DESIGN AND ANALYSIS OF PROPELLER TURBINE

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Abstract - *This project deals with design and analysis for the Optimization of Propeller with the proper application. The diameter of the propeller is restricted below 500 mm Maximum velocity of air passing through the propeller of 30m/s. the propeller will be made by aluminium alloy and Carbon Fibre to make it light weight and to increase the efficiency of turbo jet engine. A 30 bladed 340 mm diameter with fixed speed and fixed pitch propeller. The design and analysis were carried out. Blade elements theory will be used for designing the propeller. The blade span is divided into number of cross-sectional elements and for each element thrust generated and torque required. Tools like FLUENT are used to characterize the air foil in 2D environment and also its thrust, power, velocity and bending stress is evaluated using FLUENT in 3D environment. the overall analysis was carried out using ANSYS program in view of its thin profile and to have good accuracy. initially the propeller was designed in SOLIDWORKS 2019 using aluminium alloy material and the same material is used to evaluate the static stress (FLUENT) and wind tunnel test (CFD) and the results will be compared with the maximum stress like tensile and bending stress etc.*

Key Words: **Propeller design, propeller analysis, propeller efficiency, Blade element theory, static stress, Figure of merits.**

1. INTRODUCTION

This paper presents the results of computational study of Jet Engine Propellers in uniform flow conditions. Results are submitted to institute of industrial design and the performance are verified.

Propeller aerodynamic studies are performed by ANSYS code. This software is based on boundary element methodology (BEM) for the analysis of viscid fluid flows around the bodies in arbitrary motions with respect to air at rest. The computational model developed by SOLIDWORKS software and being analysed with commercial code for CFD and structural analysis using ANSYS. Description of the theoretical and computational methodology and examples of validation studies are given in Larrabee (1979a) and (Duelley, 2010).

According to initial propeller design concept and propeller momentum theory. The applicability of this particular method of propeller design to high altitude flight was then

investigated along with the simplifying assumptions and an initial concept propeller was designed and the blade is made with different element to possess light weight, high durable and high corrosion resistance. The operating point conditions along the blade length were determined and the choice of blade aerofoil section is made.

Having demonstrated that Duelley and Larrabee design method is capable of producing a propeller that performs satisfactorily over the mission with which the analysis method is capable of predicting its performance.

The expected performance of the propeller is then compared with the properties of the graded aluminium alloy from the data MIL HDBK-5k, page 3-277 and the property of Carbon Fibre from the data ASME BPV code, Section 8, Division 2, Table 5-110.

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2. INITIAL PROPELLER DESIGN

The optimal design of a propeller is to perform over such a large range of altitudes and power settings cannot be accomplished in a single iteration. The design requirements need to be analysed and an a priori design completed to determine the local flow conditions on the propeller blade. Based on these results, a candidate aerofoil must be chosen for the conditions.

2.1 Propeller Design Requirements Specification

Typical propeller design requirements focus on maximising the performance of the engine. The requirements define the required propulsive power over the various phases of its mission. In this case satisfying the requirement to fly over a large range of altitudes requires a

thorough knowledge of the relevant atmospheric characteristics from sea level up to 10 000 m.

Other constraints on the propeller design solution space are imposed by the geometry of the airframe. In this particular case a multiple air foil configuration limits the maximum diameter of the propeller. There are additional requirements of high Mach number and low Reynolds number performance demanded of the blade sections. These require an initial investigation into the feasibility before the detail design can be initiated.

As the focus of this work is on the capabilities of the propeller design and analysis methods little effort is applied to the CFD and STATIC properties of the propeller blade.

2.2 Jet Engine Description

The jet engine description is summarised in Figure 5.1 into four flight phases. These are:

- Assisted acceleration from standstill at sea level to an airspeed of 30 m/s. This is 1.3 times the predicted stall speed of 23.08 m/s – a typical speed for the climb phase.

- Climb to a cruise altitude of 10 000 m at maximum climb rate to minimise light time in commercial airspace. A minimum climb rate of 5m/s at sea level and 1 m/s at 10 000 m must be attained.

- Cruise at 10 000 m altitude for maximum range on an "out-and-return" course
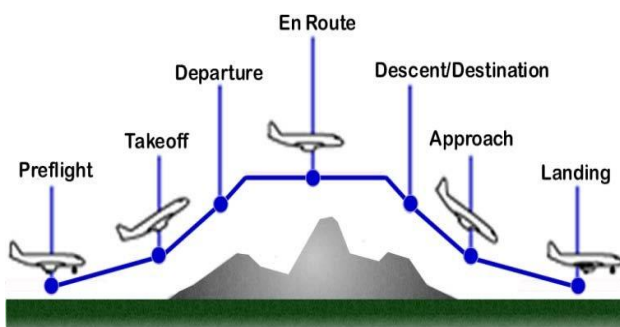
- Descend, approach and land

Fig -1: Travel Profile

2.3 Propeller Design Constraints

When designing a propeller for a required mission performance for a given airframe, the airframe geometry and power plant choice also place constraints on the design of the propeller.

The engine consisted of a 30-air foil section, 340 mm span wing and rear mounted turbine driving a propeller between the booms. A non-folding 30-blade propeller was chosen.

Large propeller diameters typically result in relatively high blade root structural loads. The structural requirements of the propeller blades normally calculated as part of the design process; do not form a formal part of this study whose focus is on the investigation into the use of Larrabee's methods although mention will be made later of the propeller's structural feasibility.

2.4 Initial Propeller Design

Larrabee's design method requires as input variables propeller diameter, velocity, root and tip aerofoil design coefficients and air density. Some of these variables are fixed by the design of the engine (propeller diameter) and some are varied in the design process. The design engine power, altitude and velocity input variables are not fixed by the airframe power plant maximum power, final operational altitude or velocity but intermediate values will be evaluated in order to produce a propeller capable of operating optimally over the run.

Pressure	417 Pa
radius	170 mm
velocity	30m/s
altitude	10 000m
No. of blade	30
Pitch diameter ratio	1:1

Table -1: Propeller Design Input

2.5 Aerofoil Analysis

Due to the high altitude operation of the propeller design the aerofoils should operate at a relatively low Reynolds Number and high Mach number. These air foil should also withstand the different types of force acting on it to avoid failure. The analysis must be applied over different material with maximum velocity conditions. This will be looked at in more detail in the following.

2.6 Choice of Materials

Having chosen the diameter of the propeller the next consideration was the selection of material: aluminium alloy and structural steel. By comparing the properties of the two materials aluminium alloy is preferred over structural steel properties that make aluminium popular and/or suitable include:

- Light & Strong

- High strength-to-weight ratio

- Ductile at low temperatures

- Corrosion resistant

- Non-toxic

- Heat conducting

- Non-magnetic

Aluminium is approximately 1/3 the weight of iron, steel, copper or brass. Reduction in shipping and handling costs.

1 cubic m aluminium = 2,700kg
1 cubic m steel = 7,800kg

By appropriate alloying and treatment, aluminium alloys are available in a variety of strengths. Some aluminium alloys have strength as high as 300 MPa and are stronger than some steels. Strength may be selected to match product needs.
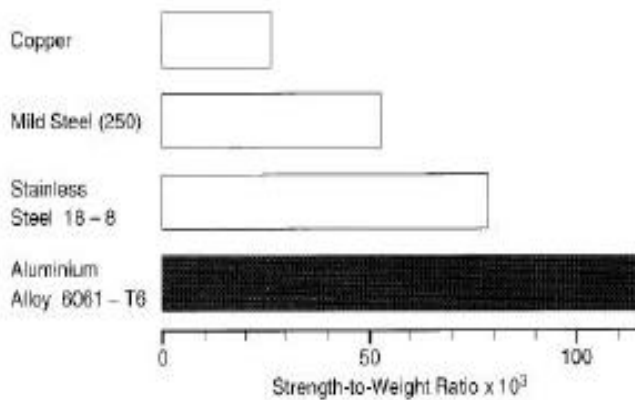

Fig -2: Material Comparison

Brittle fracture problems do not occur with aluminium. As the temperature is reduced, aluminium alloys increase in strength without loss in quality, making them particularly suitable for low temperature applications.

3. DESIGN OF AIRCRAFT PROPELLER

The Propeller consisted of a 30-air foil section, 340 mm span wing and rear mounted turbine driving a propeller between the booms. A non-folding 30-blade propeller was chosen.

3.1 Modelling of Aircraft Propeller Using CAD System

There are some good reasons for using a CAD system to support the mechanical design function:

- To increase in the productivity.
- To get better the quality of the mechanical design.
- To uniform design standards. To create a manufacturing data base.
- To remove inaccuracies due to hand-copying of drawings and irregularity between Drawings.

It is a document that includes the specifications for a part's production. Generally, the part drawings are drawn to have a clear idea of the model to be produced. The part drawing of the entire frame is drawn with all the views in SOLIDWORKS 2019 The components that are generated in

part module are imported to assembly module and by using 'Mate components' command and all these components are mated together to form the required assembly. The different views of assembly and the drawing generated in SOLIDWORKS 2019 are as shown below.
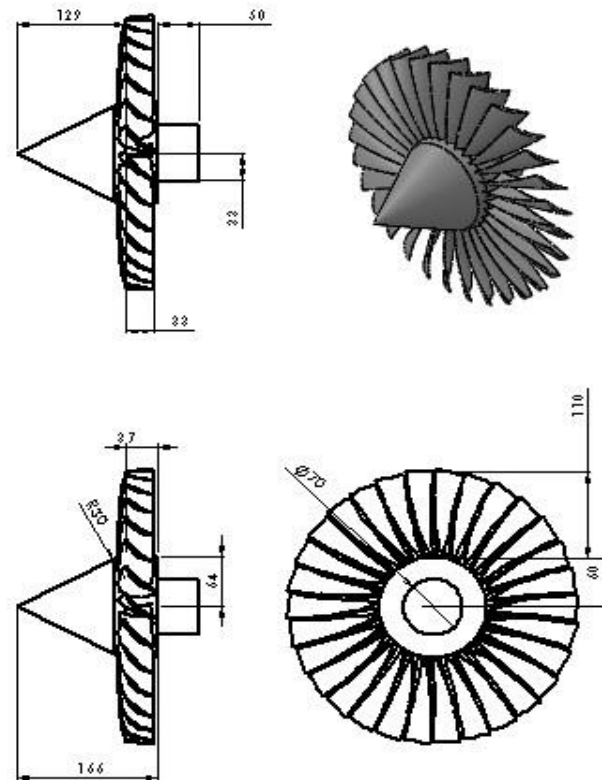
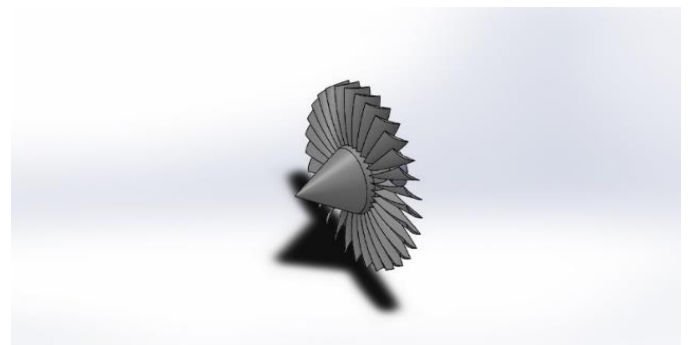**All dimensions are in mm**

Fig -3: Drawing Model

Fig -4: Isometric View

Table -2: Property of General Aluminium

MIL HDBK 0 – 5H

Property	Value	Unit
Density	2770	Kg/m3
Coefficient of thermal expansion	2.3E-5	(°C)-1
Poison's ratio	0.3	-
Young's modulus	7.1E10	Pa
Bulk modulus	6.9E10	Pa
Shear modulus	2.6E10	Pa
Tensile yield strength	2.8E8	Pa
Compressive yield strength	2.8E8	Pa
Ultimate tensile strength	3.1E8	Pa
Ultimate compressive strength	0	Pa

Table -3: Property of Carbon Fibre

ASME BPV code, Section 8, Division 2, Table 5-110

Property	Value	Unit
Density	1550	Kg/m3
Coefficient of thermal expansion	1.2E-5	(°C)-1
Poison's ratio	0.28	-
Young's modulus	2.5E11	Pa
Bulk modulus	1.8939E11	Pa
Shear modulus	9.76E10	Pa
Tensile yield strength	2.5E8	Pa
Compressive yield strength	2.5E8	Pa
Ultimate tensile strength	4.4E8	Pa
Ultimate compressive strength	0	Pa

4. CFD ANALYSIS

Three dimensional CFD analyses was carried out using commercial CFD code FLUENT on this propeller for different free stream velocities from 2m/s to 30m/s with different

conditions. Figure shows the axial velocity contour obtain from Fluent near the propeller. Thus, BEMT and CFD were in good arrangement at operating conditions.
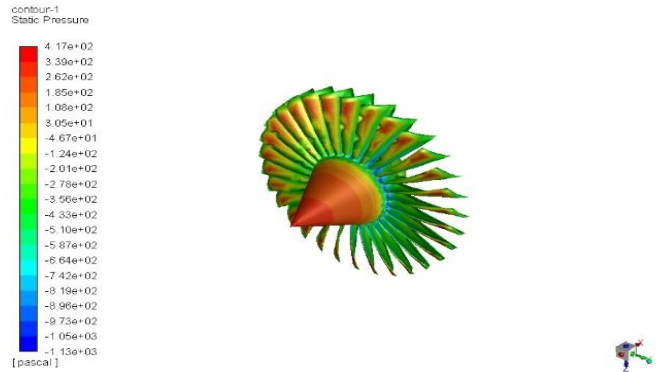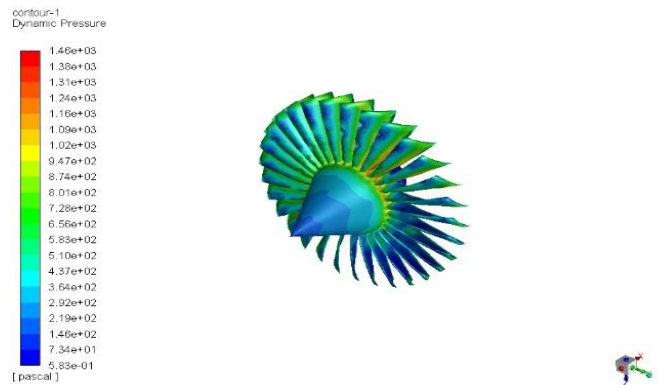

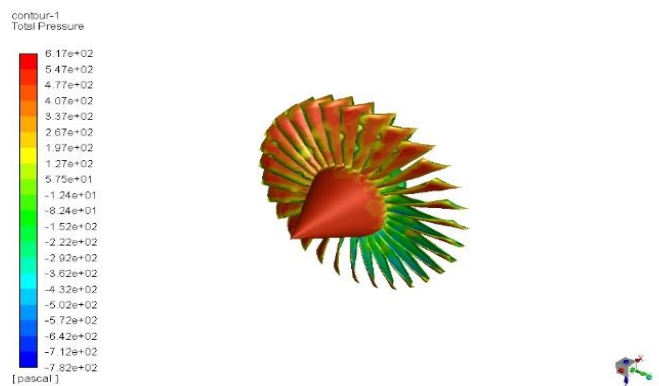**Fig -4**: Static Pressure Analysis

Fig -5: Dynamic Pressure Analysis

Fig -6: Total Pressure Analysis

CFD Data Input

1. Data   -   Solution
2. Geometry   -   Enclosed type
3. Shape   -   Cylinder
4. Coordinate alignment   -   X-axis
5. No. of planes   -   0
6. No. of Body   -   1
7. No. of Faces   -   105
8. No. of Edges   -   296
9. No. of vertices   -   195
10. Mesh type   -   Tetrahedral
11. Physics preference   -   CFD
12. Solver Preference   -   Fluent

5. STATIC STRUCTURAL ANALYSIS

Structural analysis was carried out with ANSYS code. A detail stress analysis was carried out with aluminium alloy MIL HDBK 0 – 5H material and Carbon Fibre ASME BPV code S8-D2 material for propeller using Mechanical package to ensure structural integrity. **Fig 7.5** shows finite element model of the propeller and its cross section for clarity. Static non-linear analysis was carried out at the wind velocity of 30m/s, material data, boundary conditions, thrust distribution and velocity were inputs. Analysis shows the bending stress and Von mises stress are of order 3.2987E-2 Pa and ultimate value of 6.8192E5 Pa for Aluminium alloy and Von mises stress are of order 3.3042E-2 Pa and ultimate value of 6.8269E5 Pa for Carbon Fibre. **Fig 7.8** and **Fig 7.9** shows the bending stress of the propeller.
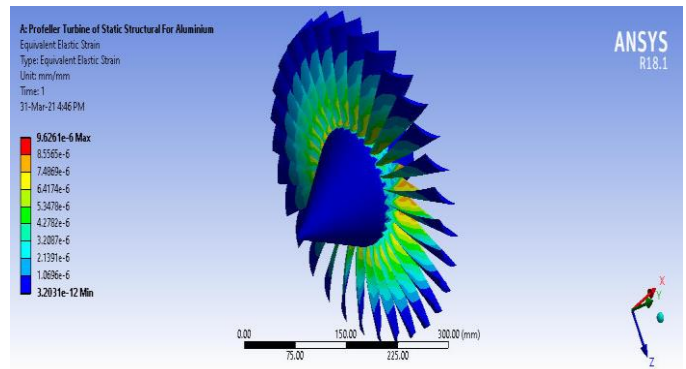

Fig -8: Equivalent Elastic Strain of the Propeller (Al Alloy)
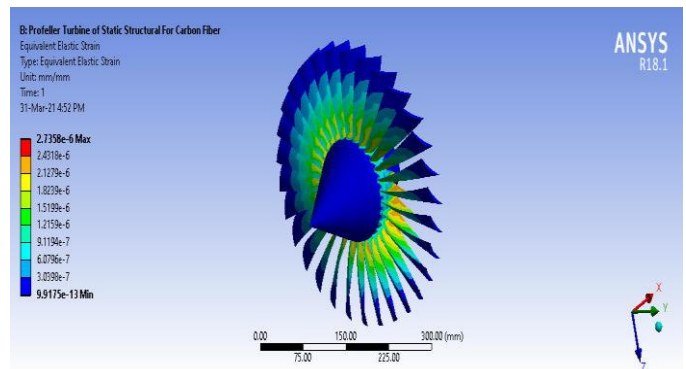

Fig -9: Equivalent Elastic Strain of the Propeller
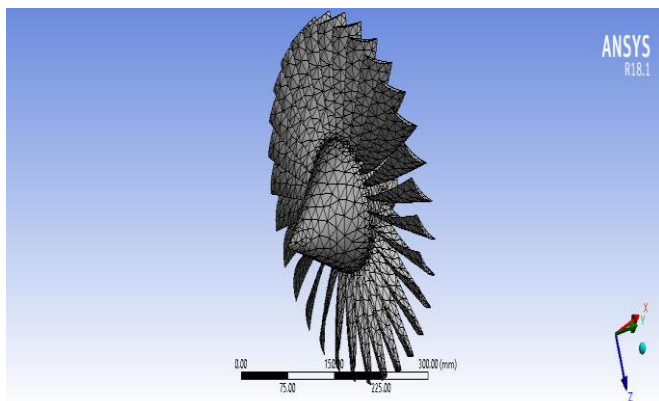
(Carbon Fibre)

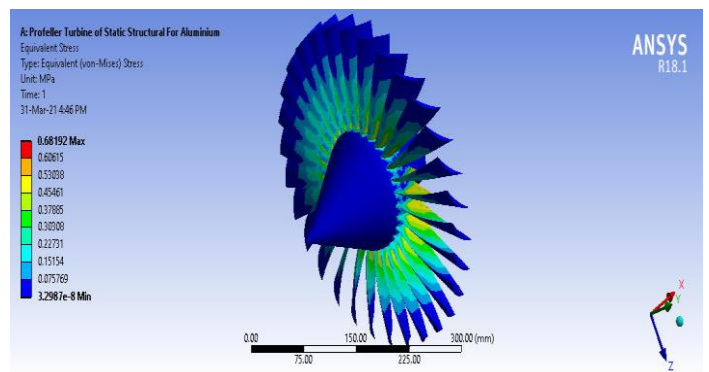**Fig -7**: Finite Element Model of the Propeller

Fig -10: Equivalent Elastic Stress of the Propeller
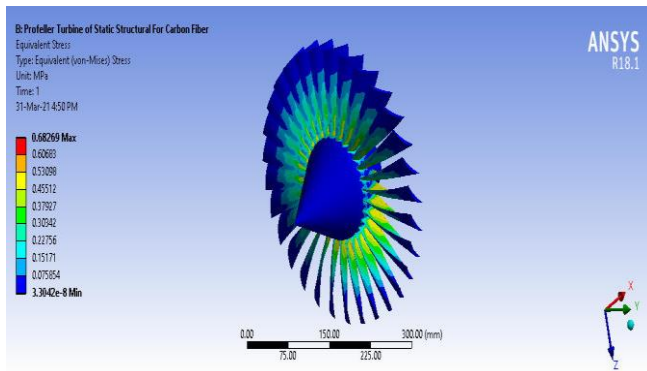
(Al Alloy)

Fig -11: Equivalent Elastic Stress of the Propeller
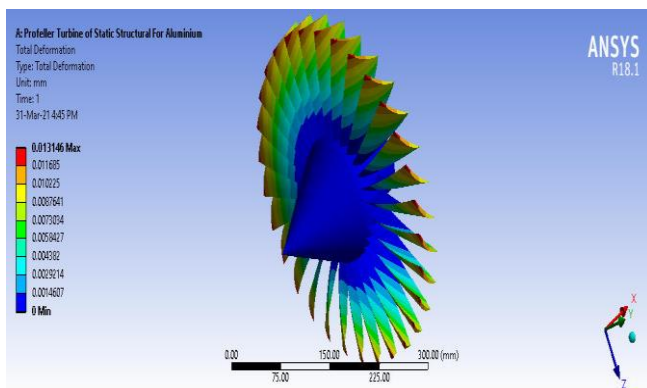(Carbon Fibre)

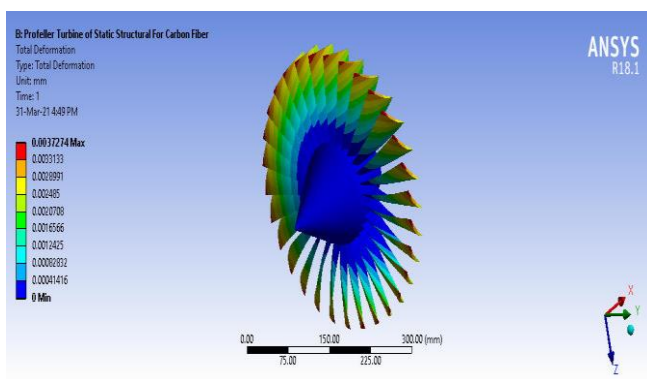**Fig -12**: Total deformation obtain from Stress Analysis
(Al Alloy)

Fig -13: Total deformation obtain from Stress Analysis
(Carbon Fibre)

Static Stress Data Input

Temperature	-	22°c
Support	-	Fixed
No. of Blades	-	30
No. of planes	-	0
No. of Body	-	1
No. of Faces	-	106
No. of Edges	-	300
No. of vertices	-	199
Mesh type	-	Tetrahedral
Nodes	-	24792
Element	-	12167
Physics preference	-	Static structural
Solver Preference	-	Mechanical
Pressure	-	417 Pa (rammed)
Material A	-	Al Alloy
Material B	-	Carbon Fibre

6. NUMERICAL RESULTS

Two different materials T6 Aluminium Alloy 6061. MIL HDBK 0 – 5H and Carbon Fibre ASME BPV code, Section 8, Division 2, Table 5-110 are analysed by ANSYS with initial design is made using SOLIDWORKS 2019. A series of air foil along with the hub is designed in solid part model and as aligned together as a single entity using assembly section.

A 30 bladed air foil is designed so that equal amount of force act on the blades. The solid assembly file is then converted to .STEP file and the propeller is tested for CFD and STATIC structural strength according to the ASTM standards and maximum stress acting on the materials were also studied. The experimental results with suitable graphs and tables for tensile, flexural properties are reported and discussed.

3.1 CFD and Static Analysis Results

A series of air foils is designed together as a propeller by SOLIDWORKS 2019 as assembly. Then, it is converted to into STEP file.

2-Dimensional and 3-Dimensional Analysis was carried out using commercial CFD code Fluent.

Different free stream velocities from 2m/s to 30m/s with different conditions:

1. Static pressure analysis
2. Dynamic pressure analysis
3. Total pressure analysis

Page 5 shows the CFD DATA INPUTS for the propeller. An outer body is created as hallow cylindrical surface to give it as wind tunnel effect and a series of air stream is allowed to pass through the propeller to find the pressure acting on the propeller with different conditions.
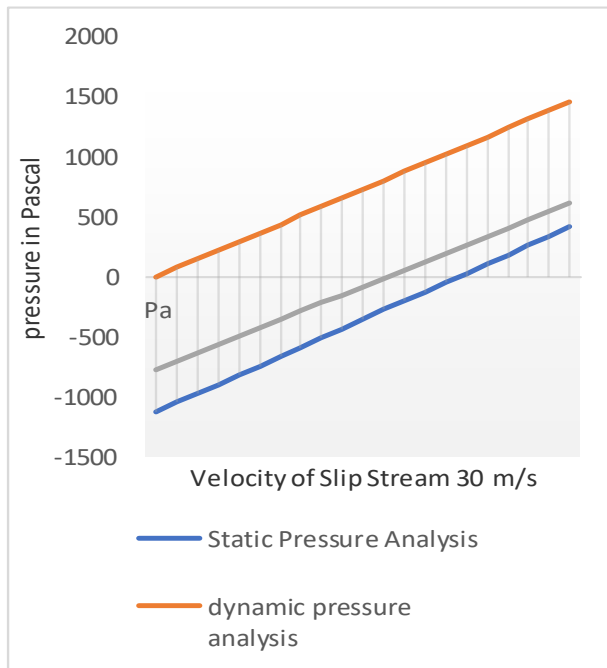

Fig -13: CFD Result

Table 7.2 shows the CFD analysis test results for the propeller. from the Table 7.2 It is found that the pressure acting on the propeller for static pressure is 417 Pa.

Table -4: CFD Output

CONDITION	VALUE	UNIT
Static Pressure	417	Pa
Dynamic Pressure	1460	Pa
Total Pressure	617	Pa

The incoming flow field to the propeller is constrained by the tunnel inlet geometry to almost parallel streamlines as opposed to the converging inflow pattern of a propeller in isolation. The wind tunnel pitot-static probe was designed as cylindrical for the propeller disc. It is possible that the gradient of the velocities induced by the propeller in the wind tunnel could provide a different velocity reading from that through the propeller disc. The horizontal offset in the curves with different velocity, residuals, energy and K-factor with respect to different iterations are given in Fig 14 respectfully.
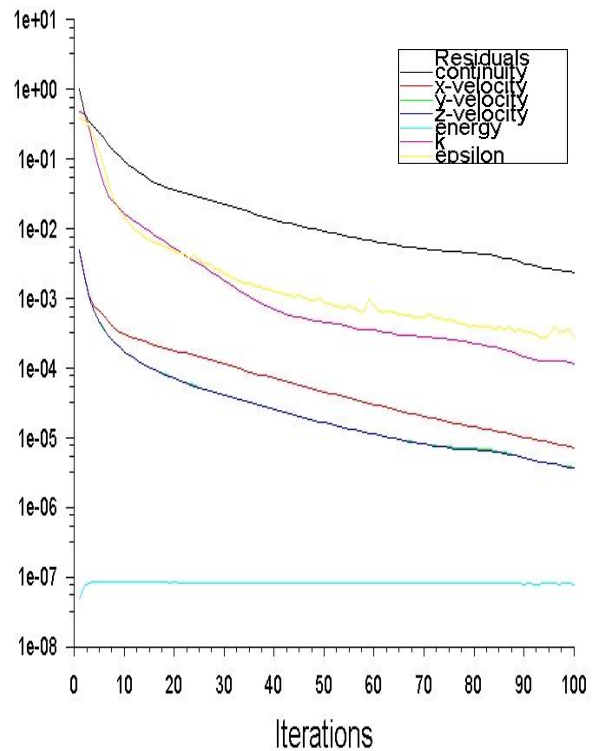

Fig -14: FFF Diagram

Table -5: Static Analysis Output

Material	ANSYS statement	value	unit
Al Alloy	Velocity to given streamline	44.89	m/s
	Equivalent stress (Von Mises)	6.8192E5	Pa
	Equivalent elastic strain	9.626E-6	-
Carbon Fibre	Velocity to given streamline	44.89	m/s
	Equivalent stress (Von Mises)	6.8269E5	Pa
	Equivalent elastic strain	2.736E-6	-

After obtaining the results from CFD the next consideration was the selection of material. A series of different material is compared with the properties with physical and chemical parameters.

After comparing with the properties of aluminium, structural steel, carbon fibre and Aluminium alloy. Carbon fibre used in BPV and T6 aluminium alloy 6061 were selected.

Fig -15: Equivalent stress Comparison

Structural analysis was carried out with ANSYS code. A detail stress analysis was carried out with aluminium alloy MIL HDBK 0 – 5H material and Carbon Fibre ASME BPV code S8-D2 material for propeller using Mechanical package to ensure structural integrity.

Static non-linear analysis was carried out at the wind velocity of 30m/s, material data, boundary conditions and pressure 417 Pa were inputs.

Analysis shows the Von mises stress are of order 3.2987E-2 Pa and ultimate value of 6.8192E5 Pa for Aluminium alloy and Von mises stress are of order 3.3042E-2 Pa and ultimate value of 6.8269E5 Pa for Carbon Fibre.

PROPERTY OF ALUMINIUM ALLOY		
Property	Value	Unit
Tensile yield strength	2.8E8	Pa

PROPERTY OF CARBON FIBRE		
Property	Value	Unit
Tensile yield strength	2.5E8	Pa

By comparing the results of Von Mises stress with yield tensile strength the results obtained from the STATIC analysis is compared with the property table given in table 2 and 3 by comparing the properties, the von mises stress is less than equivalent tensile strength, Hence the design is safe.

After obtaining the results from equivalent elastic stress the next is mechanical test for the given material. A series of different material is compared with the properties. By comparing the results of the two materials Carbon Fibre is preferred over Aluminium alloy. Carbon Fibre has 28.35% of less deformation compared to Aluminium Alloy.
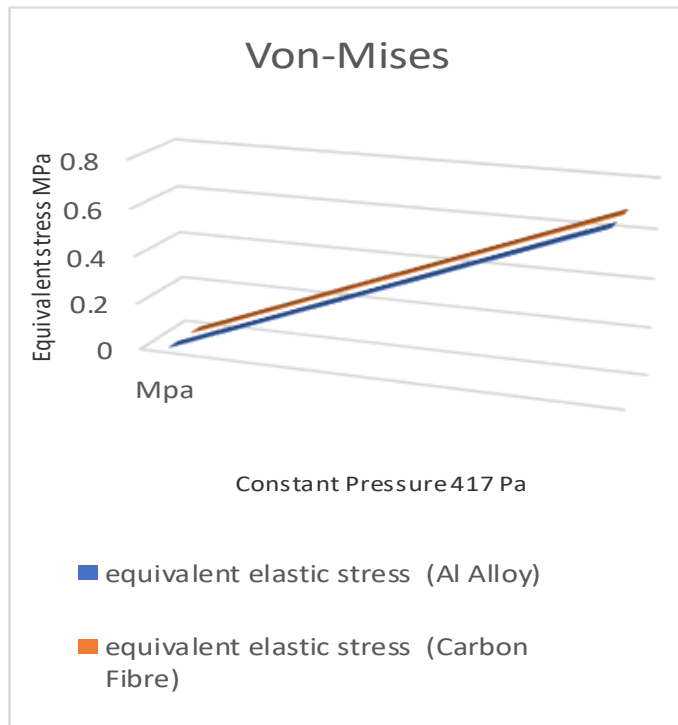
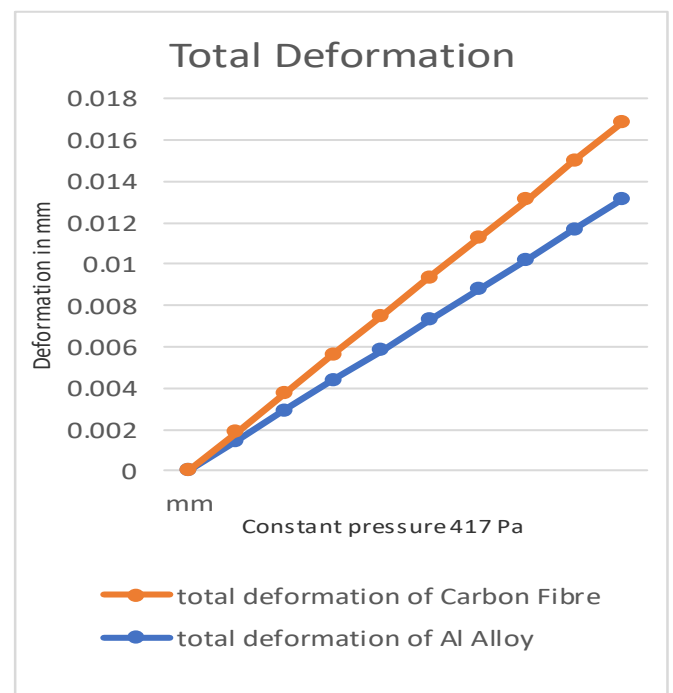| Material	ANSYS statement	value
Al Alloy	Total deformation	1.3146E-5 m
Carbon Fibre	Total deformation	3.7274E-6 m

Fig -16: Total Deformation

Overall carbon fibre has a better strength / mass comparison there are some other aspects that need to be considered, such as thermal resistance, water absorption, oxidation and durability. Carbon fibre compared to aluminium does degrade quicker as the temperature gets hotter. Carbon fibre of top quality with a good sealant resin may not absorb water. Carbon fibre can oxidize and loose strength due to absorption. The oxidation level increases with temperature, and also with chemical contaminants. Aluminium versus carbon fibre is cheaper, but carbon fibre is tensile and not ductile. Aluminium, on the other hand, is ductile, and bends easily.

Aluminium can also be soldered or welded, machined and extruded when compared to carbon fibre, which makes it easier to work with than carbon. Carbon fibre is moulded then baked to create different shapes, and therefore is more expensive. Aluminium is also cost effective and very compromising when compared to carbon, which can be too expensive depending upon its quality. The moulding process of carbon fibre is also slower than the aluminium manufacturing process. Based on the overall consideration both materials has best performance with respect to cost and with respect to production time.

7. CONCLUSION

The jet engine is a fascinating piece of machinery, and though it's basic principles there are many hurdles to overcome to build one of your own design. The propellers coupled with gas turbine together called as Jet engine or turbo Jet engine. Our main vision of this project is To Study the capabilities of a propeller design and analysing the propeller with different material applied to the initial design of the propeller used in jet engine.

An evaluation was carried out by vehicle propulsion design method with different literatures and to design a propeller that was capable of performing efficiently over the range of conditions. Likewise, the accuracy of their analysis method, based on Propeller momentum theory and blade element moment theory was evaluated for the initial propeller design.

A propeller was designed and discussed through different ideas and the blade shape, chord length, twist angle are the basic parameters used to have accuracy in analysis method at predicting performance in design point was carried out through wind tunnel test (CFD) using reduced scale propeller and also the maximum amount of deformation occur in propeller evaluate the static stress (FLUENT).

Structural analysis was carried out with ANSYS code. A detail stress analysis was carried out with aluminium alloy MIL HDBK 0 – 5H material and Carbon Fibre ASME BPV code S8-D2 material for propeller using Commercial Mechanical package to ensure structural integrity.

Analysis of the bending stress and Von mises stress for Aluminium alloy and Carbon Fibre results are obtained from CFD and STATIC analysis for the given material is compared with property table to ensure the safety of the problem. The different stress acting on the propeller with aluminium alloy and carbon fibre is also compared with physical parameters and overall composition. Carbon Fibre had undergone 28.35% of less deformation when compared to Aluminium Alloy.

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