpa. With the increasing cooling by provided 9 holes, it may have appeared that the induced stresses reduce but what is observed is controversy to this abnormally can be explain as follows:

Cooling in general reduces the temperature and they're by thermal stresses but if the cooling is uneven a section of the blade can be subjected to higher cooling levels compared to adjacent sections. Such a situation will produce higher differential explanation between these two sections and there by the thermal stresses induced will increase instated of

decreasing this effect is observed in the blade model with 9 holes with the further increase number of holes to 13 there is a drop in thermal stresses. The maximum value of stresses 218.52 Mpa and is produced in the hub. The decreasing in stresses is due to increase in cooling passages which are closely spaced. The cooling is more uniform, and the passages are provided will allow the blade material to expand freely.   This phenomenon is responsible for reduction in the stresses.

Generally, when the temperature of the body raises above the ambient temperature, the body will deform. The deformation of body is directly proportional to this temperature deference similarly when the gas turbine blade is exposed to high temperature, it will have tendency to deform. The deformation being proportional to its raising temperature. The solid blade has a maximum deformation is observed at the tip of the blade close to the leading edge where the temperature is highest.

This is maximum deformation is 0.463 mm when the blade is subjected to cooling the maximum temperature attained by the blade decreases. Hence the maximum deformation of blade also decreases with the increase in number of holes, the deformation levels decrease. The maximum deformations for Inconel 718 are observed to be 0.1097 mm, 0.091144 mm, 0.087161mm for 5, 9 and 13 holes. The corresponding values are N – 155 are 0.063738 mm, 0.051831 mm, 0.063738 mm.
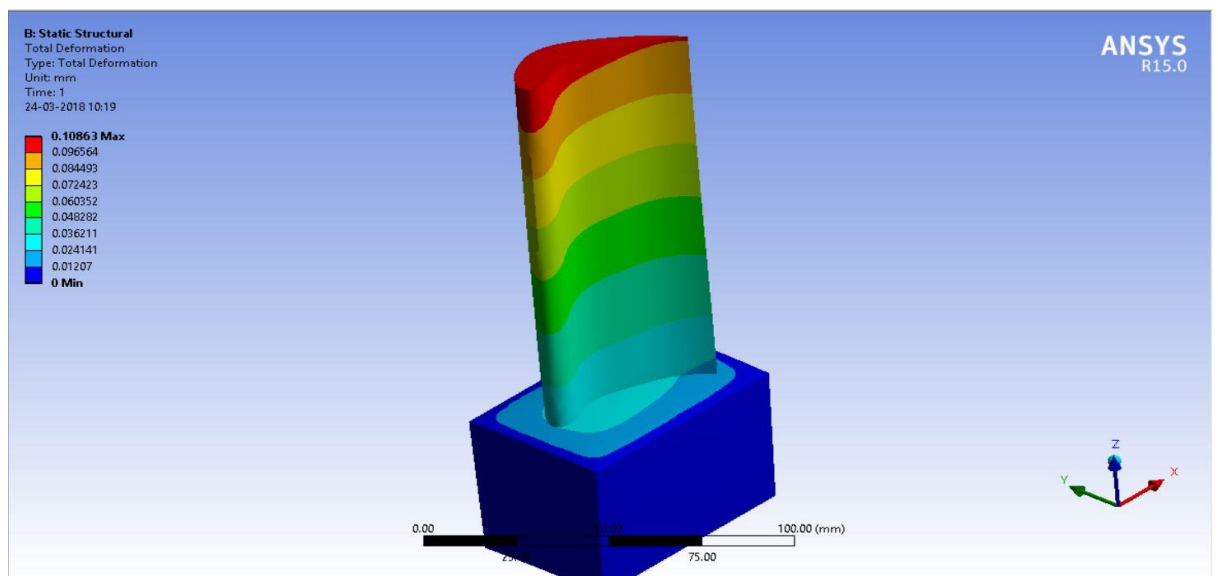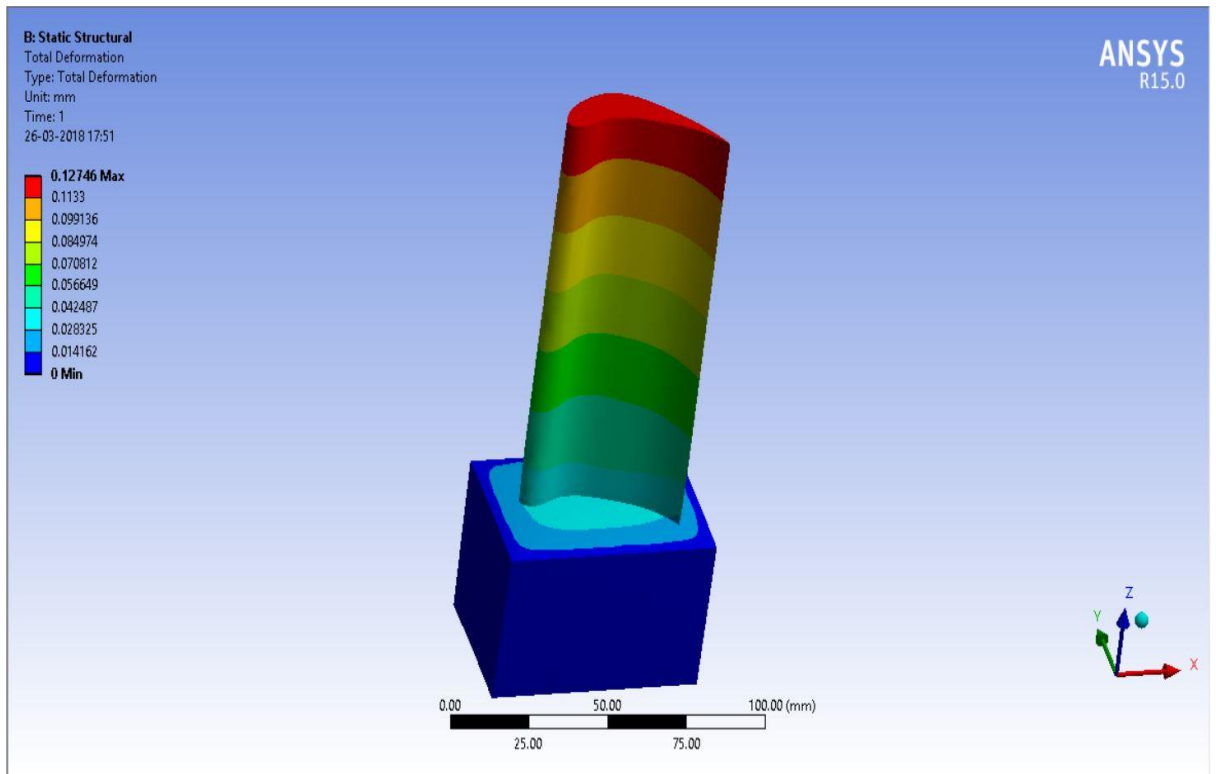

Fig 6.17. Deformation for solid blade Inconel 718

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
26-03-2018 17:51

0.12746 Max
0.1133
0.099136
0.084974
0.070812
0.056649
0.042487
0.028325
0.014162
0 Min

0.00   50.00   100.00 (mm)
       25.00   75.00

Fig6.18. Deformation for solid blade N 155

B: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
24-03-2018 10:25

0.10796 Max
0.095961
0.083966
0.071971
0.059976
0.04798
0.035985
0.02399
0.011995
0 Min

0.00   50.00   100.00 (mm)
       25.00   75.00
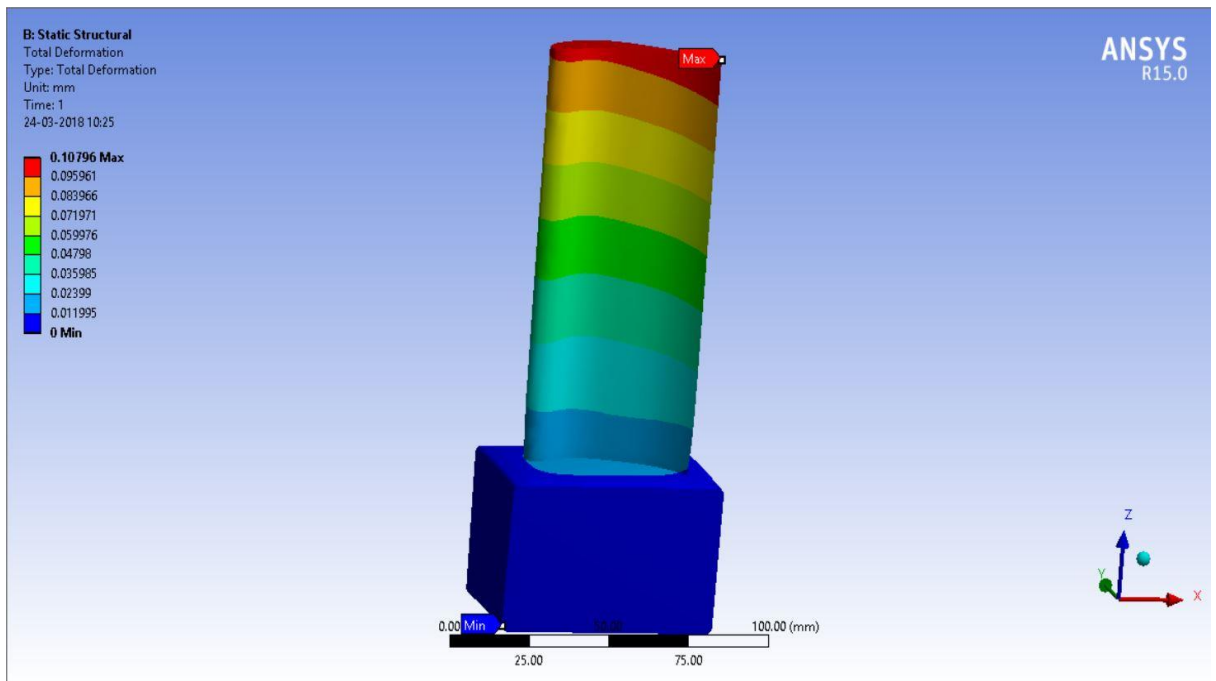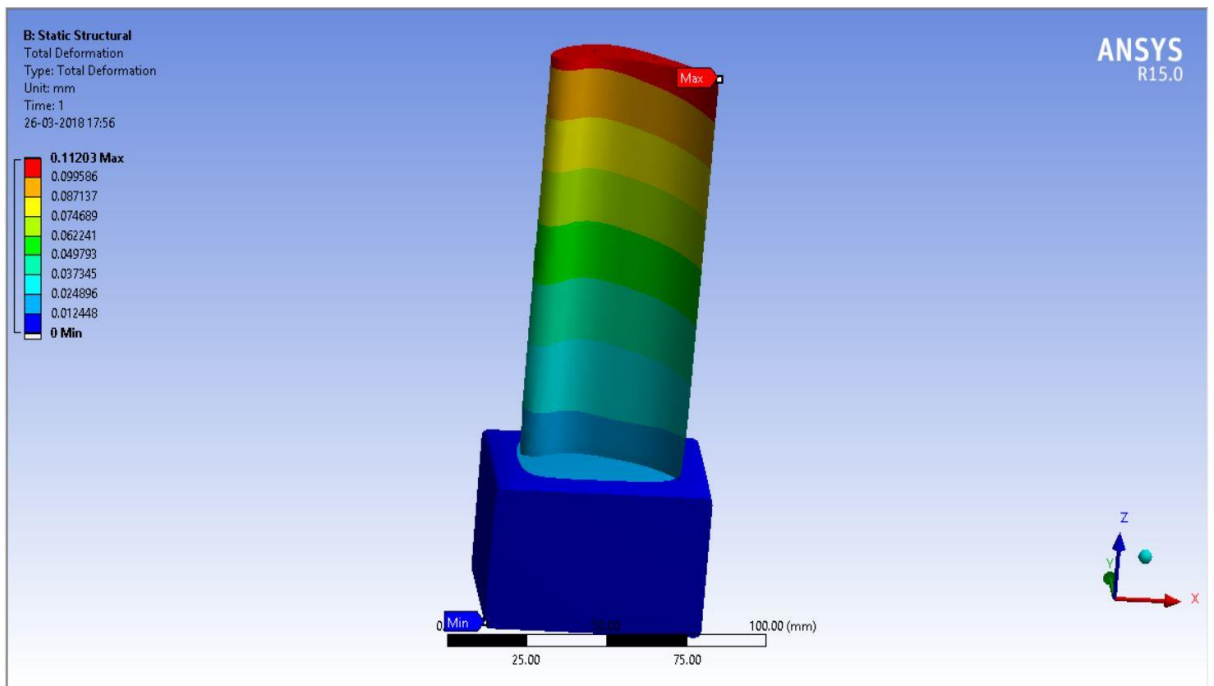
Fig6.19. Deformation for 5holes Inconel 718

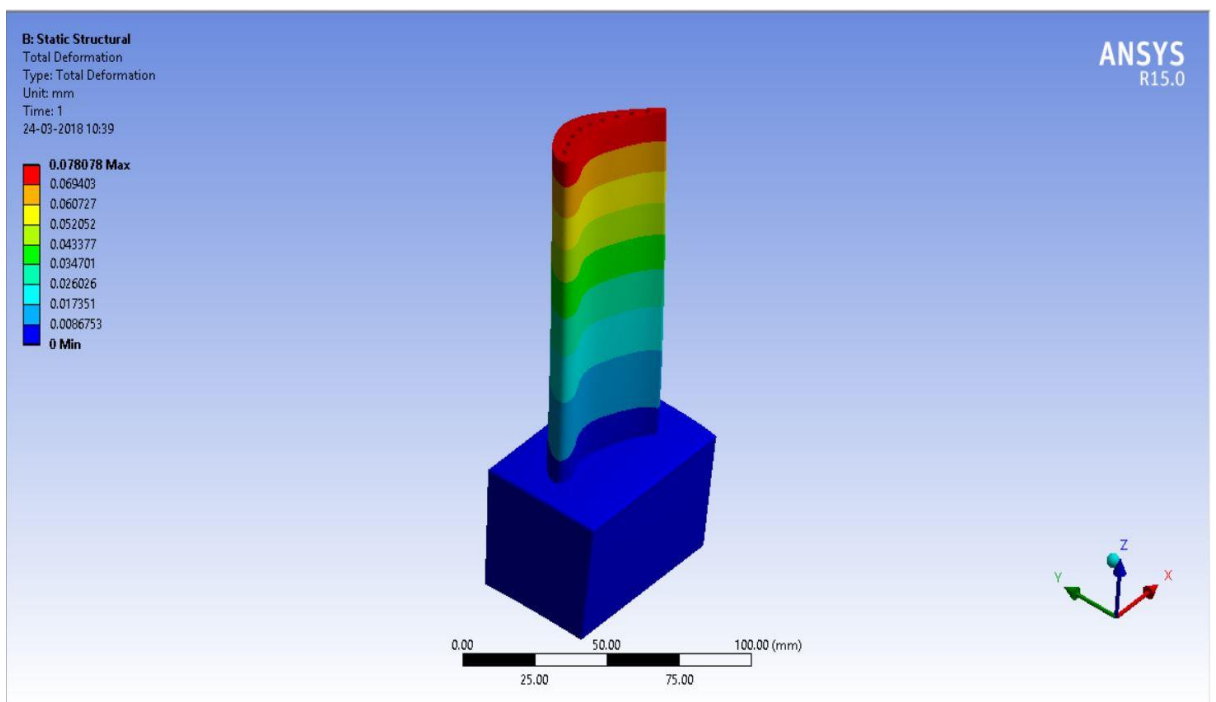**Fig6.20. Deformation for 5holes N 155**

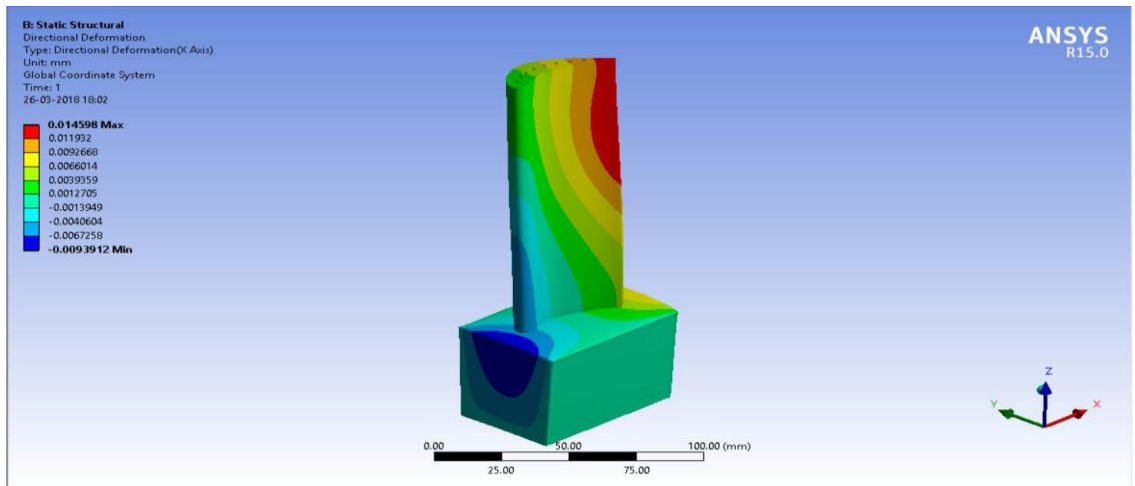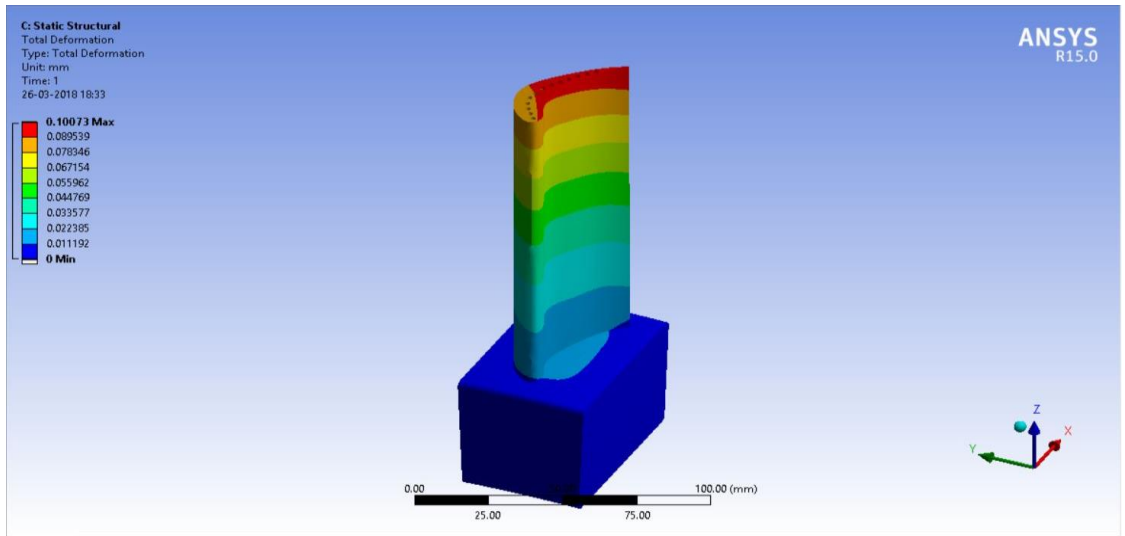**Fig 6.21. Deformation for 9 holes   Inconel 718**

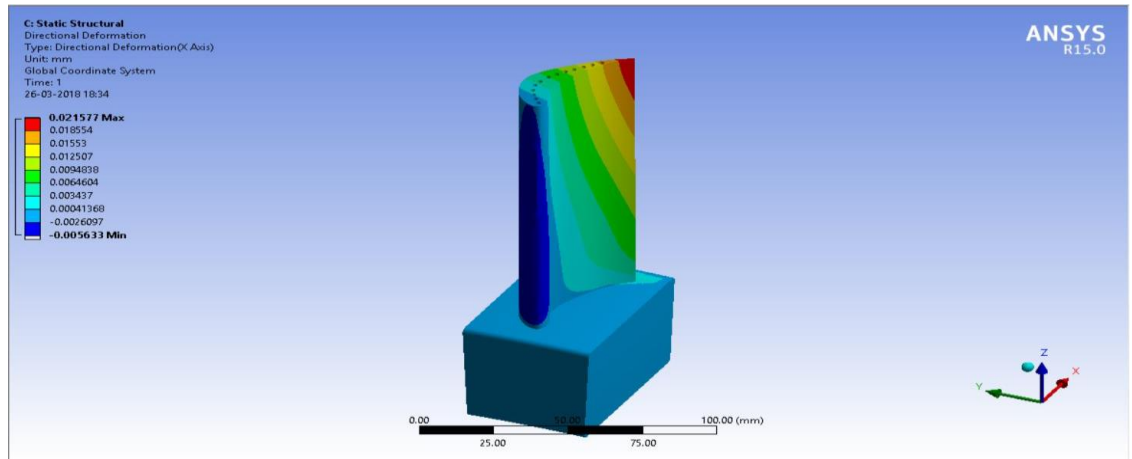**Fig 6.22. Deformation for 9 holes N 155**

Fig6.23. Deformation for 13 holes   Inconel 718

Fig6.24. Deformation for 13 holes N 155

It can also be observed that the maximum temperature, stresses and deflection produced in the blade are minimum for 13 holes. Hence the optimum number of holes that are to be provided stands at 13. Any further increasing in number of holes will reduce the blade temperature further adversely affecting the thermal efficiency and power output of the turbine.

It can be observed from the figs.4.25, 4.26&4.27 that the temperatures, stresses and deflection are on higher side for N155 material compared to Inconel 718. Hence, it can be concluded that Inconel 718 is best suited for gases higher than the 1200^0C temperature, as N – 155 has poor thermal properties when compared with Inconel 718 and it is highly unsuitable for such applications.

Table 6.1. Maximum Temperature Vs. Number of holes

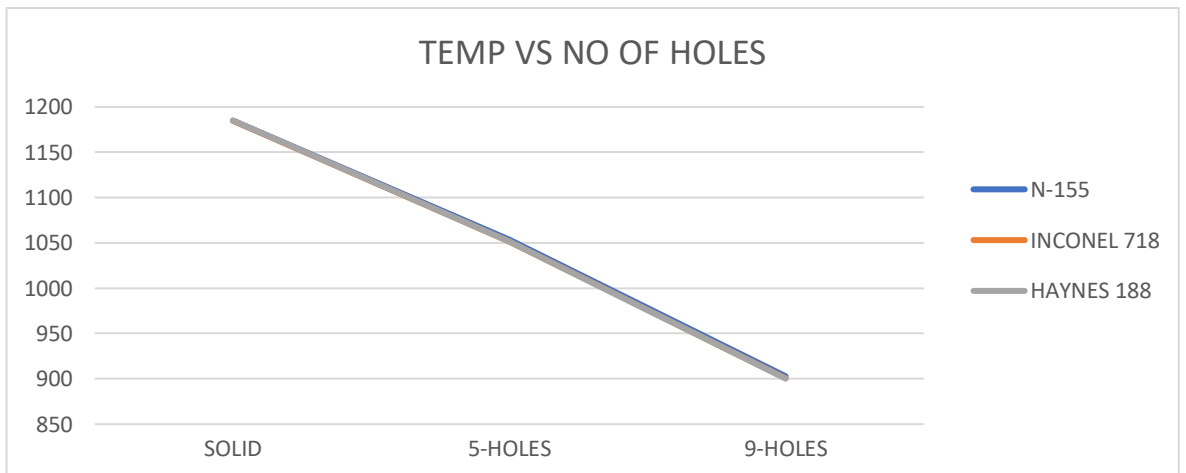| No. of Holes	0	5	9	13
N -155	1184.9^0C	1053.6^0C	902.82^0C	1001.2^0C
Inconel 718	1184.7^0C	1120.1^0C	900.57^0C	926.39^0C

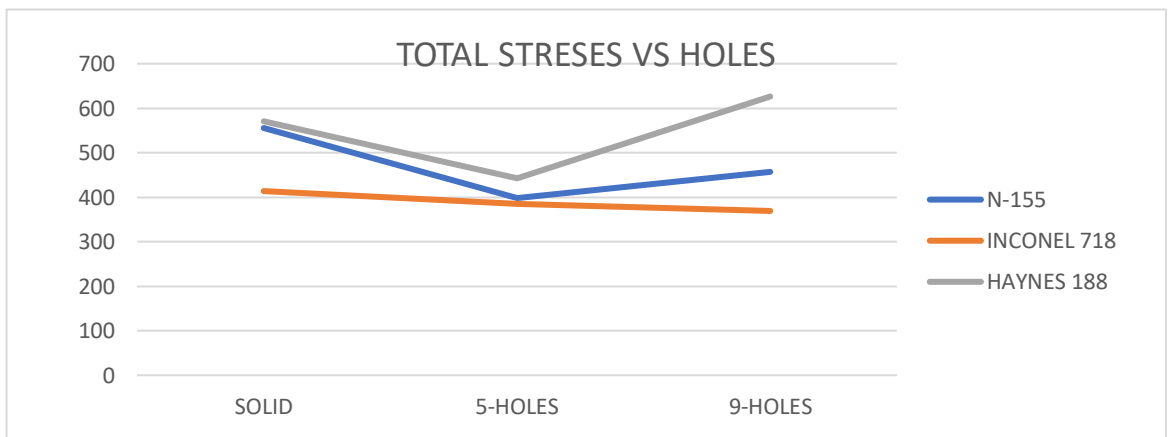**Fig 6.25. Number of holes Vs. Maximum Temperature**

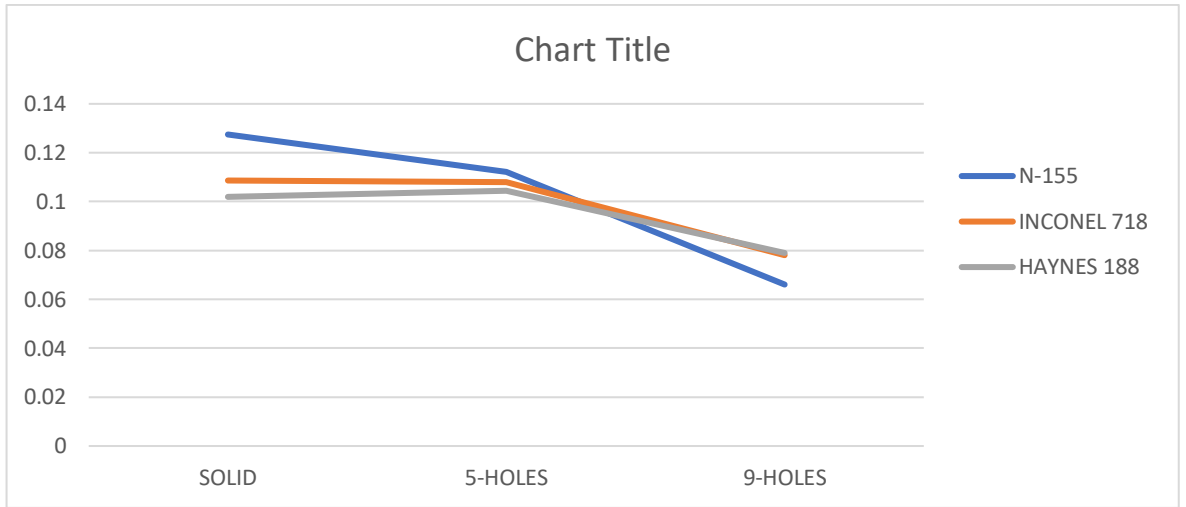**Fig 6.26. Number of holes Vs. Maximum Stress**

Fig 6.27. Number of holes Vs. Maximum Deformation

CHAPTER – 7
CONCLUSIONS

The effect of cooling of gas turbine blades is studied for two different materials of construction i.e., N - 155 & Inconel 718. It is found that the temperature has a significant effect on the overall stresses induced in the turbine blades.

The blade temperatures attained, and thermal stresses induced are lesser for Inconel718 as it has better thermal properties. The provision of cooling passages in the blades is found to alleviate the problem of high temperatures and thermal stresses in both the materials. On analysing 4 different models with varying number of holes, it is inferred that the blade model with 13 holes is best suited as the stresses produced are lower and the maximum temperature of the blade is around 800 0c. There will be a further drop in temperature with increase number of holes which is undesirable. Maximum deformation and temperatures are observed at the blade tip section when holes are provided.

CHAPTER – 8
REFERNCES

[1] B. Deepanraj, P. Lawrence and G. Sankaranarayanan **"THEORETICAL ANALYSIS OF GAS TURBINE BLADE BYFINITE ELEMENT METHOD"** Scientific World, Vol. 9, No. 9, July 2011

[2] Je-Chin Han and Akhilesh P. Rallabandi "**TURBINE BLADE FILM COOLING USING PSP TECHNIQUE"** Frontiers in Heat and Mass Transfer (FHMT), 1, 013001 (2010) DOI: 10.5098/hmt.v1.1.3001 Global Digital Central ISSN: 2151-8629

[3] Lalit Dhamecha , Shubham Gharde, Ganraj More , M.J. Naidu "**Design and Analysis of Gas Turbine Blade with Varying Pitch of Cooling Holes"** International *Journal of Engineering Trends and Technology (IJETT) – Volume 34 Number 8- April 2016*

[4] WIN LAI HTWE, HTAY HTAY WIN, NYEIN AYE SAN "**DESIGN AND THERMAL ANALYSIS OF GAS TURBINE BLADE"** International Journal of Mechanical and Production Engineering, ISSN: 2320-2092, Volume- 3, Issue-7, and July-2015

[5]L.Umamaheswararao, Dr. K. Mallikarjunarao **"Design and analysis of a gas turbine blade by using FEM"** International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 4 Issue 4 November 2014 ISSN: 2278-621X

[6] Amjed Ahmed Jasim AL-Luhaibi1, Mohammad Tariq **"THERMAL ANALYSIS OF COOLING EFFECT ON GAS TURBINE BLADE"** IJRET: International Journal of Research in Engineering and Technology ISSN: 2319-1163 ISSN: 2321-7308

[7] P.R.Surve, R.V.Shitole, D.R.Shirdhankar, S.N.Shigwan, V. S.Bagade "**Structural Analysis of Gas Turbine Blade"** International Research Journal of Engineering and Technology (IRJET) ISSN: 2395 -0056 Volume: 04 Issue: 05 May -2017

[8] Hussain Mahamed Sahed Mostafa Mazarbhuiya1, Krishna Murari Pandey "**Steady State Structural Analysis of High Pressure Gas Turbine Blade using Finite Element Analysis"** IOP Conf. Series: Materials Science and Engineering 225 (2017) 012113 doi:10.1088/1757-899X/225/1/012113

[9] Pedaprolu Venkata Vinod, T.Seshaiah, T.Victor Babu "**THE DESIGN AND ANALYSIS OF GAS TURBINE BLADE"** International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974