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ENHANCING THE THERMAL EFFICIENCY OF GAS TURBINE BLADE

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ABSTRACT

For gas turbines, aircraft propulsion, soil-based power production and industrial applications are widely used. Improved thermal efficiency of the gas turbine by increasing turbine input temperature. The current rotor intake temperature in the advanced gas turbine is above the melting point of the blade. For continuous safe operation of high-performance gas turbines, a sophisticated cooling system must be devised. Outdoor and indoor gas turbines are cooled. Various techniques of cooling blades and vanes have been suggested. The strategies used in the cooling of blades and vanes are to have radial hole to flow through high-speed cooling air.

In this paper a turbine blade in CREO parametric software has been created and modelled. The blades of the turbines are cooled using film. There are 3 holes, 7 holes, 13 holes modelled on the turbine blade with the film cooling for no holes.

The heat transfer rates, heat transfer coefficients of the blade are determined from the thermal analysis. Chromium steel is the present material used for blading and it is substituted by nickel alloys in this paper. CFD analysis, ANSYS is used for thermal analysis.

Key words: Gas Turbine Blade, Computational Fluid Dynamics, modeling

1. INTRODUCTION

The word "turbine" was coined in 1822 by the French mining engineer Claude Burden from the Latin turbo, or vortex, in a memoir, "Des turbines hydrauliques our machines rotatories à Grande Varese" (Hydraulic turbines or high-speed rotary machines), which he submitted to the Academies royale des sciences in Paris. Benoit Fourneyron, a former student of Claude Burden, built the first practical water turbine.

A turbine is a rotary engine that extracts energy from a fluid flow and converts it into useful work.

The simplest turbines have one moving part, a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they move and impart rotational energy to the rotor.

Gas, steam, and water turbines usually have a casing around the blades that contains and controls the working fluid. Credit for invention of the steam turbine is given both to the British engineer Sir Charles Parsons (1854–1931), for invention of the reaction turbine and to Swedish engineer Gusted de Laval (1845–1913), for invention of the impulse turbine. Modern steam turbines frequently employ both reaction and impulse in the same unit, typically varying the degree of reaction and impulse from the blade root to its periphery.

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 energy.

1.1 TYPES OF TURBINES

1.1.1 STEAM TURBINE

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Sir Charles Parsons in 1884.

1.1.2 GAS TURBINE

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

1.1.3 SHROUDED TURBINE

Shrouded turbine, many turbine rotor blades have shrouding at the top, which interlocks with that of adjacent blades, to increase damping and thereby reduce blade flutter.

1.1.4 CONTRA-ROTATING TURBINE

Contra-rotating, also referred to as coaxial contra-rotating, is a technique whereby parts of a mechanism rotate in opposite directions about a common axis, usually to minimize the effect of torque.

1.1.5 CERAMIC TURBINE

Ceramic turbine, Conventional high-pressure turbine blades (and vanes) are made from nickel-based alloys and often utilize intricate internal air-cooling passages to prevent the metal from overheating.

1.1.6 TURBINE BLADE

A turbine blade (See Fig. 1.1.1) is the individual component which makes up the turbine sectionof a gas turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor.

Fig. 1.1.1 Turbine Blade

1.1.7 MATERIALS

Since the design of turbo machinery is complex, and efficiency is directly related to material performance, material selection is of prime importance. Gas and steam turbines exhibit similar problem areas, but these problems areas are of different magnitudes. Turbine's components must operate under a variety of stress, temperature, and corrosion conditions. Compressor blades operate at relatively low temperatures but are highly stressed. The combustor operates at a relatively high temperature and low-stress conditions. The turbine blades operate under extreme conditions of stress, temperature, and corrosion. These conditions are more extreme in gas turbine than in steam turbine applications. As a result, the material selection for individual components is based on varying criteria in both gas and steam turbines.

1.1.8 GAS TURBINE BLADE MATERIALS

In the 1980s, IN 738 blades were widely used. IN-738, was the acknowledged corrosion standard for the industry. New alloys, such as GTD-111 possess about a 35oF (20oC) improvement in rupture strength as compared to IN-738. GTD-111 is also superior to IN-738 in low-cycle fatigue strength.

The design of this alloy was unique in that it utilized phase stability and other predictive techniques to balance the levels of critical elements (Cr, Mo, Co, Al, Wand Ta), thereby maintaining the hot corrosion resistance of IN-738 at higher strength levels without compromising phase stability.

A super alloy, or high-performance alloy, is an alloy that exhibits excellent mechanical strength and creep (tendency for solids to slowly move or deform under stress) resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. Super alloys typically have a matrix with an austenitic face-centered cubic crystal structure. A super alloy's base alloying element is usually nickel, cobalt, or nickel-iron.

1.1.9 TURBINE BLADE COATING

Blade coatings were originally developed by the aircraft engine industry for aircraft gas turbines. Metal temperatures in heavy-duty gas turbines are lower than those in aircraft engines. However, heavy-duty gas turbines generally subjected to excessive contamination or accelerated attack known as hot corrosion.

Blade coatings are required to protect the blade from corrosion, oxidation, and mechanical property degradation. As super alloys have become more complex, it has been increasingly difficult to obtain both the higher strength levels that are required and a satisfactory level of corrosion and oxidation resistance without the use of coatings. Thus, the trend toward higher firing temperatures increases the need for coatings.

2. LITERATURE SURVEY

Theju V en al.(1) has explained the design, and stresses analyze a turbine blade of a jet engine. An investigation into the usage of new materials is required. In the present work turbine blade was designed with two different materials named as Inconel 718 and Titanium T-6. An attempt has been made to investigate the effect of temperature and induced stresses on the turbine blade.

M.Lava Kumar at al.(2), in advanced gas turbines, the turbine blade operated temperature is above the melting point of blade material. A sophisticated cooling scheme must be developed for continuous safe operation of gas turbines with high performance. 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.

Alugala Sravan at al. (3) summarized 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 postprocessing and life assessment of blade.

V.Veeraragavan at al. (4) is mainly apprehensive with aircraft gas turbine engine. The turbine blade is an important part of aircraft gas turbine engine. The research focus on the 10 C4 / 60 C 50 turbine blade model, because of its common use in all types of aircraft engines.

K. Tsukagoshi at al. (5) has discussed the film cooling effectiveness on a low-speed stationary cascade and the rotating blade has been measured by using a heat-mass transfer analogy. The film cooling effectiveness on the suction surface of the rotating blade fits well with that on the stationary blade, but a low level of effectiveness appears on the pressure surface of the rotating blade. In this paper, typical film cooling data will be presented and film cooling on a rotating blade is discussed.

R. J. Goldstein at al. (6) has explained the film cooling performance for injection through discrete holes in the end wall of a turbine blade is investigated. The effectiveness is measured at 60 locations in the region covered by injection. Three nominal blowing rates, two density ratios, and two approaching flow Reynolds numbers are examined.

A. Immarigeon at al. (7) has described the present study aims to conduct a numerical investigation of a novel film cooling scheme combining in-hole impingement cooling and flow turbulators with traditional downstream film cooling and was originally proposed by Pratt & Whitney Canada for high temperature gas turbine applications.

Hui Hu at al. (8) has made an experimental study was conducted to quantify the flow characteristics of the wall jets pertinent to trailing edge cooling of turbine blades.

Dr. T. Nageswara Rao at al. (9) has summarized that the raise thermal efficiency of a gas turbine, higher turbine inlet temperature (TIT) is needed. However, higher TIT increases thermal load to its hot-section components and reducing their life span. Therefore, very complicated cooling technology such as film cooling and internal cooling is required especially for HP turbine blades.

3. DESIGN AND ANALYSIS METHODOLOGY

3.1 Design and Modelling

Computer-aided design (CAD) is the use of computer systems (or workstations) to aid in the creation, modification, analysis, or optimization of a design. CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. CAD output is often in the form of electronic files for print, machining, or other manufacturing operations. The term CADD (for Computer Aided Design and Drafting) is also used.

PTC CREO, formerly known as Pro/ENGINEER, is 3D modeling software used in mechanical engineering, design, manufacturing, and in CAD drafting service firms. It was one of the first 3D CAD modeling applications that used a rule-based parametric system. Using parameters, dimensions and features to capture the behavior of the product, it can optimize the development product as well as the design itself.

The name was changed in 2010 from Pro/ENGINEER Wildfire to CREO. It was announced by the company who developed it, Parametric Technology Company (PTC), during the launch of its suite of design products that includes applications such as assembly modeling, 2D orthographic views for technical drawing, finite element analysis and more.

ADVANTAGES OF CREO PARAMETRIC SOFTWARE

i. Optimized for model-based enterprises
ii. Increased engineer productivity
iii. Better enabled concept design
iv. Increased engineering capabilities
v. Increased manufacturing capabilities
vi. Better simulation
vii. Design capabilities for additive manufacturing

The modeling of the turbine blade are as follows:

3.1.1 Without holes (2D model)

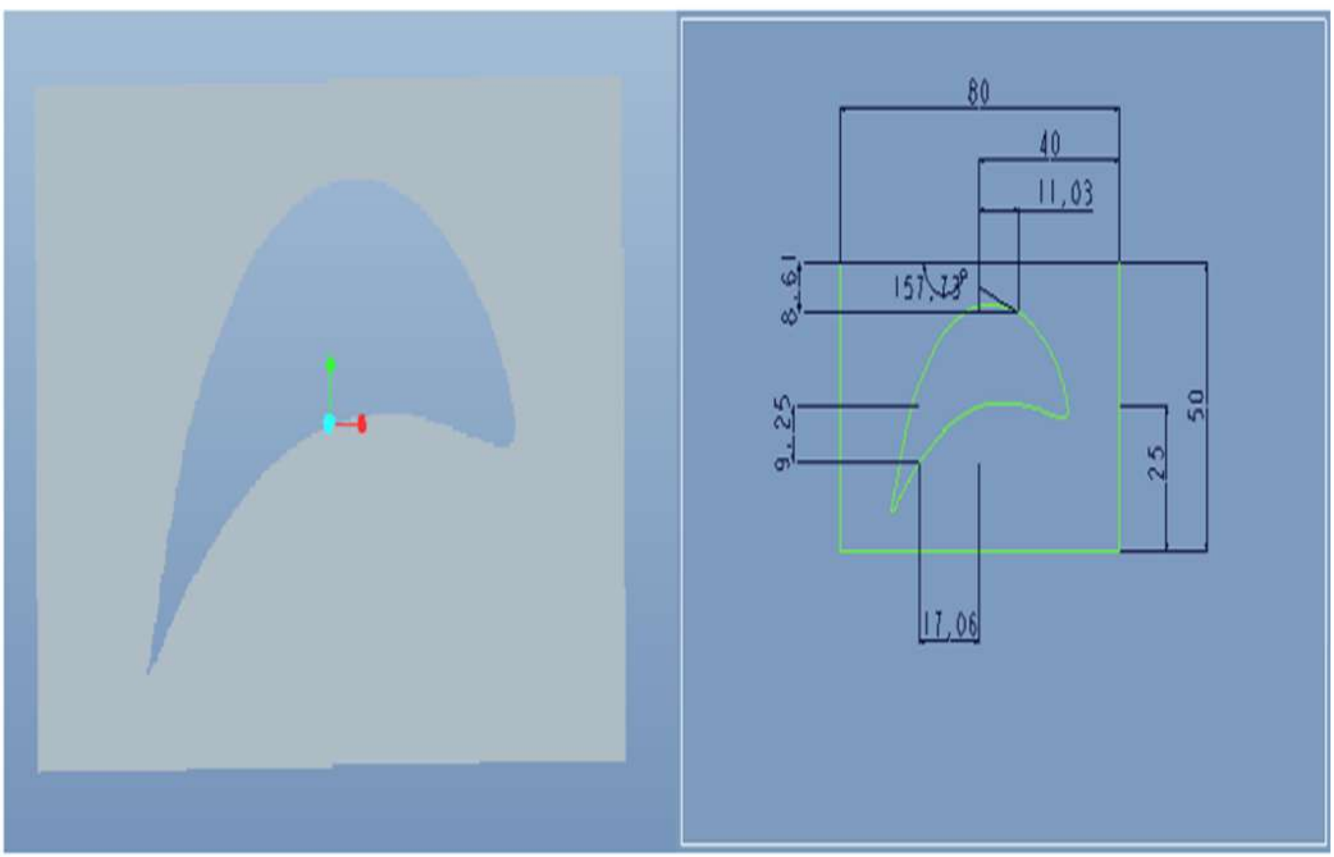


Fig 3.1.1 Turbine blade 2D model without hole

3.1.2 Without holes (3D model)

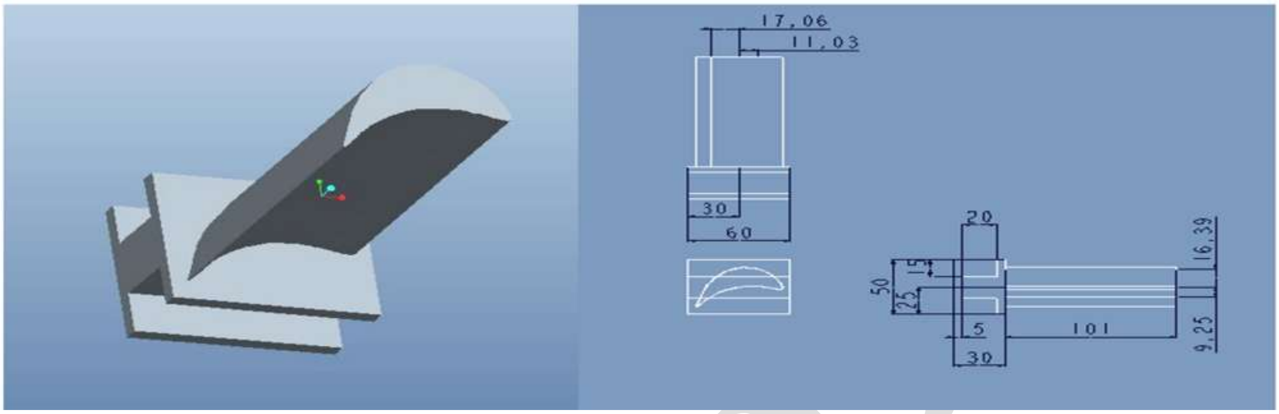
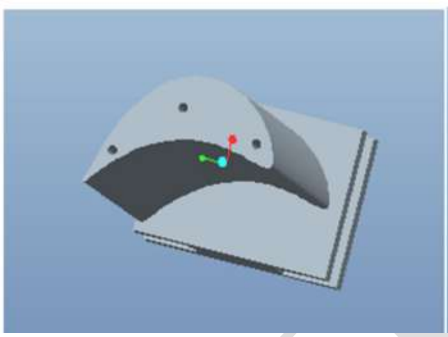
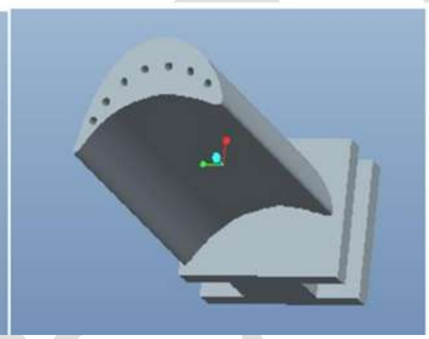


Fig 3.1.2 Turbine blade 3D model without hole

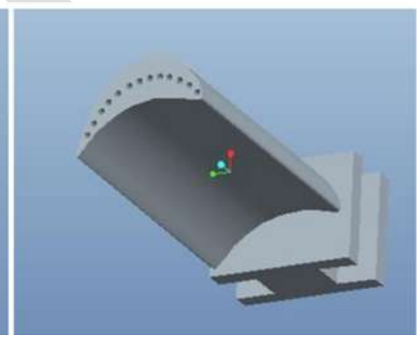
Turbine blade with 3 holes



Turbine blade with 7 holes



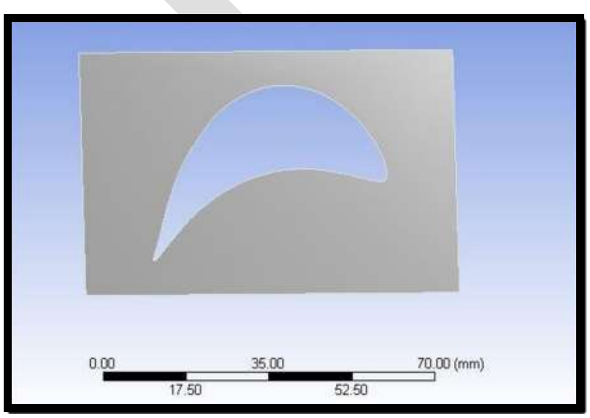
Turbine blade with 13 holes

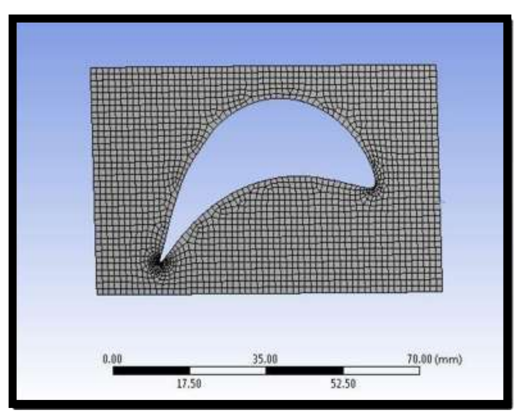


3.2 Finite Element Analysis (FEA)

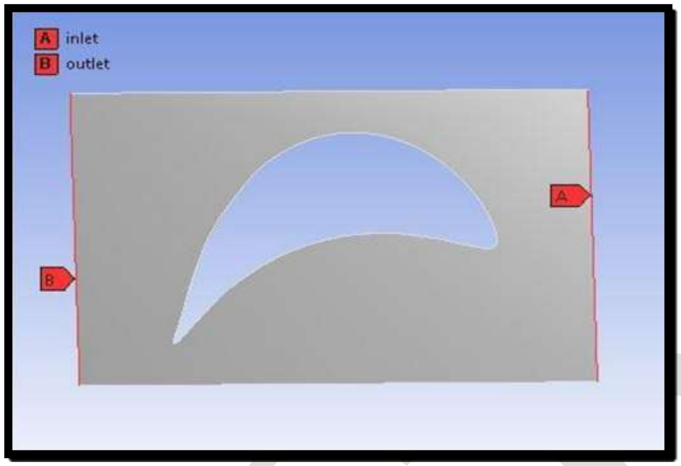
FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

3.2.1 CFD Analysis of Film Cooling Turbine Blade Without Holes





3.2.2 Specifying Boundaries for Inlet and Outlet



Inlet & outlet

Fig 3.2.2.1 Inlet and outlet

Velocity: 186.89 m/s

Thermal → Temperature:

892°CPressure=

101325Pa

PRESSURE

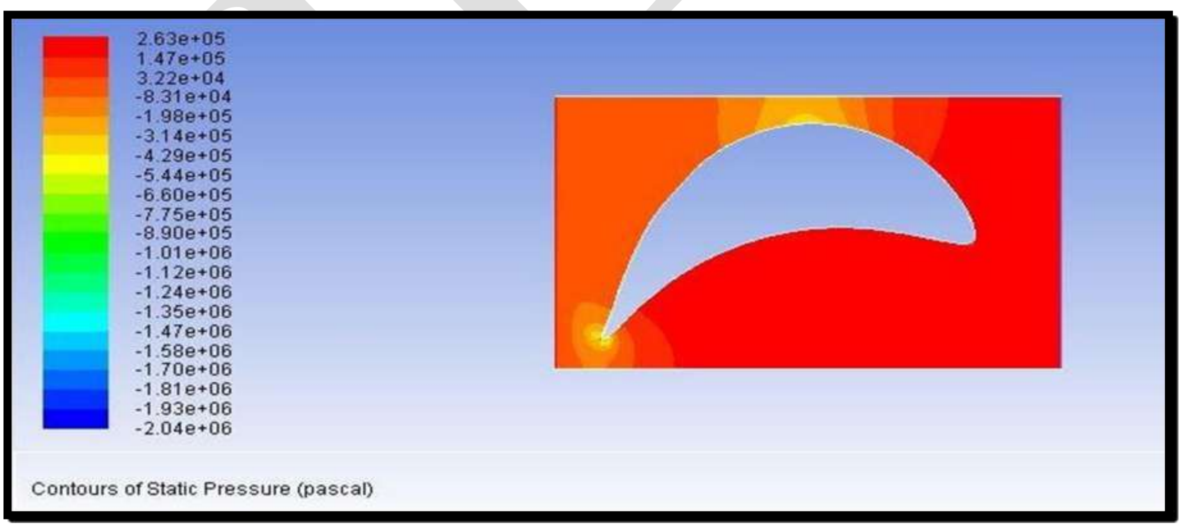


Fig 3.2.2.2 Contours of static pressure

VELOCITY

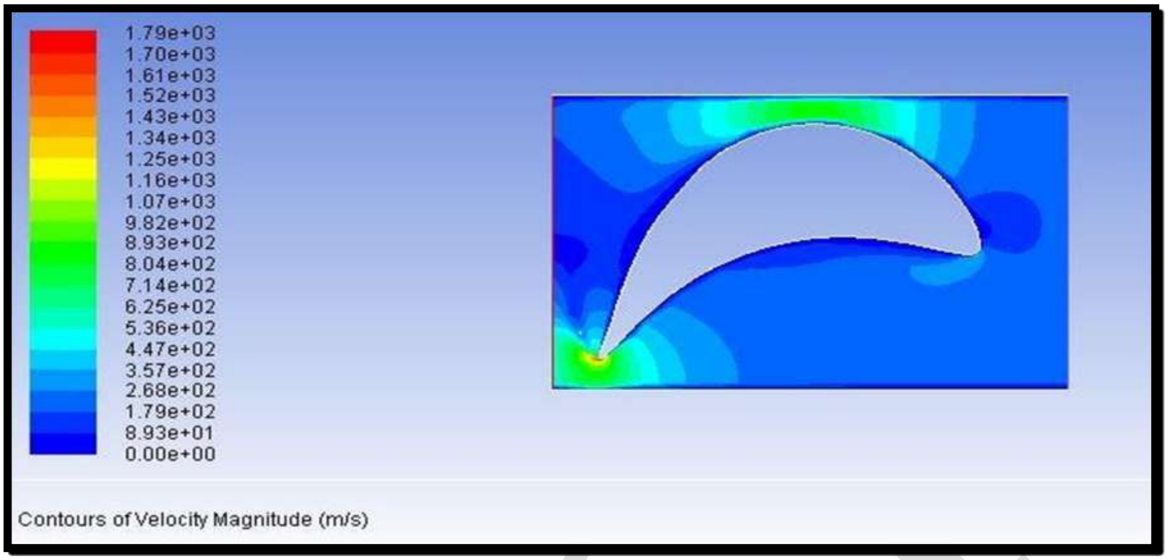
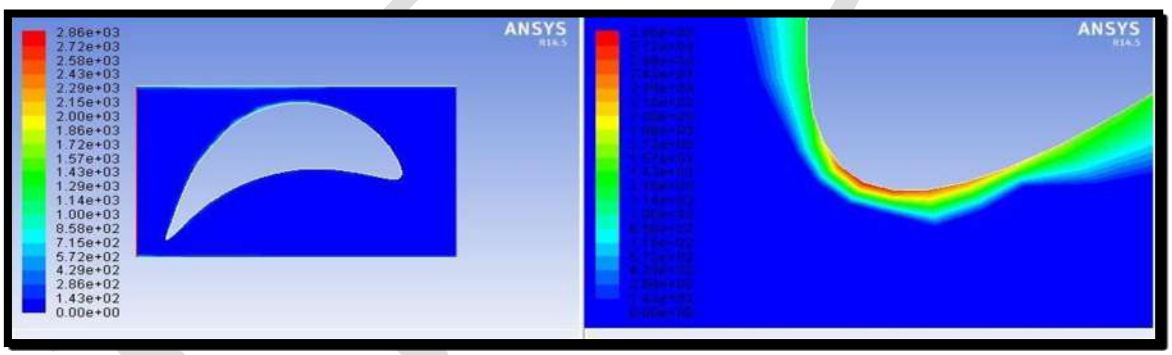


Fig 3.2.2.3 Contours of Velocity



HEAT TRANSFER COEFFICIENT

Fig 3.2.2.4 Heat Transfer Coefficient

According to the above contour plot, the maximum heat transfer coefficient of the gas turbine (See Fig. 3.2.2.4). Blade at surface edges of the turbine blade boundary edges and minimum heat transfer coefficient inside the boundary of turbine blade.

According to the above contour plot, the maximum heat transfer coefficient is 2.86e+03w/m^2-k and minimum heat transfer coefficient is 1.43e+02w/m^2-k.

3.2.3 TURBINE BLADE WITH 3 HOLES

PRESSURE

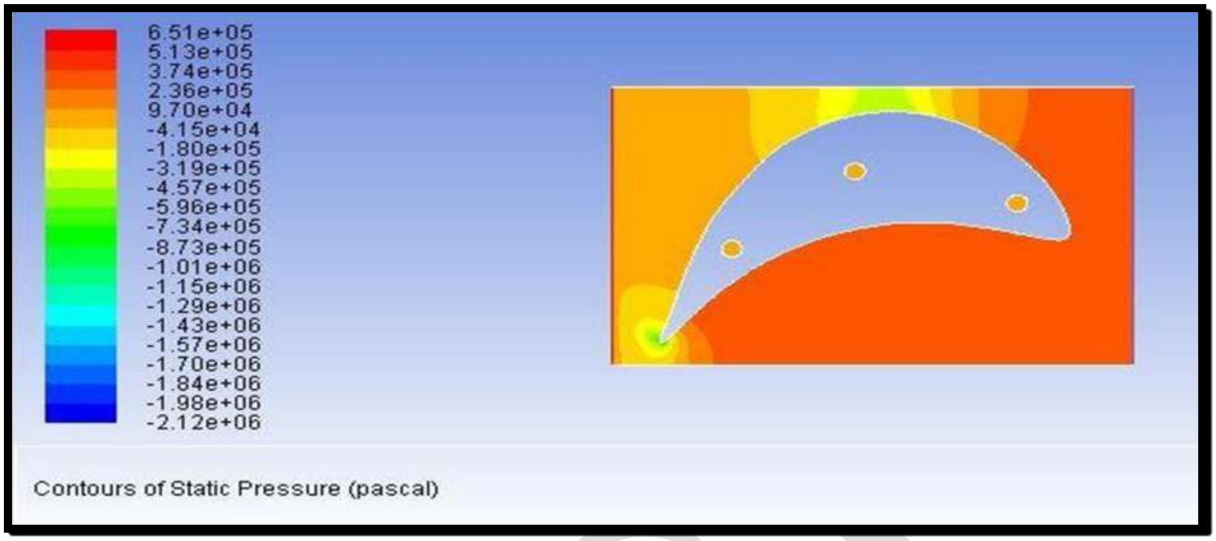
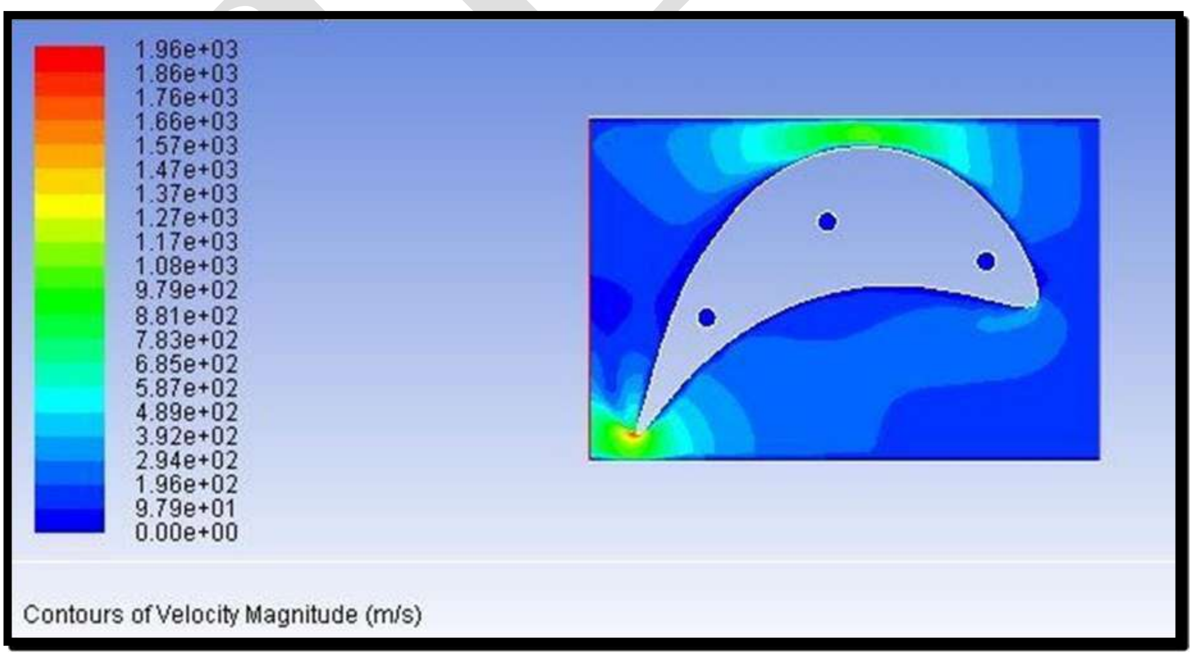


Fig 3.2.3.1 Contours of static pressure

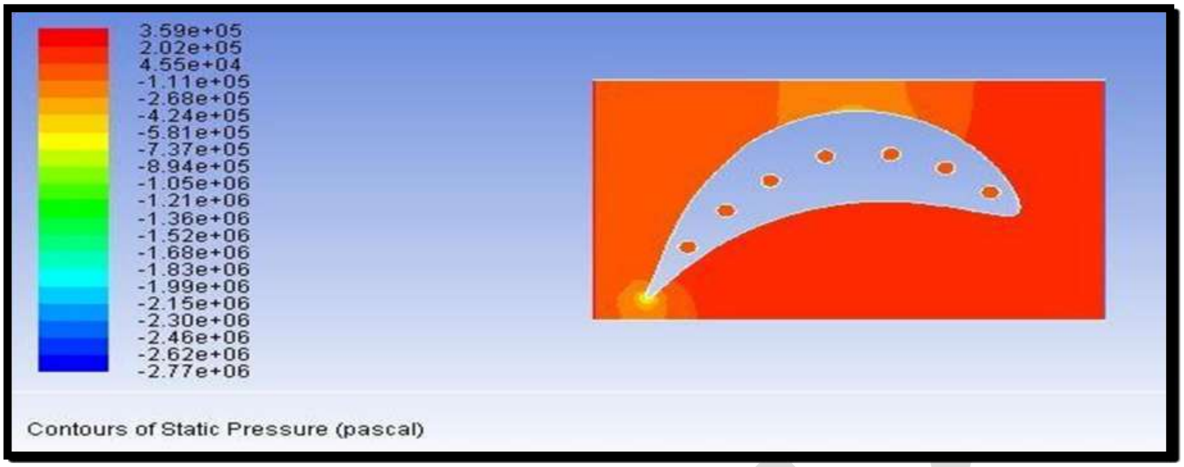
According to the above contour plot, the maximum static pressure of the gas turbine blade at inlet of the turbine blade because the applying the boundary conditions at one end surface edge as a inlet and another end surface edge as an outlet. The minimum static pressure at turbine blades the corner portion of the turbine blade.

According to the above contour plot, the maximum pressure is 6.51e+05Pa and minimum static pressure is -2.12 e+06Pa. (See Fig 3.2.3.1)

VELOCITY



According to the above contour plot, the minimum velocity of the gas turbine blade at inlet of theturbine blade



because the applying the boundary conditions at one end surface edge as a inlet andanother end surface edge as a outlet. The maximum velocity at turbine blades the corner portion of the turbine blade.

According to the above contour plot, the maximum velocity is 1.96e+03m/s and minimum static pressure is 9.79e+01m/s.

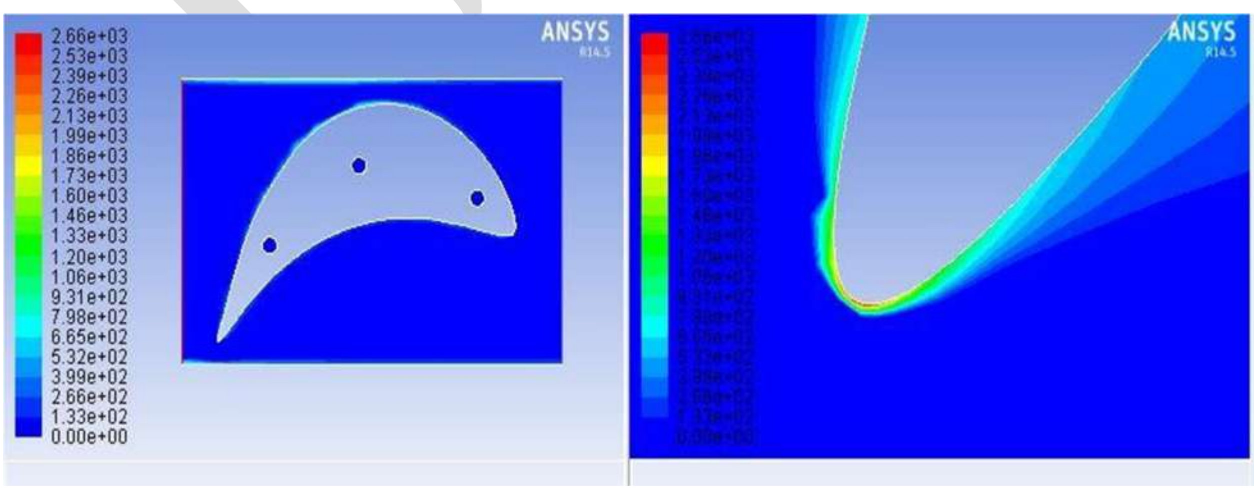
HEAT TRANSFER COEFFICIENT

According to the above contour plot, the maximum heat transfer coefficient of the gas turbine blade at surface edges of the turbine blade boundary edges and minimum heat transfer coefficientinside the boundary of turbine blade.

According to the above contour plot, the maximum heat transfer coefficient is 2.66e+03w/m^2-kand minimum heat transfer coefficient is 1.33e+02w/m^2-k.

TURBINE BLADE WITH 7 HOLES

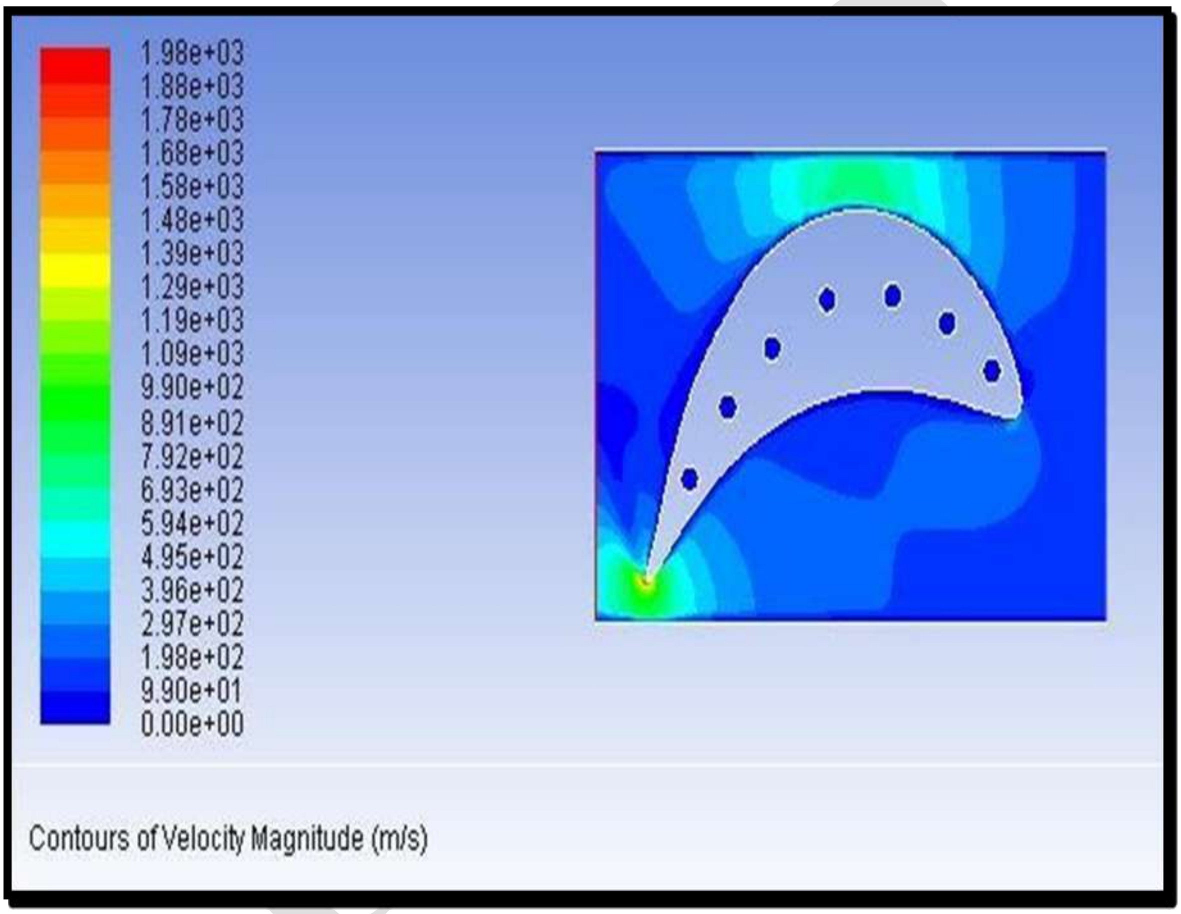
PRESSURE



According to the above contour plot, the maximum static pressure of the gas turbine blade at inletof the turbine blade because the applying the boundary conditions at one end surface edge as a inlet and another end surface edge as a outlet. The minimum static pressures at turbine blades the corner portion of the turbine blade.

According to the above contour plot, the maximum pressure is 3.59e+05Pa and minimum staticpressure is -2.77e+06Pa.

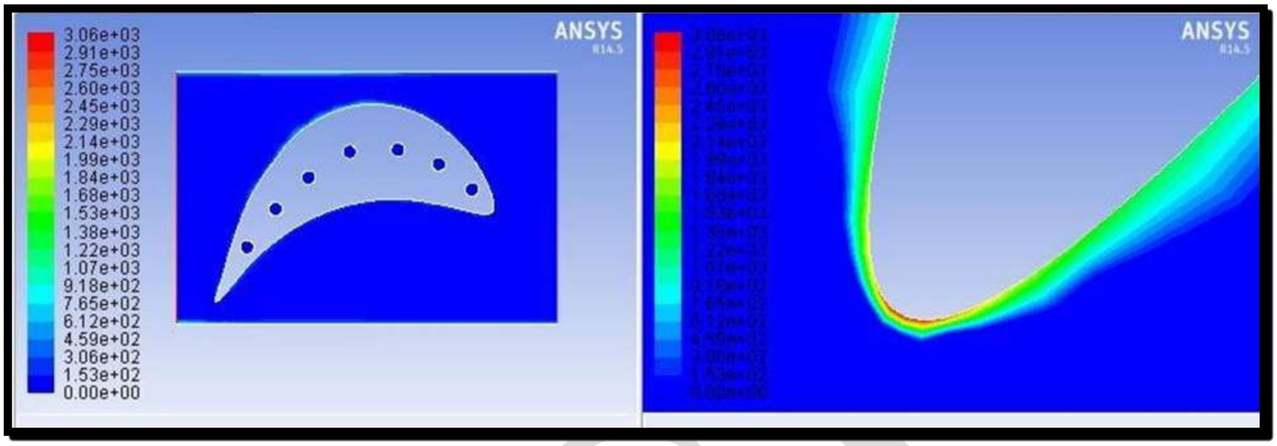
VELOCITY



According to the above contour plot, the minimum velocity of the gas turbine blade at inlet of theturbine blade because the applying the boundary conditions at one end surface edge as a inlet andanother end surface edge as a outlet. The maximum velocity at turbine blades the corner portion of the turbine blade.

According to the above contour plot, the maximum velocity is 1.98e+03m/s and minimum static pressure is 9.90e+01m/s.

HEAT TRANSFER COEFFICIENT



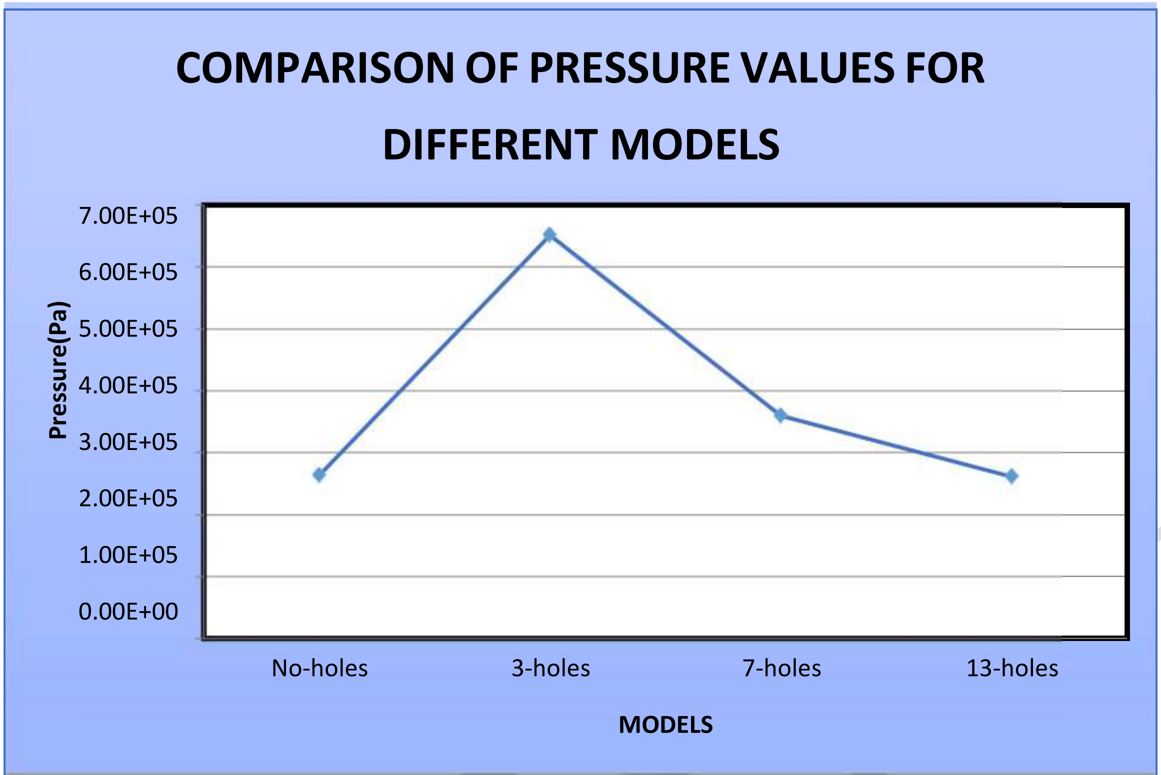
According to the above contour plot, the maximum heat transfer coefficient of the gas turbine blade at surface edges of the turbine blade boundary edges and minimum heat transfer coefficient inside the boundary of turbine blade.

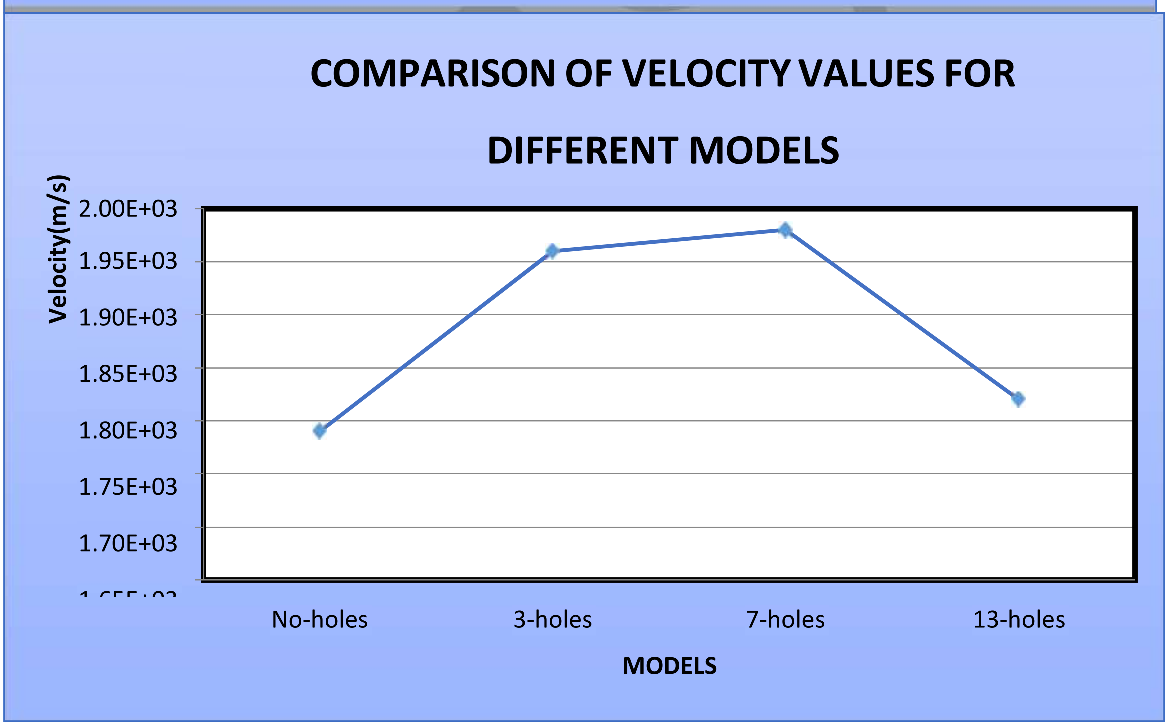
According to the above contour plot, the maximum heat transfer coefficient is 3.06e+03w/m^2-kand minimum heat transfer coefficient is 1.53e+02w/m^2-k.

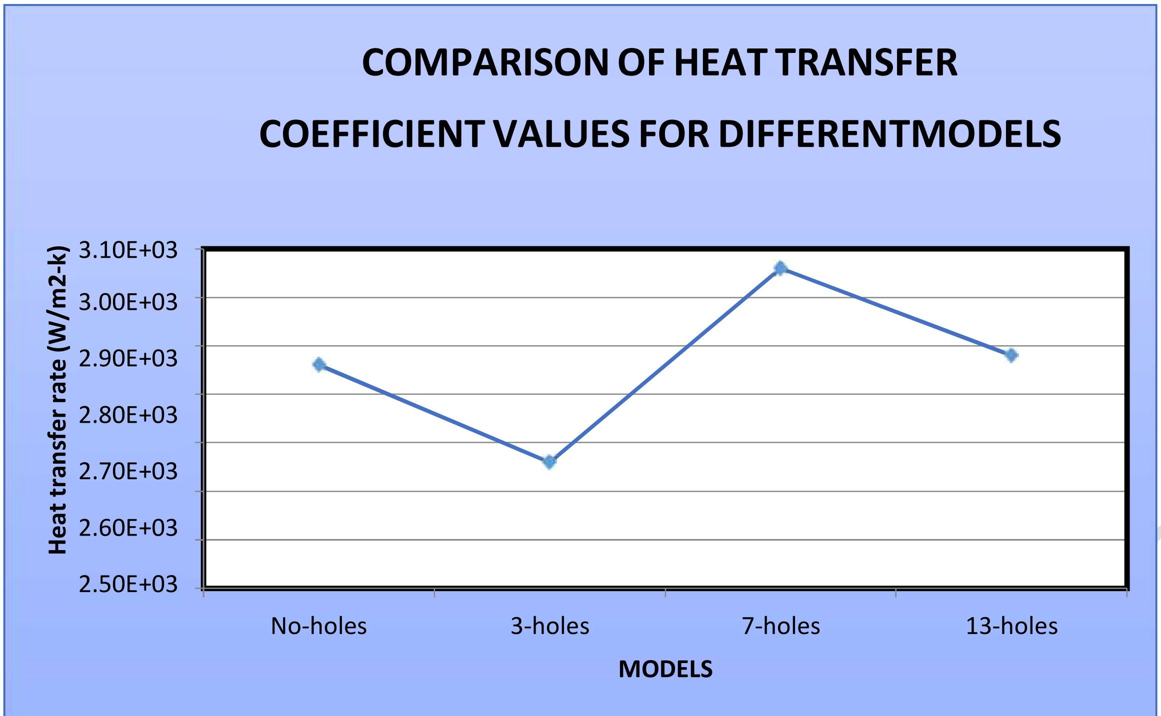
4. RESULTS AND DISCUSSION

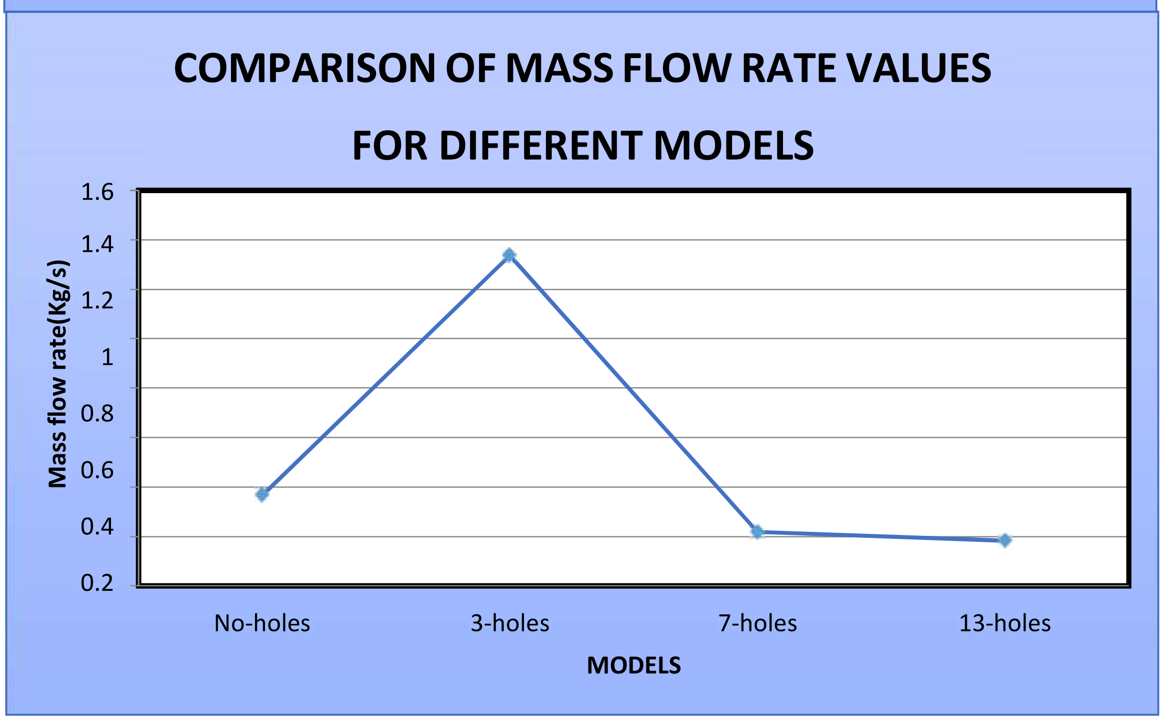
The CFD analysis results of the gas turbine blade are as follows.

Turbine models	**Results**				
	Pressure (Pa)	**Velocity(m/s)**	**Heat transfer coefficient (W/m^2-k)**	**Mass flow rate (kg/s)**	**Heat transfer rate(W)**
No-holes	$2.63e^{+05}$	$1.79e^{+03}$	$2.86e^{+03}$	0.36603546	289848
3-holes	$6.51e^{+05}$	$1.96e^{+03}$	$2.66e^{+03}$	1.3362656	1468896
7-holes	$3.59e^{+05}$	$1.98e^{+03}$	$3.06e^{+03}$	0.21849823	173056
13-holes	$2.61e^{+05}$	$1.82e^{+03}$	$2.88e^{+03}$	0.18215942	144232


COMPARISON OF PRESSURE VALUES FOR DIFFERENT MODELS
Pressure(Pa)
7.00E+05
6.00E+05
5.00E+05
4.00E+05
3.00E+05
2.00E+05
1.00E+05
0.00E+00
No-holes
3-holes
7-holes
13-holes
MODELS


COMPARISON OF VELOCITY VALUES FOR DIFFERENT MODELS
Velocity(m/s)
2.00E+03
1.95E+03
1.90E+03
1.85E+03
1.80E+03
1.75E+03
1.70E+03
No-holes
3-holes
7-holes
13-holes
MODELS


COMPARISON OF HEAT TRANSFER
COEFFICIENT VALUES FOR DIFFERENTMODELS
Heat transfer rate (W/m2-k)
3.10E+03
3.00E+03
2.90E+03
2.80E+03
2.70E+03
2.60E+03
2.50E+03
No-holes
3-holes
7-holes
13-holes
MODELS


COMPARISON OF MASS FLOW RATE VALUES
FOR DIFFERENT MODELS
Mass flow rate(Kg/s)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
No-holes
3-holes
7-holes
13-holes
MODELS

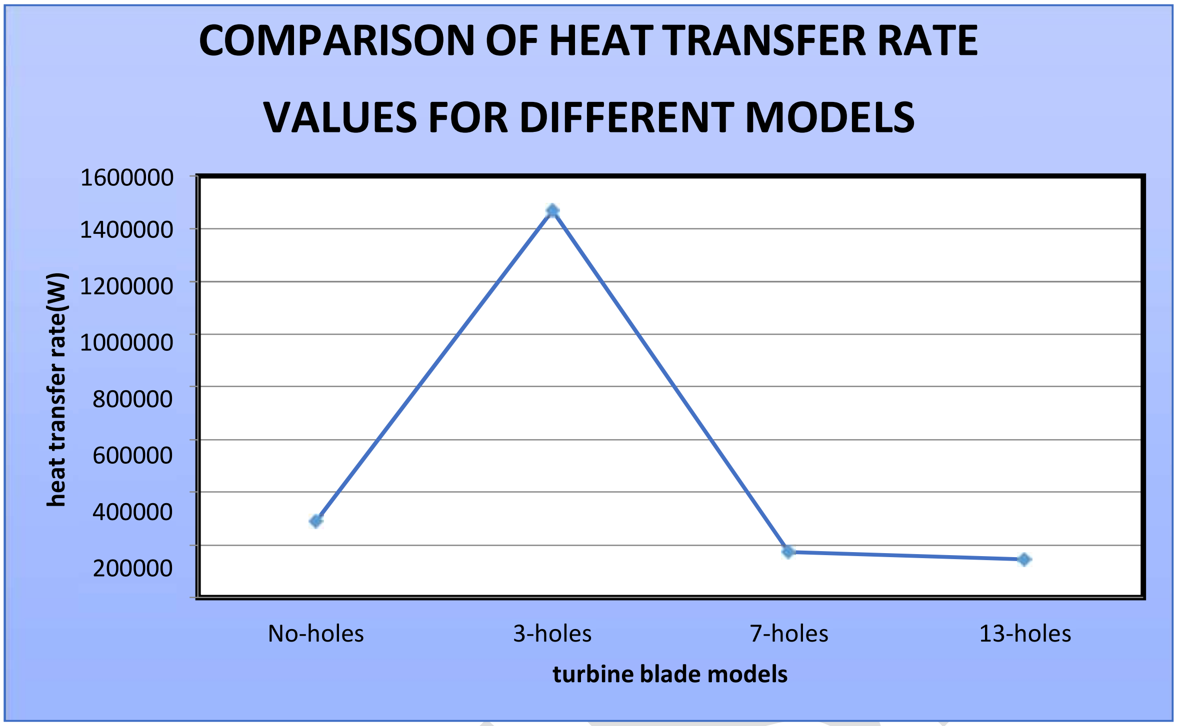


Fig 4.3 Comparison of pressure and velocity values for different models

THERMAL ANALYSIS

Models	Materials	results		
		Temperature(°C)		Heat flux(W/mm^2)
		Max.	Min.	
No-holes	Chromium steel	812	22.459	9.3625
	Nickel alloy	812	22.059	6.4744
3-holes	Chromium steel	812	22.595	9.8363
	Nickel alloy	812	22.078	6.8431
7-holes	Chromium steel	812	22.331	10.517
	Nickel alloy	812	22.04	7.2644
13-holes	Chromium steel	812	22.39	7.9833
	Nickel alloy	812	22.048	5.224

5. CONCLUSIONS

In this paper a turbine blade is designed and modeled in Pro/Engineer software. The turbine blades are designed using cooling holes. The turbine blade is designed with no holes, 3 holes, 7 holes, 13 holes. The present used material for blade is chromium steel. In this thesis, it is replacedwith Nickel alloy. Thermal and CFD analysis is done to determine the heat transfer rates and heat transfer coefficients of the blade.

By observing the CFD analysis results, the pressure gradient is more for blade with 3 holesthan blade with 7 & 13 holes. Due to high pressure gradient, the heat transfer coefficient and heattransfer rate are more for blade with 3 holes.

By observing the thermal analysis results, the heat flux is almost similar for Nickel alloy617 and Chromium Steel. So, heat transfer rate is more when Nickel alloy 617 and ChromiumSteel. But the strength of Nickel alloy 617 is more than that of Chromium Steel so using Nickelalloy 617 is better. When compared results for models, using 7 holes has more heat transfer rate. So, from the above two analysis it can be concluded that providing 3 holes for Nickel alloy617 isbetter.

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