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Modeling and Structural Analysis of Aircraft Wing with Different Materials using FEM

M. Dyuthi Priya, R. Vijaya Prakash, B. Purna Chandra Sekhar

***Abstract:** Aircraft Wing structure consists of skin, ribs and spar sections. The spar carries flight loads and the weight of the wings while on the ground. Other structural and forming members, such as ribs, are attached to the spars with stressed skin. The wings are the most critical components for producing lift in an aircraft. The design of wings may vary according to the type of aircraft and its purpose. Experimental testing of wing structure is a more expensive and time-consuming process. In this project, the detailed design of an aircraft wing structure was created using CATIA V5 R20. Then, a structural analysis of the wing structure is conducted to determine the stresses within it. The stresses are estimated using the finite element approach with the help of ANSYS-14.5 to determine the Stresses, strains, shear stress, and total deformations of the structure using different materials, including Al6061, S2 Glass, and carbon epoxy. This analysis ultimately concludes that the suitable material for the aircraft wing is...*

***Keywords:** Aircraft, Wings, Airfoil*

Abbreviations:
CFD: Computational Fluid Dynamics
UAV: Unmanned Aerial Vehicle

I. INTRODUCTION

Ribs and spars are integral to an aircraft wing's construction, providing support and rigidity to the wing section. Although strength was the primary concern of structural designers during the early stages of creating aeroplanes, they also have to consider fail-safety, fatigue, corrosion, maintainability, inspectability, and productability nowadays. The primary lifting surfaces that sustain the aircraft in flight are the wings, which are airfoils attached to either side of the fuselage. The various manufacturers used a variety of wing designs, sizes, and shapes. Regarding the desired performance of the specific aeroplane, each serves a particular purpose. The top, middle, or bottom of the fuselage can all accommodate the mounting of the wings.

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High-wing, mid-wing, and low-wing configurations are the names given to these designs, respectively.

A monoplane is an aero plane with one pair of wings, while a biplane has two sets. The number of wings can also vary. Many high-wing aircraft include wing struts or external bracing that transfer the landing and flight loads to the main fuselage structure. This style of wing construction is known as a semi-cantilever because the wing struts are often attached around halfway out on the wing. Most low-wing aircraft, as well as a few high-wing aircraft, feature complete cantilever wings that are built to support loads without external support. Semi-monocoque principles are used in the design of contemporary aircraft structures.

A. Wings

Wings are airfoils that produce lift when they are moved quickly through the air. They come in a variety of sizes and forms. Different wing designs might offer specific desirable flight characteristics. As the shape of the wing changes, so do the controls at various operating speeds, the amount of lift produced, balance, and stability. Either the wing's leading and following edges are straight or curved, or one edge is straight while the other is curved. To make the wing smaller at the tip than at the base, where it joins the fuselage, one or both edges may be tapered. Wing tips can be pointy, rounded, or even square. Demonstrates several standard leading and trailing edge forms for wings. An aircraft's wings may be fastened to the fuselage at the top, middle, or bottom. They can extend perpendicular to the fuselage's horizontal plane or at a slight upward or downward slant. The wing dihedral is the term used to describe this angle. The dihedral angle impacts the lateral stability of the aero plane. Illustrates the dihedral angle and various typical wing attach sites.

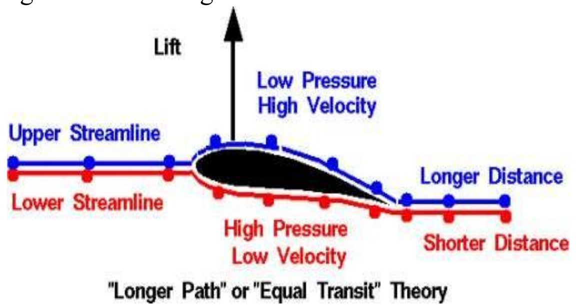
B. Types of Wings

- Non-planar wing or closed wing
- Box wing
- Annular (cylindrical)
- Joined wing
- Annular wing (planar)
- Flat
- Rhomboidal wing

C. Wing Structure

An aircraft's wings are made to propel it into the air. Their specific design for every given aircraft depends on a variety of elements, including size, weight, intended use, desired flying and landing speeds, and desired rate of climb. The left and right sides of the operator's seat in the cockpit correspond to the left and right wings of an aircraft, respectively, as shown in Figure 1.

Wings frequently have a complete cantilever design. This indicates that they are constructed without the need for external reinforcement. Internal structural members that receive assistance from the aircraft's skin support them. Other aircraft wings utilise wires or external struts to enhance wing support, load carrying, and manage aerodynamic and landing loads. The majority of wing support cables and struts are constructed of steel. Fairings are commonly found on struts and the attaching fittings to lessen drag.



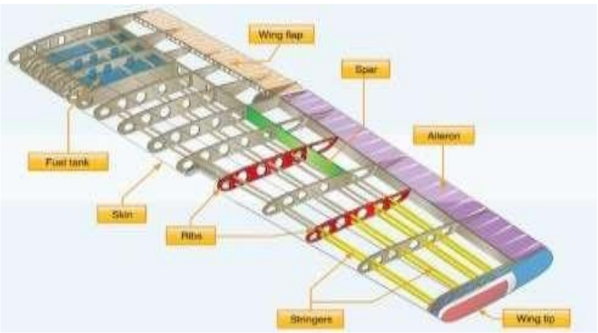
[Fig.1: Forces Acting on Wing Structure]

D. Wing Box [Figure 2]

A wing box is built with stringers and thin skins or webs. The distribution of shear, bending, and torsion loads at any portion of a wing or fuselage is its primary purpose. A rectangular shape with skin Stringer panels on top and bottom, joined by two vertical beams (a single-cell box) or more vertical beams, is a practical description of a wing box (a multiple-cell box). The following properties apply to box beams:

They consist of wide skin-stringer panels, which are subjected to shear flow due to bending moment and torsion.

- The thin skins take little of the axial compression load.
- The thin skin carries shear loads very well, and even though they may buckle under the loads, they do not fail, but continue to have the buckling load, plus significant additional shear loads in level flight; lift is equal to the weight.
- Stringers carry axial loads, and shear flow induces a change in axial load
- The usual cross-section of a wing box is unsymmetrical both in shape and in the distribution of material Resistance from air to the motion.
- Since conventional wing box taper in plan form and section, as well as in area, the effect of taper is accounted for directly.
- It is necessary to compute the principal axes of the beam before the axial stresses can be determined.



[Fig.2: Parts of the Wing on the Side]

E. Wing Configuration

The Spitfire wing may be classified as: "A conventional low-wing cantilever monoplane with unswept elliptical wings of moderate aspect ratio and slight dihedral".

- Various minor surfaces.
- High-lift devices.
- Span-wise flow control device.
- Vortex devices.
- Drag-reduction devices.

II. LITERATURE REVIEW

A. Design of an Airfoil or Airfoil Selection

The design of an airfoil is a complex and time-consuming procedure. The prerequisite for competency is knowledge of aerodynamics. Wind tunnel tests, which are the most expensive, can confirm the aerodynamic characteristics of an airfoil [10]. Large aerospace manufacturing companies, such as Boeing and Airbus, have the resources and expertise to design and create their airfoils. Small aircraft makers, experimental aircraft producers, and homebuilt manufacturers cannot afford to design their airfoils [1]. The best approach for small aircraft manufacturing companies is to choose airfoils based on the standard information found in numerous publications or websites. NACA and Eppler are two common resources for airfoils. Most aircraft designers use NACA guidelines when choosing airfoil sections.

Nguyen Minh Triet *et al [11].* In their paper, they expressed their view on the difficulty of solving aerodynamic problems analytically. Solving aerodynamic difficulties involves significant experimental costs. They therefore selected numerical techniques. They then used a typical NACA 2412 airfoil to model the aircraft wing. They performed computational fluid dynamics (CFD) simulations using ANSYS Fluent to assess the pressure and velocity distribution on the wing surface [3]. Drag and lift forces were estimated using the ANSYS Structural module. Additionally, data collected when the relative inlet velocity between the airflow and airfoil changes from 0 to 50 m/s can be used to compute the coefficients of drag and lift forces [4]. The outcomes of the simulations were compared with those of the theory.

Kakumani Sureka [12] and R. Satya Meher [5] modelled the A300 aircraft wing in their paper. Using the CAD program CATIA V5 R20, the NACA 64215 airfoil with spars and ribs was created. Later, a structural analysis of the wing skeleton was completed using the FEA program ANSYS WORKBENCH. The equivalent stress, deformation, maximum principal stress, stress intensity, and shear stress values of aluminium alloy and aluminium alloy 7068 were found to differ by a minimal amount. The results were verified, and there wasn't much of a difference between the two result values. They concluded that, to provide the structure with additional strength, aluminium alloy 7068 is recommended over aluminium alloy.

Sudhir Reddy Konayapalli [13] and Ysujath discussed the aircraft wing design. It was modelled in the CAD programme CATIA V5 R20 using the standard NACA 4412 airfoil. They used the ANSYS 14.5 programme and imported a CATIA V5 model. They noticed from the fluency analysis that as the angle of attack was increased, the dynamic pressure on the

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leading edge decreased. As the angle of attack increased, the static pressure on the bottom surface also increased. They concluded that an increase in the angle of attack increased static pressure. With an increasing angle of attack, static pressure increased on the lower surface, while dynamic pressure decreased on the lower surface. They concluded that raising the angle of attack resulted in higher dynamic pressure.

Guguloth Kavya *et al. [7] in their study designed and modelled an aircraft wing using* CAD software, Pro/Engineer. The kind of NACA profile employed has not been stated. The addition of ribs and spars altered the wing. Because of their high strength-to-weight ratios, three materials—S-Glass, Kevlar 49, and Boron fibre—were subjected to static analyses on the wing. The wing skeleton underwent a structural study using ANSYS Workbench. They concluded that the wing with ribs and spars experienced less deformation and stress than the original wing. The frequencies were determined by performing a modal analysis on the aeroplane wing. They noticed that while deformations are less common, rates are higher for wings with spars and ribs. They concluded that the shear was the result of a random vibration study.

Lica Flore and Albert Arnau Cubillo [8] provided the outcomes of the dynamic behavior on a plane wing structure. They used strain gauges in their investigation to dynamically determine the vibration parameters of the wing structure. Instead of utilizing accelerometers for vibration testing, researchers used strain gauges. After applying the load, the structure's dynamic behavior was assessed. They concluded that, while not precisely at the excitation point, the accelerometer provided natural frequency values close to it. They observed variations in the results when they used strain gauges to measure the natural frequencies at the point of stimulation [9].

Beulah Saripalli *et al. [1]* This study applied air pressure to two materials—aluminium-carbon fibre and aluminium-aramid fibre—to perform a structural analysis on the wing model created in CATIA V5. They observed that carbon fibre exhibited less deformation and stress than aramid fibre. To estimate the natural frequencies in Hz for the same two materials in the aircraft wing, dynamic analyses were also performed.

T.S. Vinoth Kumar [6] *et al*. They used the CAD program CATIA V5 R20 to create the aero plane wing utilising the standard NACA 64A215 airfoil at the base and NACA 64A210 at the tip. The analysis and preliminary sizing of an aeroplane wing used for pilot training are the primary focus of this study. In addition to calculating the obvious lift-off weight, stress distribution, wing loading, take-off distance, lower-frequency modes of vibration, and stall velocity, the primary goal was to design a suitable structure within the designated envelope. The MSC NASTRAN/PATRAN package and conventional engineering theories were employed to conduct the optimisation. With these assumptions, they optimised the design to meet the stability and strength requirements, taking into account the web and skin as shell elements and the stringer, flange, and spar as beam elements. Then they did the math.

Farrukh Mazhar [2] and Abdul Munem Khan [14] were used as design input, coupled with an implicit CAD model and an aerodynamic computational fluid dynamics study of the wing. FEA ANSYS software was used to analyse the stiffness and strength of the Unmanned Aerial Vehicle (UAV) wing. They were effective in examining the use of computational design tools. They employed a unique technique known as Artificial Neural Networks to apply aerodynamic loads as pressure functions to the wing structure [15]. To select the best practical combination of stiffness, maximum strength, lowest cost, and lightest weight, the effects of material, lay-up, and geometry were also examined. The finished wing consists of two spars, constructed from composite material.

B. Project Overview

i. Have sufficient mechanical strength and stiffness of the integral aircraft wing
ii. Can effectively shape the design of the aircraft wing
iii. Apply the lift and drag forces on the structure
iv. Select a high corrosion resistance material (using a composite)
v. Dimensions as compact as possible, to reduce the weight of the aircraft wing
vi. Finally, select a suitable material for the aircraft wing

C. Objective of the Project

i. Modeling of the aircraft wing using CATIA software
ii. Determination of linear stresses, strains, deformations, shear stresses and deformation using structural analysis, on these materials: Al6061, S2 Glass, AL 2024, carbon epoxy
iii. Meshing of the design model using ANSYS 14.5.
iv. Analysis of the tire by static analysis and modal analysis
v. Determination of frequency and mode shapes using modal analysis.
vi. Identification of a suitable structure on these different materials for the manufacturing of the aircraft structure

III. METHODOLOGY

- Create a 3D model of the wing with ribs and spars assembly using parametric software.
- Convert the surface model into a Part solid file and import the model into ANSYS to do static and modal analysis.
- Perform static analysis and modal analysis on the wing assembly
- Finally concluded the suitable material.

Loads Acting Over the Wing Structure Lift load is regarded as a crucial factor in aircraft design. The two main areas of an aeroplane where lift load is acting are the fuselage and wings. Here, the wings receive 80% of the lift load (i.e., the maximum lift load is applied to the wings), and the fuselage gets the remaining 20% of the lift load. As a result, the maximum load on wings are applied closer to the wing roots—load calculation for the wing

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structure.

- Weight of the aircraft: 14000N
- Design load factor: 6 "g"
- Factor of safety: 1.5
- Therefore, the Total design load on the aircraft will be: 126000 N
- As we mentioned earlier, the total lift load on the aircraft is distributed as 80% and 20%
- on the wing and the fuselage, respectively. Hence, total load acting on the wing = 100800 N
- Therefore, total load acting on each wing = 50400 N
- But we know the resultant load is acting at a distance of 2138 mm (45% of the distance from the wing root).
- Bending stress at root section =89035 N
- ending moment at the root of the wing can be calculated as 189.64.07*106 N mm

A. Input Parameters for Design

- Root chord: 2400 mm
- Tip chord: 2400
- Semi Span length: 5500 mm
- Exposed Span: 4750 mm
- Aircraft weight: 14000 N
- Lift Load: 6g
- Design Factor: 1.5
- Total no. of spars: 15

B. Material Properties [Figure 3]

ALUMINUM 6061-T8, S2 GLASS AND CARBON EPOXY

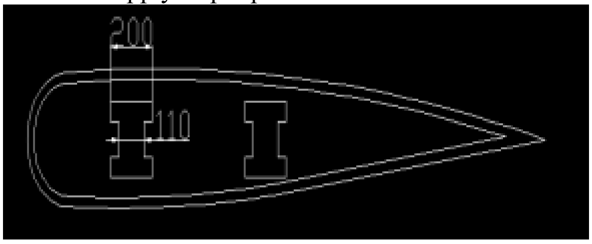
Materials	Density	Young's modulus	Poisson's ratio
Aluminium 6061-t8	2.7g/cc	69.0GPa	0.33
S2 glass	2.46g/cc	70.0GPa	0.28
Carbon epoxy	1.60g/cc	86.9GPa	0.3

[Fig.3: Material Properties]

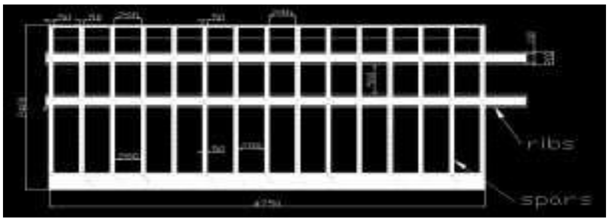
IV. DESIGN PROCEDURE OF AIRCRAFT WING

The process of designing wings is iterative, and various computations or Selections are frequently made. A decrease in the number of iterations is seen as a result of the numerous tools and programmers based on numerical methods and aerodynamics that have been created over the past few decades. In most cases, transport aircraft wings are constructed with two spars. The spar has two ends: a free end located near the wing tip and a root end attached to the wing base, close to the fuselage, as shown in Figures 4 and 5. Any engineering construction that uses cantilever beams will have a configuration remarkably similar to this one. L-angle fittings are used to join the ribs with the spars. The whole wing structure, as modelled in CATIA V5, is shown in Figure 6, along with the location of the spar and ribs as seen from the root of the wing.

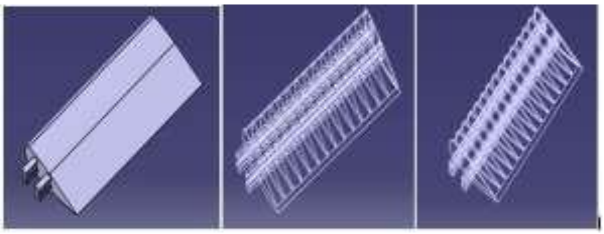
Using the provided dimensions, create the structure in the Sketcher Workbench. Proceed to the part design and then apply pad 4750. Create the I-section apply pad in the Component Design Workbench using the Sketcher workbench. After creating the planes, offset the distance by 280 mm and apply a spar pad of 50 mm.



[Fig.4: Left View of Aircraft Wing]



[Fig.5: Top View of Aircraft Wing]



[Fig.6: Aircraft Isometric View in Catia]

V. INTRODUCTION TO ANSYS

To evaluate a broad range of issues encountered in engineering mechanics, ANSYS is a large-scale multipurpose finite element programmed created and maintained by ANSYS Inc.

A. Basic Steps in FEA

- Discretization of the domain
- Application of Boundary conditions
- Assembling the system equations
- Solution for system equations
- Post-processing the results.

VI. ANALYSIS PROCEDURE IN ANSYS

Designed the component in CATIA Workbench after importing it into ANSYS Workbench. Now, select the steady-state thermal analysis.

i. Engineering materials (material properties).
ii. Create or import geometry.
iii. Model (apply meshing).
iv. Set up (boundary conditions) [Figure 9]
v. Solution
vi. Results

A. Static Structural Analysis [Figure 7]

The static structural analysis determines the stresses, displacements, shear stresses, and forces induced by a load, taking into account minimal damping and inertia effects. It is believed that the loads and the structure's response would

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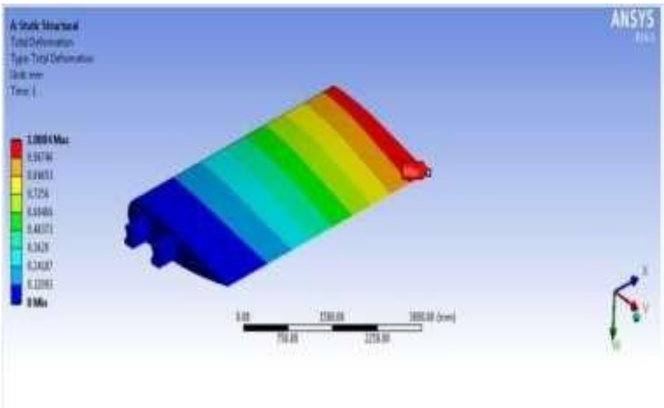
remain stable over time and will only gradually change. The ANSYS WORKBENCH solver can be utilized to simulate a static structural load.

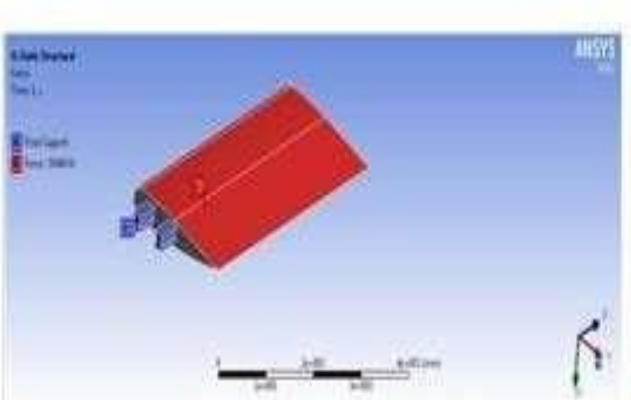
The various types of loading that can be used in a static analysis include, as shown in the following figures, selecting a static structural application, applying material properties in the engineering data, selecting geometry import, and creating a model. apply boundary conditions in setup Apply the lift force of 50400N to the top surface of the wing's fixed spar as indicated in the picture below, then construct a solution after observing the stresses, strains, total deformations, and shear stress.

B. Meshing [Figure 8]



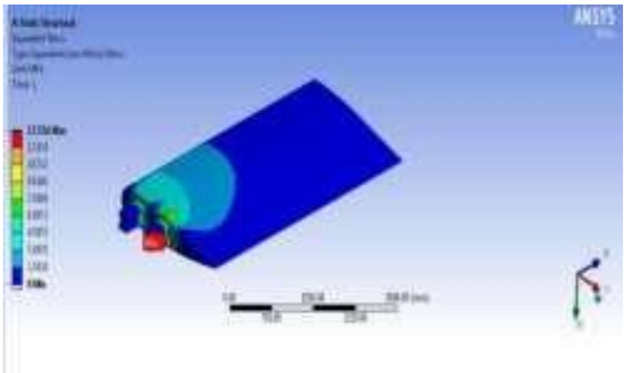
[Fig.7: Strain ON AL6061]

[Fig.8: Mesh Nodes: 321111 Elements 17052]

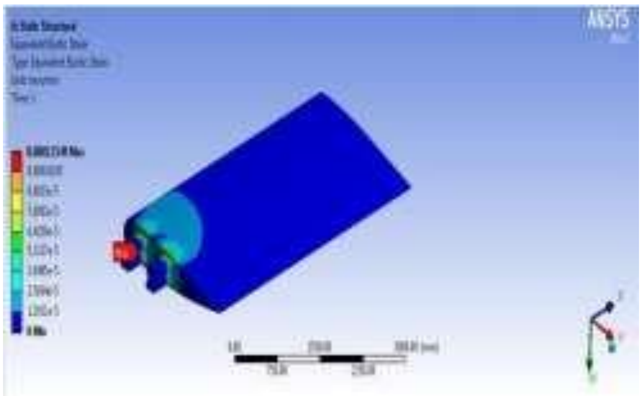


[Fig.9: Boundary Conditions]

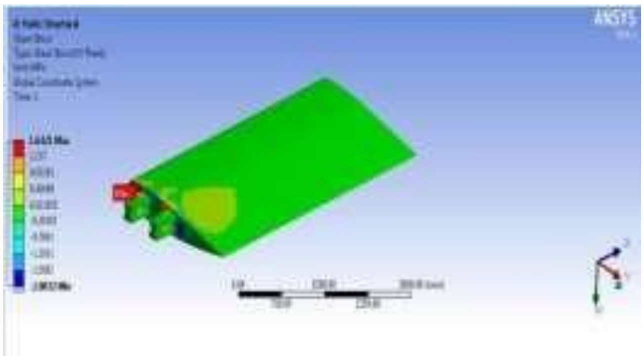
C. Al6061 Material in Static Analsys [Figure 10-12]



[Fig.10: VON-Mises Stress on AL6061]



[Fig.11: Total Deformation on AL6061]



[Fig.12: Shear Stress on AL6061]

VII. MODAL ANALYSIS

The study of the dynamic characteristics of structures under vibration excitation is known as modal analysis. In aircraft, vibration is caused by the lift load and the load from mounting the engine on the wing. The structure's overall mass and stiffness are used in the modal analysis to determine the different periods at which it will naturally resonate. The computation of a structure's inherent frequencies and natural mode shapes could be significant. They reveal the frequencies at which the structure can be energized into resonance. This knowledge is frequently sufficient to change the structural designto lessen noise and vibration. A component's working frequency may cause structural damage or failure if it is close to one of the natural frequencies of the structure; hence, a dynamic interaction between the component and its supporting structure is crucial. Therefore, we continue to examine the wing structure for various frequency modes. The problems mesh parameters

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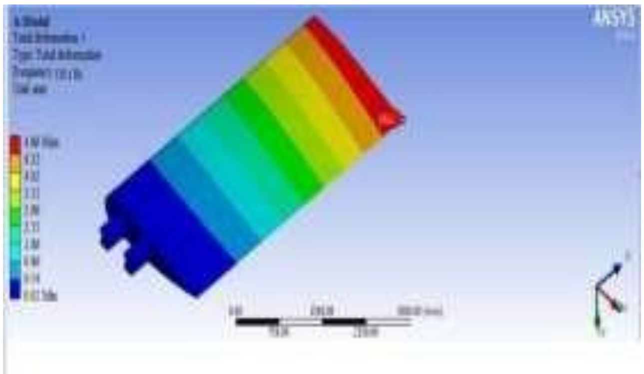
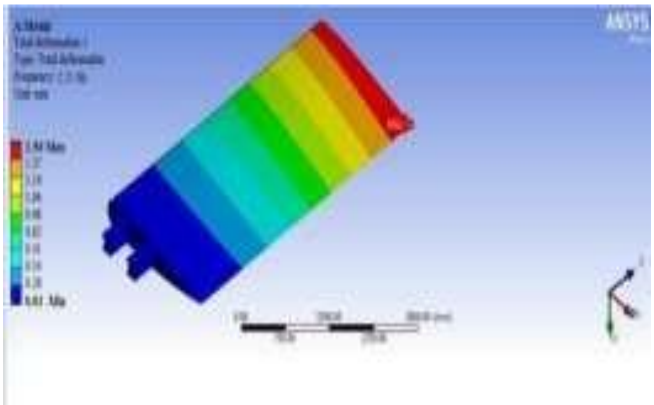
and boundary conditions would be the same as those listed above. To determine the overall deformation under six modes, an analysis was conducted.

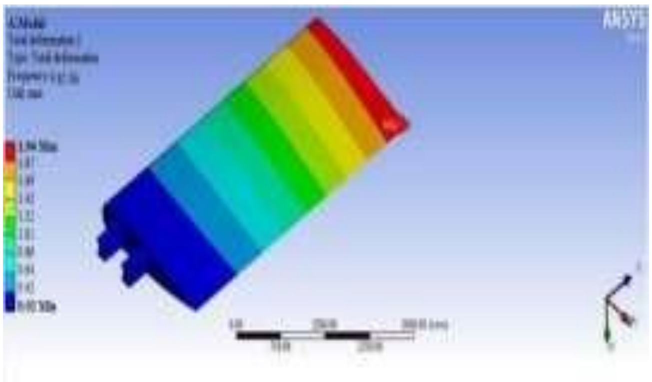
A. Modal Analysis of Al6061 Material [Figure 13- 18]



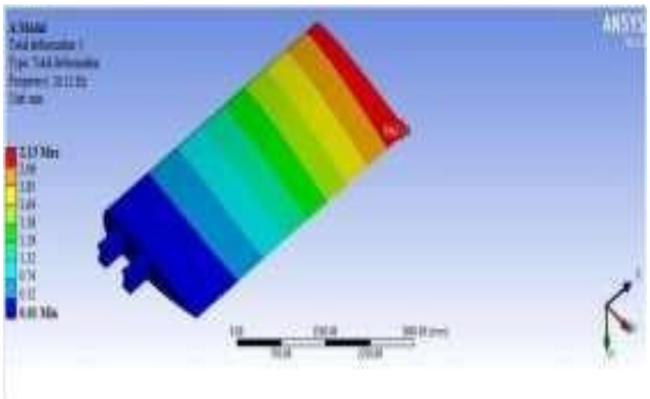
[Fig.13: Mode 1 of AL6061 Material]



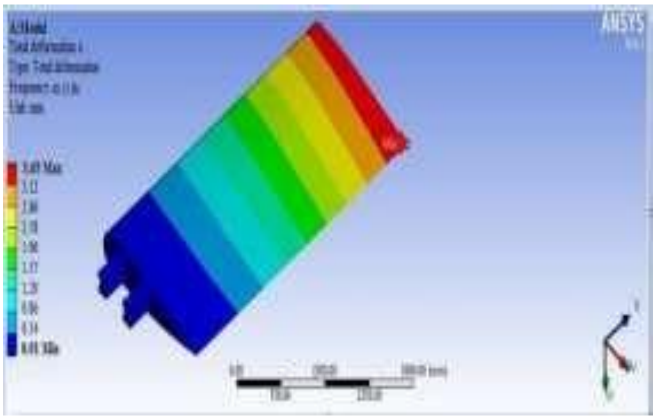
[Fig.14: Mode 2 of AL6061 Material]



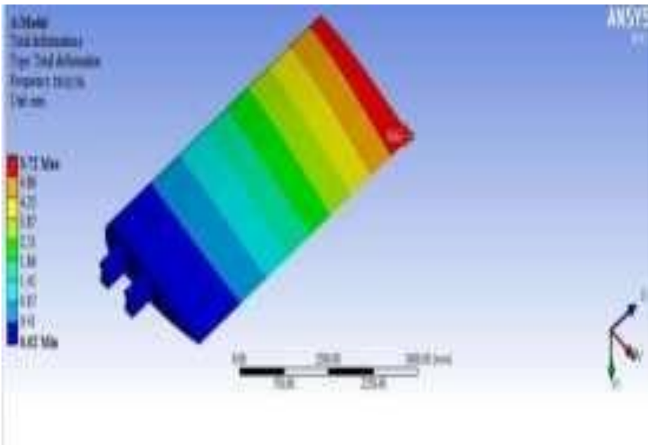
[Fig.15: Mode 3 of AL6061 Material]



[Fig.16: Mode 4 of AL6061 Material]

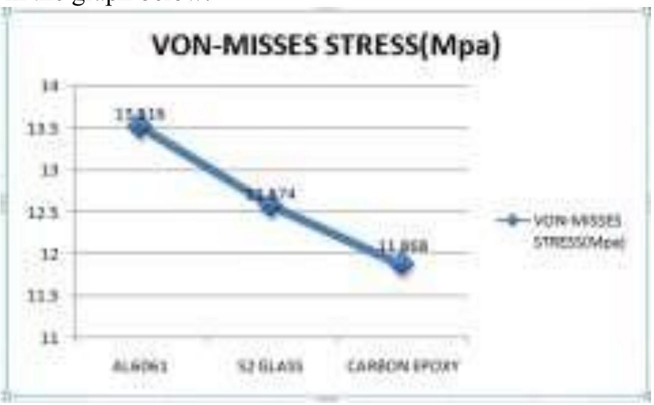


[Fig.17: Mode 5 of AL6061 Material]



[Fig.18: Mode 6 of AL6061 Material]

Static analysis of von Mises stress graph. The graph below shows that, with variation in stresses, three different materials —S2 GLASS, AL6061, and CARBON EPOXY — have the least stress compared to other materials, as shown in the graph below.



[Graph 1: VON-MISSES Stress Graph]

Static analysis total deformation graph. The graph below shows that, with the Variation of Total deformations, three different materials, S2

B. Glass, Al6061, Carbon Epoxy

Materials like carbon epoxy material have the least total deformation compared to other materials, as shown in the graph below.

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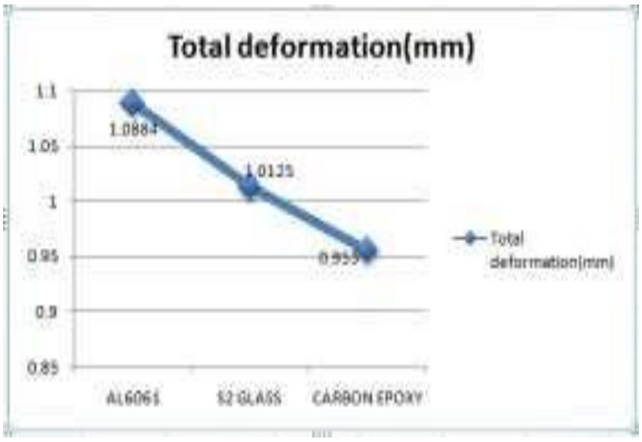
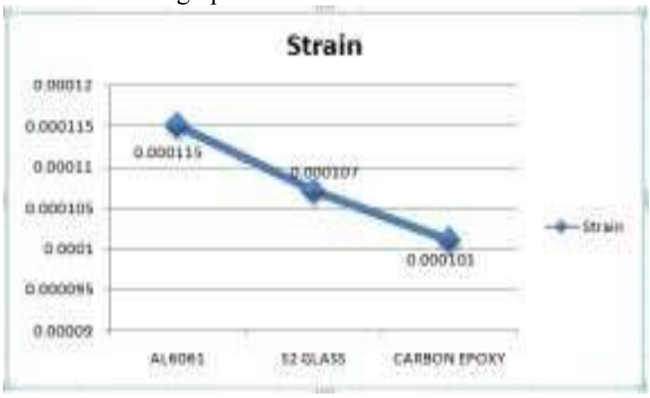


[Graph 2: Total Deformation Graph]

C. Static Analysis Strain Graph

The graph below shows that, with variation in strains, three different materials —S2 GLASS, AL6061, and CARBON EPOXY — have the least strain compared to other materials, as shown in the graph below.



[Graph 3: Strain Graph]

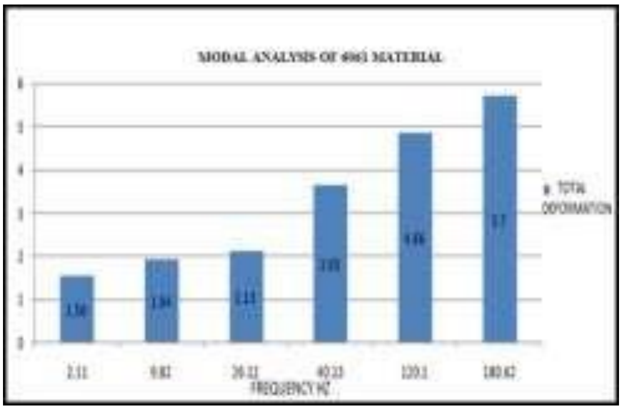
D. Shear Stress Graph

The graph below shows that, with variation in shear stresses, three different materials —S2 GLASS, AL6061, and CARBON EPOXY —have the least shear stress. As shown in the graph, the carbon epoxy material exhibits the lowest shear stress among the other materials.

[Graph 4: Shear Stress Graph]

E. Modal Analysis of Al6061 Material

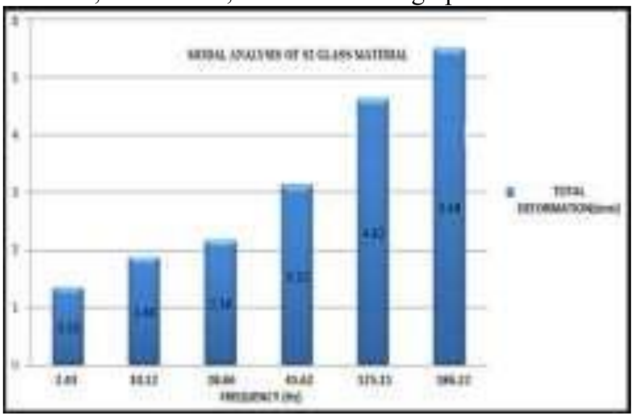
Graph 5 below shows that, with variation in total deformations concerning the different frequencies of these materials, AL6061, as shown in the graph below.



[Graph 5: AL6061 Material Graph]

F. S2 Glass Material

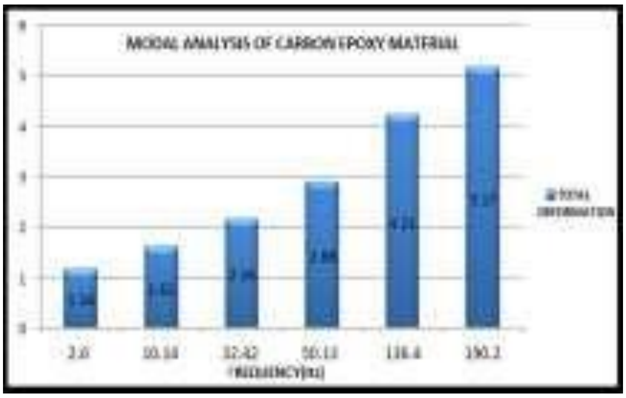
Graph six below shows that, with the Variation of total deformations concerning the different frequencies of these materials, S2 GLASS, as shown in the graph below.



[Graph 6: S2 Glass Material Graph]

G. Carbon Epoxy Material

The graph below illustrates the variation in total deformations for different frequencies of the carbon epoxy material.



[Graph 7: Carbon Epoxy Material Graph]

VIII. CONCLUSION

Modelling, static, and modal analysis have been completed. The design process is conducted in CATIA, and the analysis process is performed in ANSYS. We are using three different materials: S2 Glass and Carbon Epoxy. Presently used material for the Aircraft Wing is Al6061 Material. We have considered

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composites, such as carbon-epoxy materials. By employing a polymeric composite Aircraft wing, the same load-carrying capacity is achieved with a weight reduction. Based on the results, it was inferred that the carbon epoxy composite aircraft wing exhibits superior strength, less deformation, lower strain, and lower Von Mises stress and shear stress, and is lighter in weight compared to AL6061 and S2 glass materials. Therefore, we conclude that it is preferable to use Carbon Epoxy as a material for aircraft structures.

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After aggregating input from all authors, I must verify the accuracy of the following information as the article's author.

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