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STATIC STRUCTURAL ANALYSIS OF A TURBINE ROTOR BLADE OF A GAS TURBINE ENGINE IN UNTWISTED AND PRE-TWISTED CONFIGURATIONS

DESIGN AND ANALYSIS

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Abstract - *In this work, we intend to study two configurations of a rotor blade, that is untwisted and pre-twisted blade, and the deformation it undergoes on the application of different loads. Rotor blades come under heavy influences from the flow coming from the stator blades. Three type of forces that pre-dominantly act on the rotor blade are, centrifugal, axial and tangential. The forces act on the centroid of the blade. The modelling of the blade will be carried out using catia and static structural analysis will be carried out in ANSYS workbench 15.0. After doing this, the blade will be given a pre-twist of 4 degree and 6 degree and the deformation will again be analysed. Then a conclusion will be made whether which blade configuration should be installed in a gas turbine engine for optimum efficiency and thrust.*

Keywords- *Rotor blades, Pre-twist blades, Static- Structural Analysis, Untwisted rotor blades.*

I. INTRODUCTION

1.1 Working principle of a gas turbine engine.

Gas turbine engines work on the principle of a Brayton cycle. Fresh atmospheric air flows through a compressor that brings it to higher pressure. Energy is then added by spraying fuel into the air and igniting it so the combustion generates a high-temperature flow. This high-temperature high-pressure gas enters a turbine, where it expands down to the exhaust pressure, producing a shaft work output in the process. The turbine shaft work is used to drive the compressor. The energy that is not used for shaft work comes out in the exhaust gases, so these have either a high temperature or a high velocity. The purpose of the gas turbine determines the design so that the most desirable energy form is maximized.

In an ideal gas turbine, gases undergo three thermodynamic processes: an isentropic compression, isobaric (constant pressure) combustion and an isentropic expansion. Together, these make up the Brayton cycle.

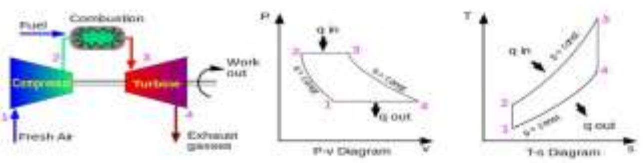

Figure1: schematic diagram of a gas turbine engine, its P-V and T-S diagram.

1.2 Stator and Rotor blades.

1.2.1 Stator Blades

The Stator blades are high cambered aerofoils, which are also known as Eyebrow aerofoils. These aerofoils do not have any rotational velocity but they are placed before rotors to give the required direction to the airflow for optimum energy transformation by rotors.

The stator blades are designed to work at very high temperature, as the incident gases are gases from combustion chamber

1.2.2 Rotor Blades

Rotor blades are also high cambered aerofoils, which are also known as eyebrow aerofoils. The rotor blades are connected to the main engine shaft. These rotors work as the main energy transformers, they transform the energy depending upon the pressure and subsequently it is converted into mechanical energy by the means of shaft. The rotors have very high rotational velocity.

As the rotor blades are highly cambered they slow down the localized velocity of the airflow and energy transformation takes place from the fluid to the main engine shaft.

Figure 2. Rotor blade arrangement

II. MODELING OF ROTOR BLADES [2], [3], [4], [5], [7]

For static structural analysis, we decided to model a single untwisted rotor blade in CATIA-V5R21.The following blade co-ordinates were plotted in CATIA in order to sketch the blade cross section.

SR.NO	X	Y	SR.NO	X	Y
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	5.70	30	49	0.27E-1
12	49	0	31	48.90	0.288E-1
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	0.30E-1
18	38.2	8.77	37	19.8	0.30E-1
19	45	3.95	38	19.8	15.12

Table 1. Co-ordinates of the rotor blade

Dimensions of blade:

Base of the blade: 49*27mm.
Height of the base: 5mm.
Flange of the blade: Length=26.5mm
Breadth=5mm
Width=27mm.
Web: 3.8mm.

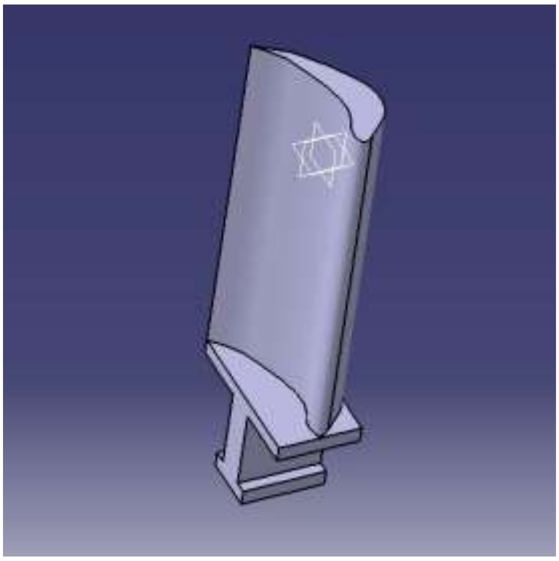

Figure 3. Isometric view of rotor blade

2.1 Modelling of Untwisted blade

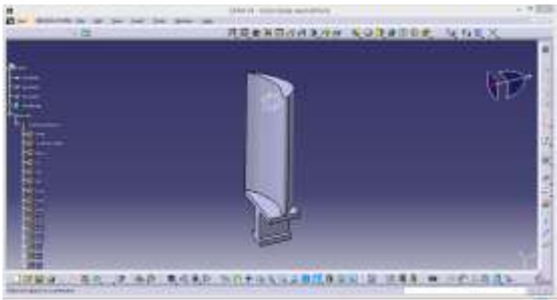

Figure 4. Rotor blade

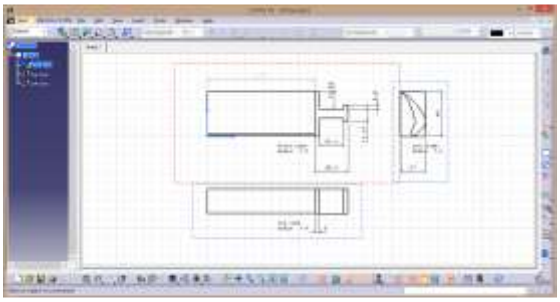

Figure 5. Drafting view

2.2 Design of 4 degree pre-twisted blade

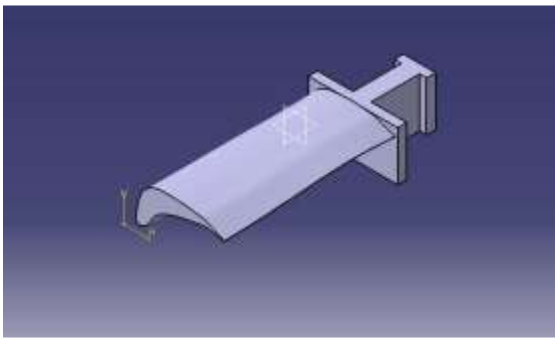

Figure 6. 4 degree pre-twist blade

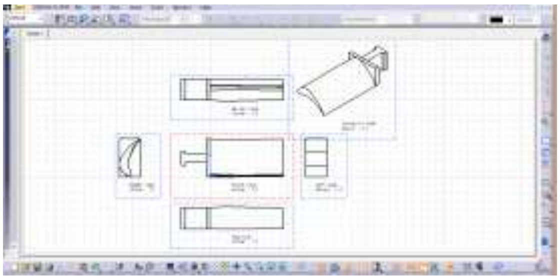

Figure7. Drafting view of 4 degree pre-twist blade

2.3 Design of 6 degree pre-twist blade

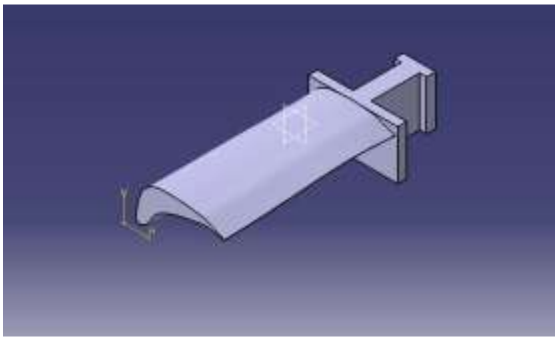

Figure 8. 6 degree pre-twist blade

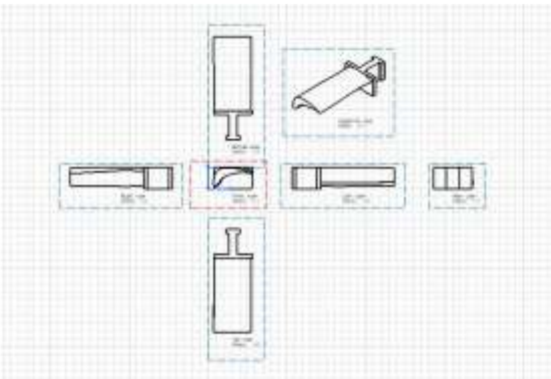

Figure 9. Drafting view of 6 degree pre-twist blade

III. ANALYSIS[1], [6]

3.1 Analysis of untwisted rotor blade

According to our problem statement, we wanted to see the deformation of an untwisted Blade under static structural analysis.

The material chosen for analysis are titanium alloy and Aluminium 2024 alloy. The material properties are:
Properties Units Titanium alloy Aluminium 2024
Alloy

Properties	Units	Titanium alloy	Aluminum 2024 alloy
Density	kg/m3	4700	2725
Modulus of elasticity (E)	GPa	205	73
Poisson ratio(μ)	-	0.33	0.33
Ultimate tensile strength	MPa	1000	470

Table 2. Properties of alloys

The steps involved in CFD analysis process are:
1. Problem statement.
2. Mesh generation.
3. Iterative solver.
4. Post processor.
5. Verification and validation.

3.1.1 Mesh generation:

We have generated a tetrahedron mesh because tetrahedrons fit into the curvatures of blade and do not fail at the nodes. Instead of using the patch conforming method, we used patch independent method, where minimum size of the element and maximum size of the element can be defined. By doing so, smaller elements can be generated on the curvatures wherein they fit properly. The minimum size of an element defined was set as 2.5 mm and maximum at 3.5 mm .The following mesh is generated as shown in the figures.

Statistics	
Nodes	85099
Elements	56994
Mesh Metric	None

Table 3. Number of nodes and elements

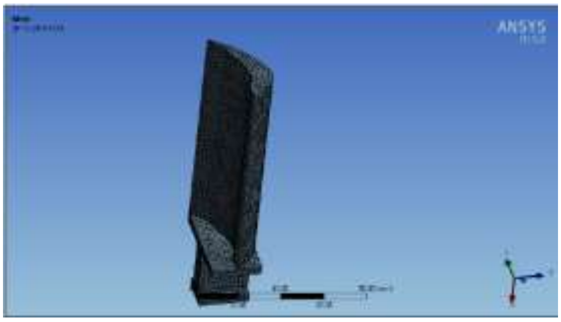

Figure 10. Tetrahedral Mesh on Rotor blade

The forces and power developed in the first stage rotor blades were evaluated using the equations that were used for first stage rotor blades.

The forces are as follows:

1. Axial force of magnitude 3.82N.
2. Centrifugal force of magnitude 38039N.
3. Tangential force of magnitude 248.2N.

3.1.2 Point of application of force:

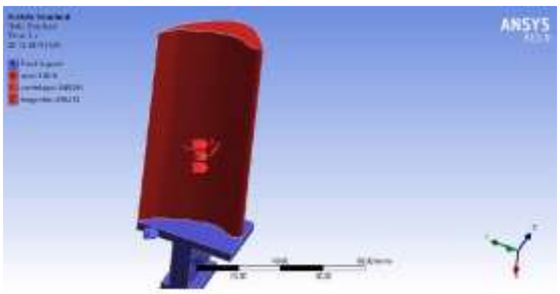

Figure 11. Point of application of force

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A fixed support is provided on the base of the blade, as that portion will remain fixed.

The blade is a cantilever type, where the centrifugal force dominates.

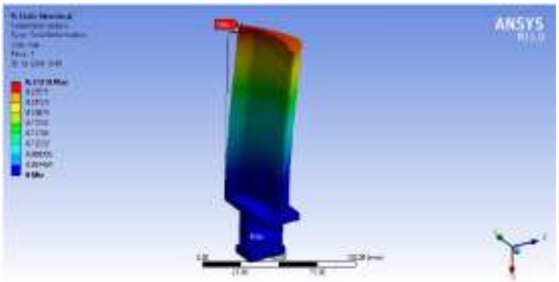


Figure 12. Titanium alloy deformation

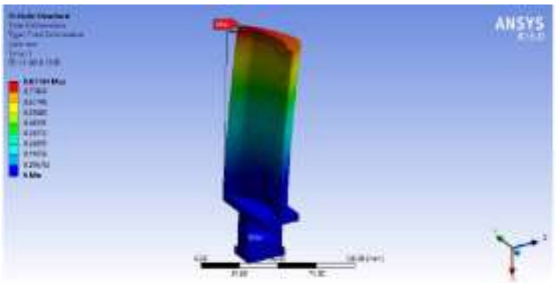


Figure 13. Aluminium 2024 alloy deformation

Titanium Alloy	0.310mm
Aluminium 2024 Alloy	0.8710mm

Table 4. Analysis result

3.1.3 Analysis for 4 degree twist

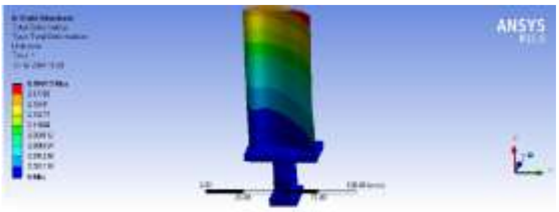


Figure 14. Deformation on 4 degree pre-twist blade

3.1.4 6 degree pre-twist

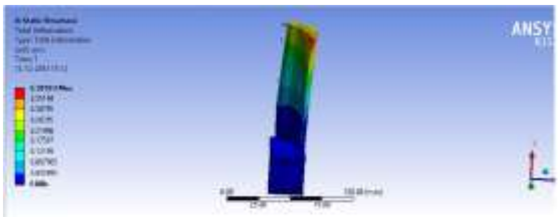


FIGURE 15. Deformation of 6 degree pre-twist

IV. RESULT AND DISCUSSION.

4.1 Result for untwisted blade:

Sr.no	Material	Computational results	Research paper results	Difference
1	Titanium alloy	0.31018 mm	0.352754 mm	12%
2	Aluminum 2024 alloy	0.87104 mm	0.987052 mm	11%

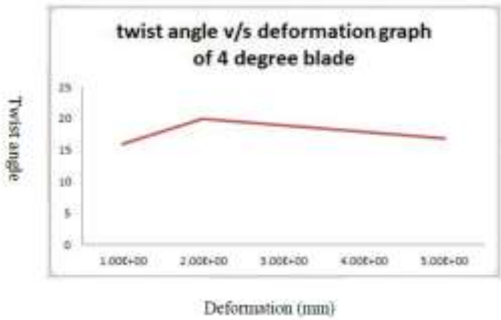
Table 5. Results of untwisted blade

4.2 Result and validation for twisted blade:

Twist angle	Material	Computational results
4 degree	Titanium alloy	0.19915 mm
6 degree	Titanium alloy	0.39593mm

Table 6. Result and validation for twisted blade

4.2.1 4 degree blade:



Inlet angle: 15.93 degree.

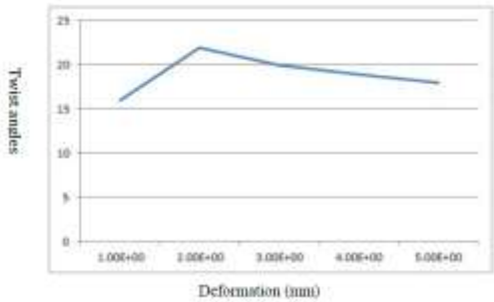
At plane 2, an increment of 4 degree is done as 15.93+4=19.93deg.

At plane 3, 19.93-1=18.93deg.

At plane 4, 18.93-1=17.93deg.

At plane 5, 17.93-1=16.93 deg.

4.2.2 6 degree blade:



Inlet angle: 15.93 degree.

At plane 2, an increment of 6 degree is done as 15.93+6=21.93deg.

At plane 3, 21.93-1=20.93deg.

At plane 4, 20.93-1=19.93deg.

At plane 5, 19.93-1=18.93 deg.

VI. CONCLUSIONS

Aft carrying out the procedure for the design and analysis of the rotor blade it was observed that for untwisted blade deformation was found to be 0.310mm for titanium alloy and 0.875mm for aluminium alloy 2024, from the above obtained results it can be concluded that titanium alloy can preferred over aluminium 2024 as it offers much less deformation when it is exposed to axial, centrifugal and tangential forces.

Next, the blade was given a twist of 4 and 6 degree respectively. The results were then validated with the results obtained from untwisted blade. In the twisted blade titanium alloy was used as the solo material. After carrying out the design and analysis of the twisted rotor blade it was found that 4 degree rotor blade had deformation of 0.13mm while the 6 degree had 0.39mm deformation. From the above obtained results it can be concluded that giving the rotor blade a 4 degree twist reduces the deformation while the 6 degree twist increases the deformation. Hence a minimum deformation has to be given to the rotor blades as a pre twist.

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