FINITE ELEMENT ANALYSIS BASED ON MODELING AND STRUCTURAL ANALYSIS OF AIRCRAFT WING USING CONVENTIONAL AND COMPOSITE MATERIALS

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ABSTRACT

The aircraft wing structure is comprised of intricate components including skin, ribs, and spar sections, with the spar bearing both flight and ground loads. Ribs and other structural elements attach to the spars, reinforcing the stressed skin. Given the pivotal role of wings in generating lift, their designs vary according to aircraft type and purpose. However, experimental testing of wing structures proves to be prohibitively expensive and time-consuming. This project addresses these challenges by undertaking a comprehensive approach to aircraft wing structure design, initiated with CATIA V5 R20 modeling. Subsequent structural, modal, and fatigue analyses aim to unveil critical insights into stresses, frequencies, and lifespan. Employing the finite element method via ANSYS-14.5, a series of assessments including static, modal, and fatigue analyses are executed to scrutinize stresses, strains, shear stress, total deformations, vibration frequencies, and factor of safety. Dynamic analysis further delves into frequencies and total deformations, leveraging materials such as AL 7075 T6, AL-ZN-MG-ALLOY 7178, TITANIUM ALLOY 10V-2Fe-l3Al, carbon fibers, and Kevlar fibers. Ultimately, the project's objective is to pinpoint the most suitable material for constructing the aircraft wing, aiming to optimize performance and durability.

Key words: Aircraft, wing, static, modal, CATIA, stress, total deformation, ANSYS

INTRODUCTION TO AIRCRAFT WINGS

The wings of an aircraft are its indispensable lifeline, finely crafted to harness aerodynamic forces and enable flight. Deprived of these crucial extensions, the dream of soaring through the heavens would remain a mere aspiration. In the elegant ballet of aviation, wings take center stage, elegantly orchestrating the intricate interplay between lift and drag. Their precise placement, contours, and dimensions are meticulously calibrated to optimize performance, ensuring the aircraft can gracefully defy gravity. Whether directly attached to the fuselage or supported by struts and braces, wings serve as the cornerstone of the aircraft, fortifying its aerodynamic capabilities and facilitating seamless journeys across great distances.

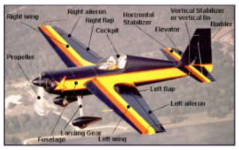


Figure 1 parts of aircraft

Wings transcend their static nature; they dynamically adapt to the evolving demands of flight. From the sleek delta wings of supersonic jets to the expansive spans of gliders, each aircraft boasts a unique wing design crafted for its specific mission and performance standards. Beyond their fundamental function of generating lift, wings serve as platforms for innovation and technological progress. Engineers continually push the boundaries of wing design through the integration of cutting-edge materials and the implementation of advanced control surfaces, unlocking new levels of efficiency and capability. In essence, aircraft wings epitomize humanity's ceaseless pursuit of innovation, symbolizing our limitless ambition and showcasing our mastery of the skies. As we gaze upon the graceful silhouette of an airplane in flight, let us marvel at the profound significance of its wings, as they represent the embodiment of progress, propelling us ever closer to the endless possibilities that lie beyond the horizon.

AERODYNAMICS:

The four forces of flight are:

- Gravity
- Lift
- Drag
- Thrust

Let's explain them one by one.

GRAVITY AND LIFT

Wings transcend their static nature; they dynamically adapt to the evolving demands of flight. From the sleek delta wings of supersonic jets to the expansive spans of gliders, each aircraft boasts a unique wing design crafted for its specific mission and performance standards. Beyond their fundamental function of generating lift, wings serve as platforms for innovation and technological progress. Engineers continually push the boundaries of wing design through the integration of cutting-edge materials and the implementation of advanced control surfaces, unlocking new levels of efficiency and capability. In essence, aircraft wings epitomize humanity's ceaseless pursuit of innovation, symbolizing our limitless ambition and showcasing our mastery of the skies. As we gaze upon the graceful silhouette of an airplane in flight, let us marvel at the profound significance of its wings, as they represent the embodiment of progress, propelling us ever closer to the endless possibilities that lie beyond the horizon.

THRUST AND DRAG

Thrust propels an object forward, while ground speed is essential for an aircraft to generate lift and maintain stability, preventing it from nose-diving. Understanding the mechanics of engine propulsion involves grasping Newton's Third Law of Motion: Every action (force applied) has an equal and opposite reaction, exerting force in the opposite direction.

WINGS SHAPES AND DESIGNS:

- **Rectangular Wings**: These are the simplest form of wings, commonly found in early aircraft designs. While they provide adequate lift and stability, they're not as aerodynamically efficient as other wing shapes.
- **Elliptical Wings**: Elliptical wings offer superior aerodynamic efficiency compared to rectangular wings. They help reduce induced drag, which is drag created as a byproduct of lift production.
- **Tapered Wings**: Tapered wings have a narrower chord (width) at the wingtip compared to the wing root (where it attaches to the fuselage). This design helps balance weight distribution and lift across the wing span.
- **Swept Wings**: Swept wings are angled backward along the leading edge. This design is commonly used in high-speed aircraft because it helps reduce drag at transonic and supersonic speeds.
- **Delta Wings**: Delta wings are triangular-shaped, with a wide span and short chord length. They offer high maneuverability and are often seen in fighter jets and some commercial aircraft.

COMPONENTS AIRCRAFT WING:

- **Leading Edge**: The leading edge of the wing is the foremost part that encounters the airflow. It's designed to minimize drag and manage airflow to delay or prevent airflow separation, which can lead to a stall.
- **Trailing Edge**: The trailing edge is the rear part of the wing. It houses control surfaces such as ailerons, flaps, and spoilers, which are used to control the aircraft's roll, pitch, and yaw.
- **Wingtip**: The wingtip is the outermost part of the wing. It plays a role in reducing drag by minimizing the formation of wingtip vortices, which are caused by the pressure difference between the upper and lower surfaces of the wing.
- **Wing Spar**: The wing spar is the primary structural component that runs along the span of the wing, providing support and strength. It helps distribute the aerodynamic forces experienced by the wing during flight.
- **Wing Rib**: Wing ribs are cross-sectional components that give the wing its shape and help maintain its structural integrity. They're typically spaced along the wing's span to provide support to the wing skin.
- **Wing Skin**: The wing skin is the outer covering of the wing. It's designed to be aerodynamically smooth and structurally robust to withstand the forces encountered during flight.

LITERATURE REVIEW

AVNISH KUMAR [1][2015] in his "Investigation of aerofoil design." Said that Lift coefficient was found to be higher for Asymmetric aerofoil than the Symmetric aerofoil for same chord length and maximum camber of the aerofoil at same angle of attack. “Modeling and analysis on wing of A380 flight” conducted structural & thermal analysis on AIR BUS A380WING TO calculate the stress, strain & thermal flux for finding the wing to be safe. For simulation and modeling the 8 used software like CATIA for determining model for analysis FEA package ANSYS. In their simulation the obtained stress and strain values were within the limiting range. The maximum stresses that wing of a flight can with stand are 700pa. But obtained stress was 400pa.

P.JEEVANANTHAM, L.MANKUMAR [2] [2012] in their paper dealt with the structural design and flow analysis of M wing in an aircraft. The wing design involves its initial considerations and selection of airfoil, area of the wing, wing loading characteristic and weight of the wing. Their design proved to be viable by the results that they obtained from the virtual flow analysis of the wing analyzed by the Design-Foils tool test results.

NIKHIL A. KHADSE & PROF. S. R. ZAWERI [3][2010] in their paper presents modal analysis of aircraft wing. A cad model of a aircraft wing has been developed using modeling software PROE5.0 and modal analysis was carried out by using ANSYSWORKBENCH14.0.modal analysis has been carried out by fixing one end (root chord) of aircraft wing while other end(tip chord) is free. They also used a cantilever beam modal analysis for validation of the simulation of the airfoil. This investigation revealed that natural frequency obtained from numerical and theoretical approach were in close agreement, which validated FE model of the cantilever beam for modal analysis.

T .GULTOP, [4] (2005) studied the impact of perspective degree on Airfoil performance. The reason for this study was to focus the ripple conditions not to be kept up throughout wind tunnel tests. These studies indicate that aero elastic insecurities for the changing arrangements acknowledged showed up at Mach number 0.55, which was higher than the wind tunnel Mach number point of confinement velocity of 0.3.

R. DAS, R. JONES [5] (2002) “Damage tolerance based design optimization of a fuel flow vent hole in an aircraft structure”, Journal of Structural Multidisciplinary Optimization, the application of damage tolerance based optimization to investigate the shape optimization of a Fuel Flow Vent Hole (FFVH) located in the Wing Pivot Fitting of an F-111 aircraft. It is noteworthy that the presence of such „cutouts‟ is common in engineering structures used in many industries such as rail, aerospace, naval, and mining. These „cutouts‟ are typically used for lightening the structure or for providing passage for equipments and cooling. Hence, the methodologies outlined in this paper to optimize the cutout shape can be easily extended to durability based shape design in similar structures. The shape optimization of the vent hole was performed using the three basic design criteria relevant to damage tolerance design, viz, stress, residual strength, and fatigue life.

K. KALITA, S. HALDER[6] (1998) “static analysis of transversely loaded Isotropic and Orthotropic plates with central cutout”, Journal of Institution of Engineers, India series, observed that maximum shear stress in all boundary conditions occurs at the cutout periphery. As expected in all cases, maximum deflection is seen near the cutout and decreases towards the constraints. The variation of SCF for all the plates, in general, is more in orthotropic plate as compared to isotropic plate. It is observed that SCF depends on elastic constants and hence differ from material to material. The induced stresses in all cases have been intentionally limited within the elastic range by selecting a suitable applied load.

T.V. BAUGHN AND P.F. PACKMAN [10] (1986), conducted a finite element analysis to determine the structural integrity of a high-wing cable-supported ultra light aircraft. A simple, symmetrical, half-structure macro-model was analyzed and subjected to level flight loading and two-wheel-landing loading conditions. Flexural and bending stiffness for the supported and unsupported wing were also determined. A preliminary damage tolerance analysis was conducted in which selected cable elements and wing compression struts were removed, the redistributed loads calculated, and possible aircraft flight configurations examined. The model can generate all cable loads, displacement of each structural node (for each loading condition), generate displacement plots, and locate potential highly stressed regions.

BAUGHN, T. AND JOHNSON, D. [11] (1986), proposed a design change from high-wing cable-supported to strut supported aircraft. One of the most common designs is the high wing cable supported ultra light. Because of its simple shape and method of construction owners like to modify the structure and aerodynamic surfaces to attempt to improve the performance of the aircraft. One of the more common modification requests is for the conversion from a cable supported to a strut supported aircraft. The objective of the modification is to reduce the drag and improve the performance of the ultra light. The purpose of their study is to determine the structural performance of the cable supported aircraft and compare it to the structural performance of a strut supported version of the same aircraft and to provide an estimate of the change in drag associated with the conversion from cable supported to strut supported.

PROJECT OVER VIEW

1. Ensuring the robust mechanical integrity and rigidity of the integrated aircraft wing is paramount. This entails not only withstanding the stresses and strains encountered during flight but also maintaining structural integrity under various operational conditions.
2. Crafting an aerodynamically efficient design for the aircraft wing is crucial. This involves meticulous shaping and contouring to minimize drag, optimize lift generation, and enhance overall flight performance.
3. The ability to effectively manage lift and drag forces exerted on the wing structure is essential. This necessitates precise engineering to ensure that the wing can efficiently generate lift to support the aircraft's weight while minimizing drag for enhanced fuel efficiency and aerodynamic performance.
4. The selection of materials with superior corrosion resistance, particularly in composite structures, is imperative. Given the harsh environmental conditions often encountered during flight, such as exposure to moisture, salt, and other corrosive elements, employing high-quality composite materials can prolong the lifespan and reliability of the wing assembly.
5. Striving to minimize the dimensions of the aircraft wing is key to reducing overall weight. By adopting a compact design approach, unnecessary bulk and weight can be eliminated, thereby enhancing the aircraft's fuel efficiency, manoeuvrability, and payload capacity.
6. Lastly, meticulous consideration must be given to the choice of materials for the aircraft wing. Factors such as strength-to-weight ratio, fatigue resistance, thermal stability, and manufacturing feasibility must be evaluated to select the most suitable material for optimal performance and longevity of the wing assembly. This entails a comprehensive assessment of various materials, including advanced composites, alloys, and hybrid structures, to meet the demanding requirements of modern aerospace engineering.

OBJECTIVE OF THE PROJECT:

1. Using CATIA software, model the aircraft wing
2. Using structural analysis, determine the linear stresses, strains, deformations, shear stresses, factor of safety, life, and deformation on the following materials: carbon fiber, titanium alloy 10V-2Fe-3Al, Kevlar fiber, AL 7075 T6, and AL-ZN-MG-ALLOY 7178.
3. Design model meshing with ANSYS 15.
4. Aircraft wing analysis using the application of modal and static analysis
5. Using modal analysis, frequency and mode shapes are determined.
6. Determining the best structure among these several materials to be used in the construction of the aircraft

METHODOLOGY:

The methodology followed in the project is as follows:

- Using parametric software, create a 3D model of the wing with spars and ribs assembled.
- To do static and modal analysis, convert the surface model into a Part solid file and load it into ANSYS.
- Conduct both static and modal analyses of the wing assembly.
- Ultimately determined the appropriate content.

Wing Span		4500mm
Chord Length		1000mm
Airfoil		BOEING BACXXX
Taper Ratio		1
Sweep Angle		0°
Ribs Design	Root and Tip Thickness	40mm
	Other Ribs	20mm
Spars	Length	4500mm
	Thickness	60mm

Table 1 dimensions of the aircraft wing

MATERIAL PROPERTIES:

Materials utilized in aircraft design the aircraft's design must adhere to strict specifications, which have an impact on the materials and structural complexity of the finished product. The aircraft's design may make use of a variety of materials to take advantage of characteristics including strength, flexibility, specific weight, and corrosion resistance. Depending on the initial strength-to-weight ratio needs and the preferred directions of the applied stresses, other materials may also be employed in the design of particular aircraft parts.

Materials	Density Kg/m^3	Poisson's ratio (μ)	Young's Modulus (GPa)	Ultimate Tensile Strength (MPa)
AL 7075-T6	2780	0.33	71	570
AL-ZN-MG ALLOY 7178	2800	0.33	78	600
Ti 10V-2Fe- 3AL	4650	0.32	110	1050
CARBON FIBER	1800	0.30	230	1800
KEVLAR FIBER	1440	0.35	125	3600

Table material properties

DESIGN PROCEDURE OF AIRCRAFT WING:

The process of designing a wing is iterative, typically including multiple selections or calculations. There has been a decrease in the number of iterations as a result of the development of numerous tools and software based on numerical methods and aerodynamics in recent decades. In transport aircraft wing design, two spar architecture is typically used. The spar closest to the wing's leading edge is referred to as the front spar, while the spar closest to the wing's tail is referred to as the rear spar. The spar has two ends: a free end that is located near the tip of the wing and connected to the fuselage at the "root of the wing." Any engineering structure's cantilever beam layout is fairly similar to this setup. L-angle fittings are used to join the spars and ribs. The locations of the spar and ribs from the wing root are displayed here, along with a picture of the entire CATIA V5 model of the wing construction. In Sketcher Workbench, create the structure using the dimensions listed above. After creating the spars, apply pad with a bar that is 30 radii and an elongated length of 40 mm. After creating the elongated hole, which is 16 mm, 360 mm, and 560 mm from the start point again, proceed to the sketcher workbench and create the oval-shaped section. Apply pad in part design work bench according to above dimensions.

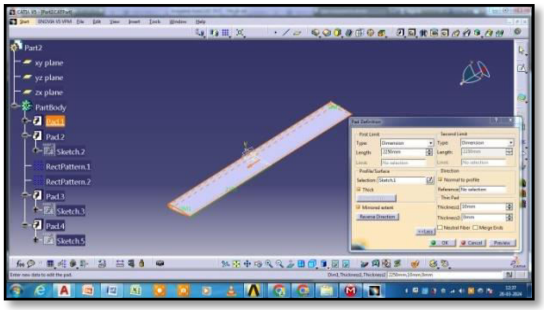


Figure 2 multiple views of aircraft wing

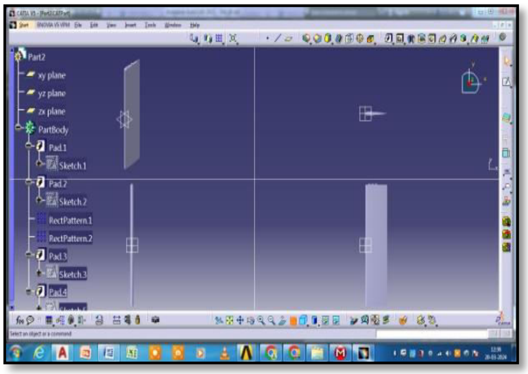


Figure 3 realistic view of aircraft wing

INTRODUCTION TO ANSYS

ANSYS is one of the best analysis and simulation software used to simulate engineering solutions. ANSYS 2.0 was released as the first version in the year of 1971. ANSYS simulates 3d models or structures or machine parts designs to stress, strength, temperature distribution, thermal conductivity, elasticity, fluid flow, air flow, etc.

The Workbench graphical user interface consists of the Toolbox, the Project Schematic, the Toolbar, and the Menu bar. The most common way to begin work in Workbench is to drag an item, such as a component system (application) or an analysis system, from the Toolbox to the Project Schematic, or to double-click on an item to initiate the default action. You will view your component and/or analysis systems - the pieces that make up your analysis - in the Project Schematic, including all connections between the systems. The individual applications in which you work will display separately from the Workbench graphical interface, but the actions you take in the applications will be reflected in the Project Schematic.

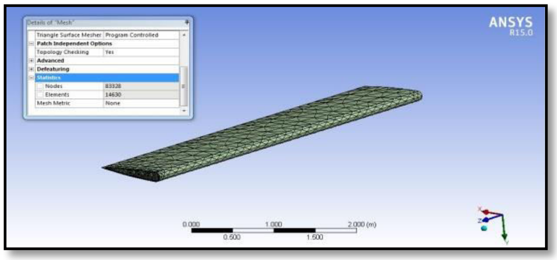
INTRODUCTION TO FEM

For the vast majority of geometries and problems, Partial Differential Equations cannot be solved with analytical approaches. Instead, we can approximate these equations using discretisation methods that can be solved using numerical methods. Therefore, the solutions we get are also an approximation of the real solution to those PDEs. The method was originally developed for engineering analysis to model and analyze complex systems in mechanical, civil, and aeronautical engineering. The basics of the method can be derived from Newton's laws of motion, conservation of mass and energy, and the laws of thermodynamics. FEM can be used, for example, to determine the structural mechanics of different parts of a car under different loading conditions, the heat flow through engine part, or the distribution of electromagnetic radiation from an antenna. An important aspect of FEM is how the Computer-aided design (CAD) model is prepared for the analysis and is being subdivided during meshing (discretisation into smaller elements). CAD software such as **CATIA** can be used to define 3D shapes of an object and then imported into a separate FEA tool which subdivides the object into appropriately sized elements according to the desired boundary conditions or mesh.

STATIC STRUCTURAL ANALYSIS

The static structural analysis calculates the stresses, displacements, shear stress and forces in structures caused by a load that does not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that the loads and the structure's response are assumed to change slowly with respect to time. A static structural load can be performed using the ANSYS WORKBENCH solver. The types of loading that can be applied in a static analysis include go to static structural apply material properties in engineering data after go to the geometry import igs file after go to the model generate the mesh as show below figures again go to the setup apply boundary conditions apply lift force 500Pa top surface on wing fixed spars one end as shown below figure again go to the solution generate after go to the results observed the stresses, strains, total deformations, shear stress .

MESH:


Details of "Mesh"

Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	Yes
Advanced	
Defeaturing	
Statistics	
Nodes	83328
Elements	14630
Mesh Metric	None

Figure 4 meshing nodes: 83328, elements: 14630

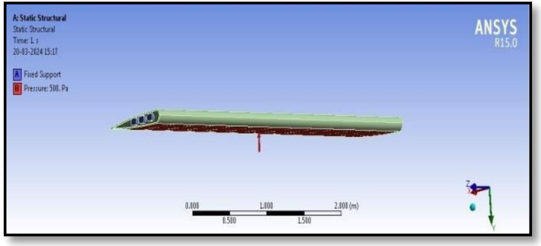


Figure 5 boundary condition 500pa

STATIC STRUCTURAL ANALYSIS

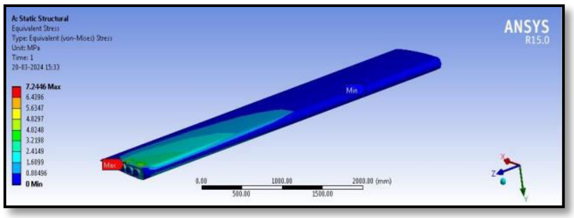


Figure von misses stresses

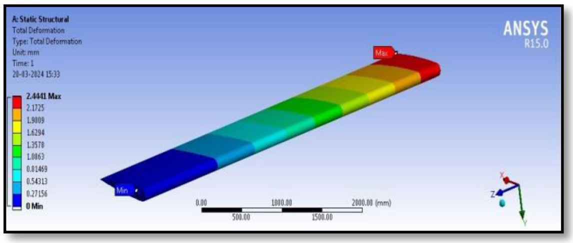


Figure 6 total deformation

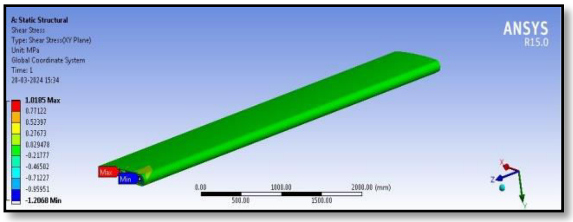


Figure 7 shear stress

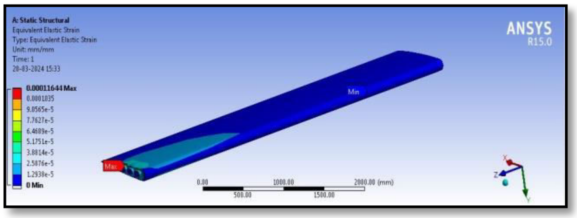


Figure 8 strain

MODAL ANALYSIS OF KEVLAR FIBER:

The study of a structure's dynamic characteristics under vibration excitation is known as modal analysis. In aircraft, vibration is caused by the lift load and the load from the engine mounted on the wing. The different times at which the structure will naturally resonate are determined by the modal analysis using the structure's total mass and stiffness attribute. Calculating a structure's natural frequencies and mode shapes could be very important. They provide us with the frequencies at which resonant motion of the structure can be excited. This knowledge is often enough to change the structural design in a way that minimizes vibration and noise. Furthermore, if a component's working frequency is near one of the natural frequencies of the supporting structure, it may result in structural failure or damage, making the dynamic interaction between the component and its structure crucial. Thus, we continue and examine the wing structure for various frequency ranges. The problem's boundary conditions and mesh settings would be the same as they are above. To determine the overall deformation under the six modes, an analysis was conducted.

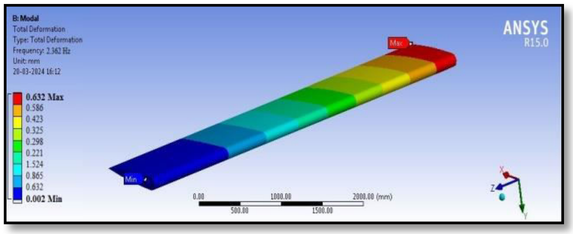


Figure 9 mode 1 of kevlar fiber material

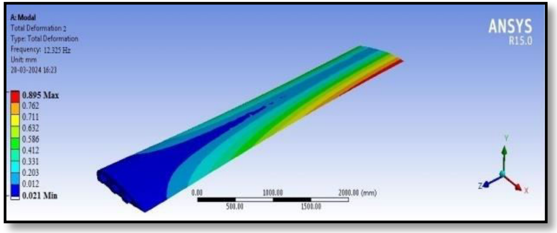


Figure 10 mode 2 of kevlar fiber material

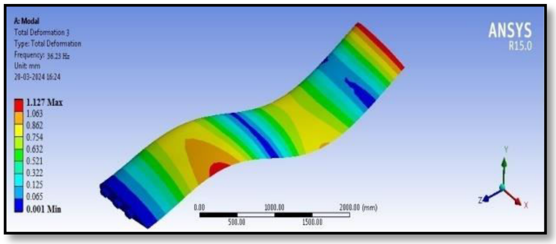


Figure 11 mode 3 of kevlar fiber material

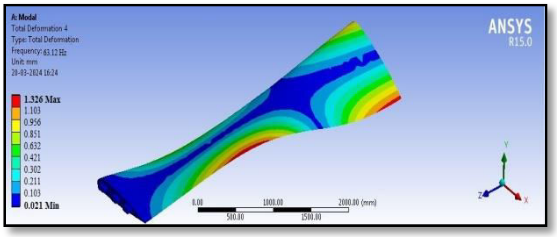


Figure 12 mode 4 of kevlar fiber material

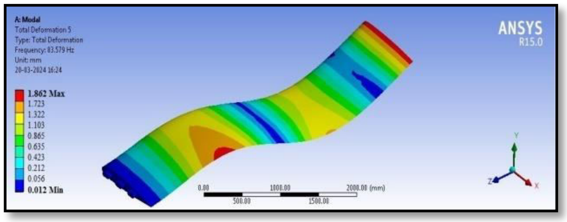


Figure 13 mode 5 of kevlar fiber material

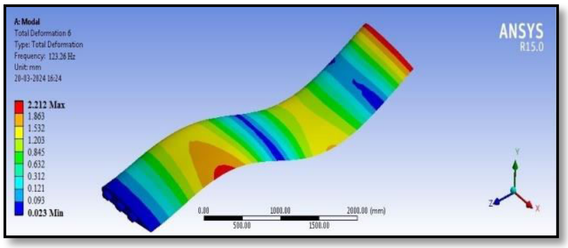


Figure 14 mode 6 of kevlar fiber material

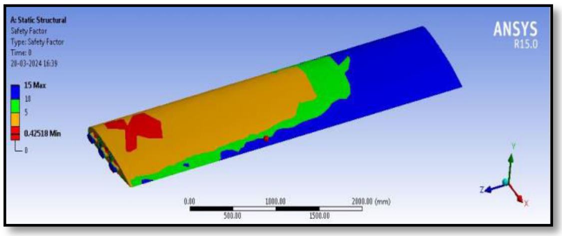


Figure 15 factor of safety of kevlar fiber material

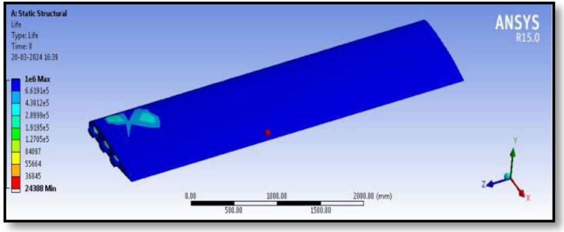


Figure 16 life of kevlar fiber material

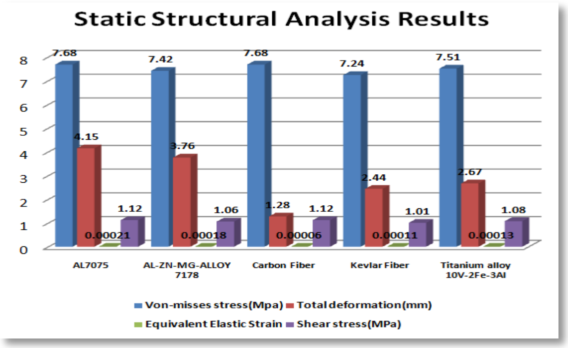
STATIC STRUCTURAL RESULTS

Materials	Von-misses stress(Mpa)	total deformation(mm)	strain	shear stree(Mpa)
AL7075	7.68	4.15	0.00021	1.12
AL-ZN-MG-ALLOY 7178	7.42	3.76	0.00018	1.06
Carbon Fiber	7.68	1.28	0.00006	1.12
Kevlar Fiber	7.24	2.44	0.00011	1.01
Titanium alloy 10V-2Fe-3Al	7.51	2.67	0.00013	1.08

Table 2 structural analysis results

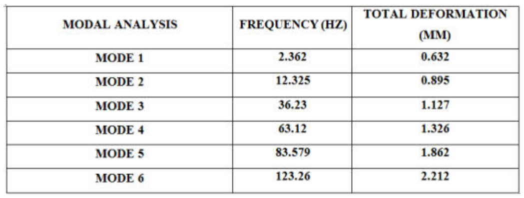
FINAL RESULTS OF STATIC STRUCTURAL ANALYSIS

Here are the all materials static structural analysis results are plotted in a below graph for AL 7075 T6 , AL-ZN-MG-ALLOY 7178, CARBON FIBER, TITANIUM ALLOY 10V-2Fe-3Al, Kevlar fibers are described with their maximum values obtained by static structural analysis.



Graph 1 static structural results

MODAL ANALYSIS RESULTS



MODAL ANALYSIS	FREQUENCY (HZ)	TOTAL DEFORMATION (MM)
MODE 1	2.362	0.632
MODE 2	12.325	0.895
MODE 3	36.23	1.127
MODE 4	63.12	1.326
MODE 5	83.579	1.862
MODE 6	123.26	2.212

Table 3 modal analysis of kevlar fiber material

CONCLUSION

- In the design process conducted through CATIA, followed by analysis utilizing ANSYS, a comprehensive evaluation was undertaken on three distinct materials: AL7075, AL-ZN-MG-ALLOY 7178, and Titanium alloy 10V-2Fe-3Al, alongside carbon fibers and Kevlar fiber.
- For static analysis, lift force was applied to the wing across the materials. Analysis revealed that wing structures reinforced with ribs and spars made of Kevlar and carbon fiber exhibited superior characteristics, displaying lower von-Mises stress, strains, deformations, and shear stresses compared to alternative materials. Despite maintaining equivalent load-bearing capacity, these composite materials facilitated weight reduction and extended fatigue life.
- Modal analysis was then performed to assess frequencies, indicating higher frequencies for the modified model but lower deformations. Notably, Kevlar and carbon fiber exhibited lower frequencies when integrated into the left side of the wing structure. Specifically, carbon fiber showed frequencies of 2.362 Hz (mode 1), 12.32 Hz (mode 2), and 36.23 Hz (mode 3), with corresponding deformations of 0.632 mm, 0.89 mm, and 1.127 mm, respectively.
- Conclusively, considering both economic and strength perspectives, carbon fiber emerges as a favorable choice, while Kevlar fiber stands out for its exceptional strength characteristics in the construction of aircraft wing structures.

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