Design and Analysis of Gas Turbine Rotor Blade

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***Abstract*— The turbine blades are responsible for extracting heat energy from high temperature, high-pressure gas. In the present paper, the base profile of the turbine rotor blade is selected depending on the application as a turbojet engine. The geometry of the first stage rotor blade is constructed and analyzed for fluid using the ANSYS software. Then the new rotor blade is designed with the modifications in the existing rotor blade and analyzed for flow for different parameters like incident angles and outlet angles. This process is carried out for a number of iterations and the optimal design of the turbine rotor blade is obtained which will give better sustainability in severe working conditions with the same flow pattern of the gaseous flow.**

***Keywords*—Gas turbine rotor blade, CFD analysis, Face-split,Velocity Vector Distribution**

I. INTRODUCTION

The gas turbine in its most common form is a rotary heat extractingmachine. Gas turbines are used in many applications[1-4] from a small turbojet to a bigger gas turbine in power plant, where turbine blades are the key limiting factors that affect the performance of the gas turbine system mainly. Turbine blades are subjected to very strenuous environment inside a gas turbine like high temperature, high pressure and high velocity of gases as they act as a medium to transfer the maximum amount of heat energy from gases to the rotor. The design of the rotor blade plays an important role in a better performance ofthe gas turbine. Hence, researchers are working continuously to get a better rotor blade design, but as the design changes,many output parameters are affected and optimal design is not obtained. These problems form an area where it is needed to work for better work efficiency of the turbine blade, where turbine rotor blades can withstand high thermal stresses, fatigue loading,and vibration.

Temperature results in a significant effect on the overall stresses in the turbine blade [1]. The range of Reynolds number is also considered while designing the aerodynamic shapes of the blade profile [3]. Though all the considerations are taken care of while designing the turbine rotor blade, some working parameters always affect the performance of the blade. The paper aims to design a highly efficient gas turbine rotor blade for a high-pressure turbojet engine. The objective of the research work is to design and build a CAD model of the turbine blade from published data. Further, the design is analyzedfor given boundary conditions and the results are compared with published data. The design of the blade is further modified according to working conditions.

II. DESIGN OF TURBINE ROTOR BLADE

Various research papers were studied [1-3]to understand specific design procedure of the turbine rotor blade.

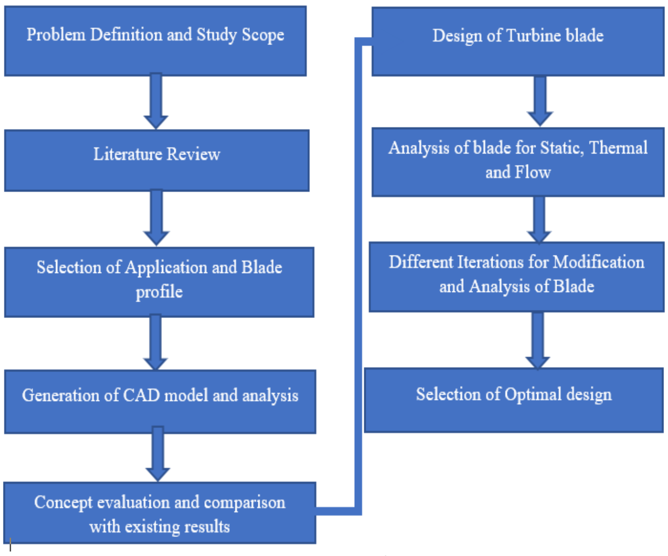


Figure 1. Design Procedure for Turbine Blade

A . Blade Selection and Blade Specification

At high temperature, the gas turbine blades experience extreme service conditions. The blades in that area are highly loaded by centrifugal force thereby experiencing high rotational speed and vibrations. Literature in this field suggests that, if the turbine inlet temperature is increased gradually, efficiency decreases. Considering the above conditions SGT800 blade with 7MW power generation and rotating at 3400 rpm is selected for the project work [1], whereas the blade generated a high amount of stresses when working under maximum temperature. The maximum velocity of the gaseous flow is observed to be low. Hence, this blade is considered for research work.

Inconel 718, a nickel-based superalloy is a basic material for the selected turbine blade. The material has a high strength in temperature up to 1400^0 F. It also exhibits excellent tensile and impacts strength [1].

TABLE 1
MATERIAL PROPERTIES OF INCONEL 718

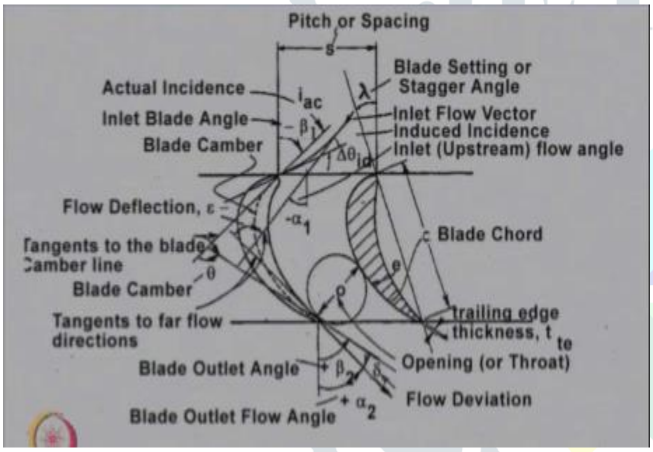
Density	8193.3 kg/m^3
Tensile Yield Strength	110 GPa
Tensile Ultimate Strength	137.5 GPa
Specific Heat	435 kg ^{0}C

B. Specifications of Basic Profile

The basic profile selected for the turbine rotor blade is used as a reference profile for further design of the blade. The blade profile is generated with the help of spline curves on a rectangle of dimensions 49x27 mm^2.

Blade inlet flow angle = 23.85^0
Blade inlet angle = 135^0
Blade outlet angle = 37.88 ^{0}
Diameter of blade midspan = 1.308 m
Design speed of rotor blade = 3400 rpm
Blade height = 117 mm
Chord length = 49.88 mm
Total no of blades on the rotor in single stage = 72

By using these specifications, a rotor blade is generated, meshed and then imported in ANSYS Workbench. Each blade acquires an angle sector of 5^0 [1].



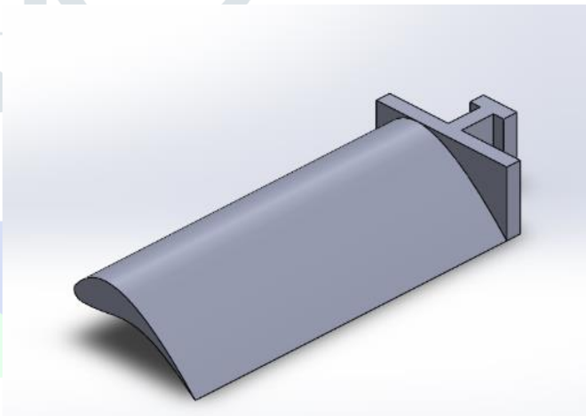


Figure.2 Terminology of Blade Profile (Roy & Pradeep, 2016)Figure.3 Basic Profile CAD Model of Rotor Blade

C. Design Procedure of the Turbine Rotor Blade

The Design of the rotor blade is considered for different inlet and outlet angles to obtain better performance under given working conditions. A Number of iterations are considered in which certain parameters are changed for every iteration. The range for an incident angle is 3^0-16^0, in which the incident anglecan be changed so to change the flow direction.

TABLE 2
CHANGED VALUESOF PARAMETERSFORDIFFERENT EQUATION

	Changed parameters in the profile (in deg.)
1	Flow inlet angle =25^0
2	Flow inlet angle = 26^0
3	Flow inlet angle = 27^0
4	Flow inlet angle = 28^0
5	Flow inlet angle = 29^0
6	Flow inlet angle = 30^0
7	Flow inlet angle = 31^0
8	Blade outlet angle = 42^0
9	Blade outlet angle = 40^0
10	Blade outlet angle = 44^0

For all the iterations, the CAD model of the turbine blade is generated with changed parameters.Three blade assembly is constructed for analysis of blades.The constructed geometry of the rotor blade is then analyzed for flow conditions for all iterations.

III. Analysis of Gas Turbine Rotor Blade

Flow analysis is done to obtain blade performance in working conditions. The inlet parameters for flow analysis are calculated according to the working conditions.

A. Boundary Conditions Calculations

Inner radius (R_i) = 595.7 mm

Outer radius (R_o) = 712.7 mm

Flow area (A_0) = $\pi R_o^2 - \pi R_i^2$

= 480923.79 mm^2

Mass flow rate of hot gases in turbine (M_0) = 130 kg/s

Density of hot gases at 870 ^{0}C (ρ) = 6.09414 kg/m^3

Pressure ratio = 20:1

Inlet flow velocity of hot gases V = $\frac{M0}{\rho A}$= 44.36 m/s

Inlet velocity = 44.36 m/s

No. of inlet when face split applied = 30

Hence, angle of 1^0 per inlet is obtained

The X component in XY plane is Vcos45

X = Vcos45 = 44.36cos45

= 31.38 m/s

The Y component in XY plane is Vsin45

Y = Vsin45 = 44.36sin45

= 31.38 m/s

B. Blade Geometry Calculations

The X-component will not change its direction as the inlet face varies, but the Z-component would change its direction as the inlet inclination changes the angle from -15 ^{0} to +15^0 aboutthe +Y axis.

For example:

Inlet 1 shares the area from -15^0 to -14^0

Y=Vsin45

Y^1= Y cos(-14.5)

Y^1= Vsin45 cos(-14.5)

Similarly

Z = Ysin(-14.5)

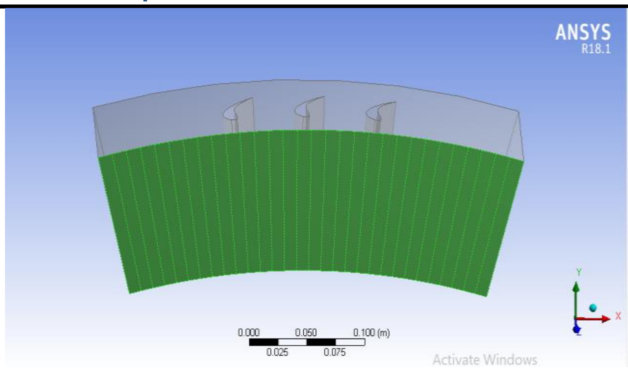
Z = Vsin45 sin(-14.5)

The calculations for the inlet velocity are as follows:

TABLE 3
VALUESOF VELOCITYIN DIFFERENT DIRECTION

Inlet Face No.	Mean Angle (deg.)	Normal Velocity (m/s)	Velocity in X-Direction (m/s)	Velocity in Y-Direction (m/s)	Velocity in Z-Direction (m/s)
1	-14.5	44.37	31.38	31.38	-7.8570
2	-13.5	44.37	31.38	31.38	-7.3270
3	-12.5	44.37	31.38	31.38	-6.7936
4	-11.5	44.37	31.38	31.38	-6.2577
5	-10.5	44.37	31.38	31.38	-5.7200
6	-9.5	44.37	31.38	31.38	-5.1800
7	-8.5	44.37	31.38	31.38	-4.6390
8	-7.5	44.37	31.38	31.38	-4.0960
9	-6.5	44.37	31.38	31.38	-3.5532
10	-5.5	44.37	31.38	31.38	-3.0000
11	-4.5	44.37	31.38	31.38	-2.4626
12	-3.5	44.37	31.38	31.38	-1.9161
13	-2.5	44.37	31.38	31.38	-1.3691
14	-1.2	44.37	31.38	31.38	-0.8216
15	-0.5	44.37	31.38	31.38	-0.2739
16	0.5	44.37	31.38	31.38	0.2739
17	1.2	44.37	31.38	31.38	0.8216
18	2.5	44.37	31.38	31.38	1.3691
19	3.5	44.37	31.38	31.38	1.9161
20	4.5	44.37	31.38	31.38	2.4626
21	5.5	44.37	31.38	31.38	3.0000
22	6.5	44.37	31.38	31.38	3.5532
23	7.5	44.37	31.38	31.38	4.0960
24	8.5	44.37	31.38	31.38	4.6390
25	9.5	44.37	31.38	31.38	5.1800
26	10.5	44.37	31.38	31.38	5.7200
27	11.5	44.37	31.38	31.38	6.2577
28	12.5	44.37	31.38	31.38	6.7936
29	13.5	44.37	31.38	31.38	7.3270
30	14.5	44.37	31.38	31.38	7.8570

The inlet velocity is aligned according to the circumference of the enclosure. However, to minimize the errors, the inlet of the enclosure is divided into 30 equal parts of 1^0 each as shown in the Figure 3. The analysis of the above domain is carried out under operating conditions and compared accordingly.



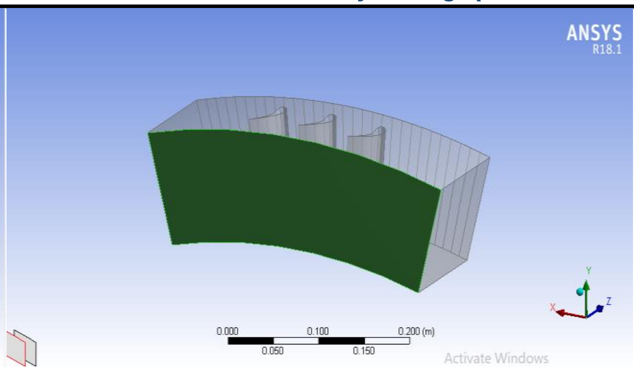
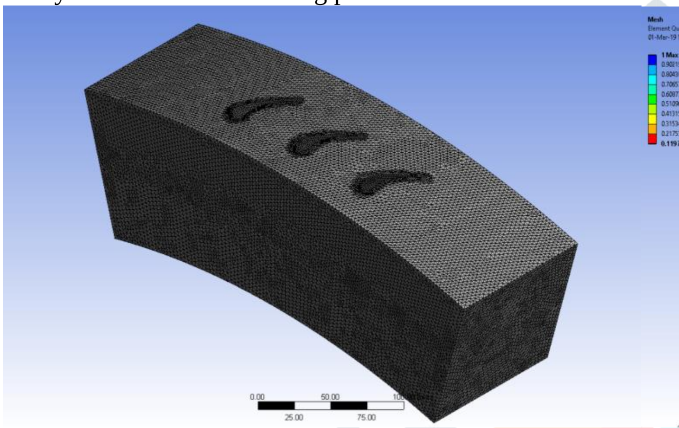


Figure.4 Inlet of Fluid Domain into 30 parts

Figure 5. Outlet of Fluid Domain

C. Meshing of Blade Geometry

The meshing of the rotor blade geometry is carried out using tetrahedral and hexahedral elements. Body mesh and body sizing is provided to the geometry of the blades. Refinement is given at the edges of the blade profile. Body sizing of a 3mm element mesh is provided with behaviour as soft. Growth rate for the mesh is defined as 1.2 .For all the iterations same fluid domain, boundary conditions and meshing parametersis used for further analysis of the blade geometry.



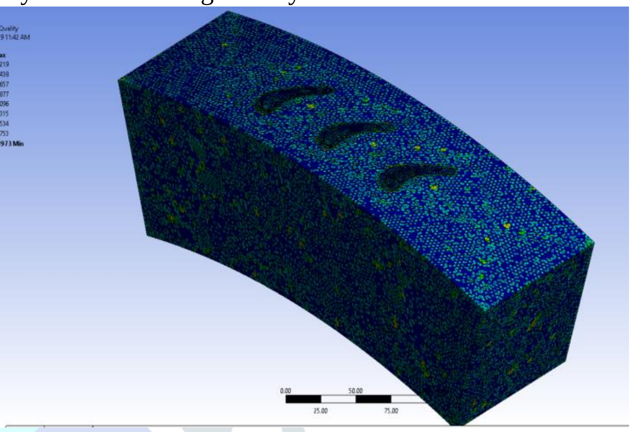
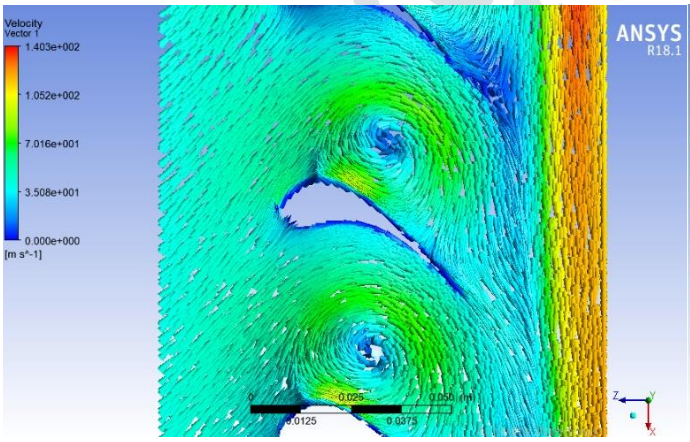


Figure.6 Mesh of Fluid Domain Figure.7Element Quality of Mesh

D. Flow Analysis of the Geometry and selection of the blade profile

The flow analysis for basic profile of the blade and all the iterations is done. Then results obtained from the flow analysis are compared for the selection of final profile. The velocity distribution is observed at three different planes. These are the flow patterns obtained from flow analysis of turbine blade for given working conditions.



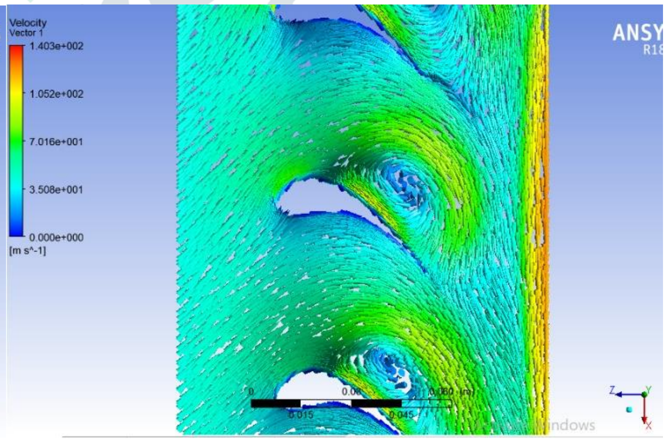


Figure.8 Velocity Vector Distribution of Iteration 4 Profile at 29mm from the root of the Blade

Figure.9 Velocity Vector Distribution of Iteration 4 Profile at 58.5mm from the root of the blade

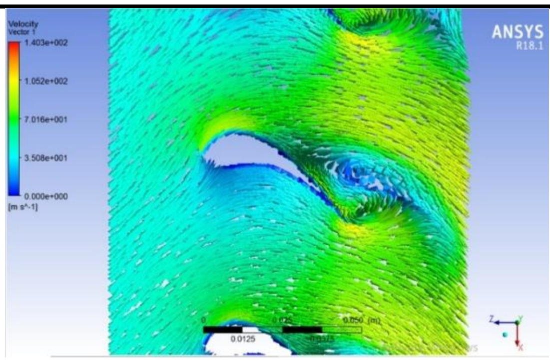


Figure.10 Velocity Vector Distribution of Iteration 4 Profile at 88mm from theroot of the Blade

IV. RESULTS AND DISCUSSION

The flow analysis of the basic profile of the turbine blade and all iterations is done. The results obtained after analying rotor blade of each iteration are compared with the results obtained from analysis of basic blade profile. The results of the analysis are listed below:

1) For each profile, flow pattern changes from root to tip of the blade geometry. Near the root area, flow is more turbulent while turbulence of the flow decreases gradually as we move from root to tip.
2) Velocity vectors are changing continuously over the suction side of the blade from root to tip of the blade profile.

TABLE 3
VALUEOFMAXIMUMVELOCITYATDIFFERENTPLANE

	Velocity at 29 mm from root of the blade	Velocity at 58.5 mm from root of the blade	Velocity at 88 mm from root of the blade
Basic blade profile	102.6 m/s	101 m/s	70.5 m/s
Blade profile from iteration 4	105.2 m/s	104 m/s	71 m/s

The values mentioned in the table are the maximum value of velocity vectors over the blade profile at given plane.

Maximum values of velocity obtained for the blade profile of iteration 4 are nearly equal to the maximum values obtained for the basic blade profile for flow analysis.

V. CONCLUSION

Flow analysis of the turbine rotor blade for number of iterations is done to obtain a turbine blade which gives better performance for the flow of hot gases and given working conditions. From the overall work done on the gas turbine rotor blade, the following results are obtained:

1) From the flow analysis, the results obtained for iteration 4 are considerably matches with results obtained for the basic selected profile. Hence, in the final design blade profile from iteration 4 is selected.
2) While meshing the blade geometry, automatic mesh platform with tetrahedral mesh type is used to get better and smooth flow over the surface. Refinement at surface of the blade is given to obtain more accuracy in the results.
3) Gas turbine rotor blades work in the severe conditions like high pressure, high temperature and high velocity of hot gases. In such conditions, flow analysis helps to obtain performance and sustainability of the blade in actual working conditions.
4) The turbulence of the flow is always observed on the suction side of the turbine blade and is maximum near the root of the blade. Amount of turbulence of the flow significantly affects the velocity distribution and hence the performance of the gas turbine blade.

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