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# **Design and Analysis of Composite Wing**

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**ABSTRACT:** The design and analysis of composite wings play a crucial role in advancing aerospace engineering by improving structural efficiency, weight reduction, and aerodynamic performance. This study focuses on evaluating the mechanical and aerodynamic characteristics of composite wings using different material configurations and air foil profiles. The structural analysis examines total deformation, Von Mises stress, and strain distribution for various composite materials, including Epoxy Carbon Woven (230 GPa) Prepreg, Epoxy Carbon UD (230 GPa) Prepreg, and Epoxy Carbon UD (395 GPa) Prepreg, in comparison with conventional aluminium alloys. The results highlight the superior strength-to-weight ratio and stiffness of composite materials, demonstrating their advantages over aluminium in aircraft applications. Additionally, a Computational Fluid Dynamics (CFD) analysis was conducted on NACA 2412 and NACA 4412 air foils to assess their aerodynamic efficiency under a uniform velocity of 30 m/s. The study provides insights into pressure contours, lift, and drag forces, comparing the performance of both air foils. The combined results of Finite Element Analysis (FEA) and CFD confirm that composite wings provide enhanced structural and aerodynamic performance compared to traditional materials

**KEYWORDS:** Air foil Design, Composite Wings, Carbon Epoxy Composite, Modal Analysis, Structural Analysis, Computational Fluid Dynamics(CFD).

## **I. INTRODUCTION**

The aerospace industry has increasingly adopted composite materials due to their high strength, lightweight nature, and superior durability compared to conventional metals like aluminum and titanium. Among these, carbon fiber epoxy woven composites have gained significant attention for aircraft applications, particularly in wing structures, where weight reduction and structural efficiency are critical. The need for composite materials for aircraft wings is, Aircraft wings are subjected to high aerodynamic loads, temperature variations, and fatigue cycles during operation. Traditional metallic wings, although strong, are often heavier, leading to higher fuel consumption. Composite materials, especially carbon fiber reinforced epoxy laminates, provide an optimal balance of strength, stiffness, and reduced weight, making them highly suitable for modern aviation. By utilizing carbon epoxy woven composites, engineers can design aerodynamically efficient, structurally strong, and fuel-efficient wings, making them a crucial component of next- generation aircraft.

### **Mechanical Properties of Composites:**

The mechanical properties of composite materials play a crucial role in determining their strength, durability, and structural performance in aerospace applications. In aircraft wings, materials must withstand aerodynamic loads, vibrations, and environmental stress while maintaining a lightweight structure. Carbon fiber epoxy woven composites are widely used due to their high strength-to-weight ratio, stiffness, and fatigue resistance.

### **Classification of Composites:**

Composite materials are broadly classified based on their matrix material and reinforcement type. The classification helps in understanding the different properties, applications, and advantages of each type. Composites are engineered to achieve superior strength, stiffness, and durability compared to conventional materials like metals and plastics.



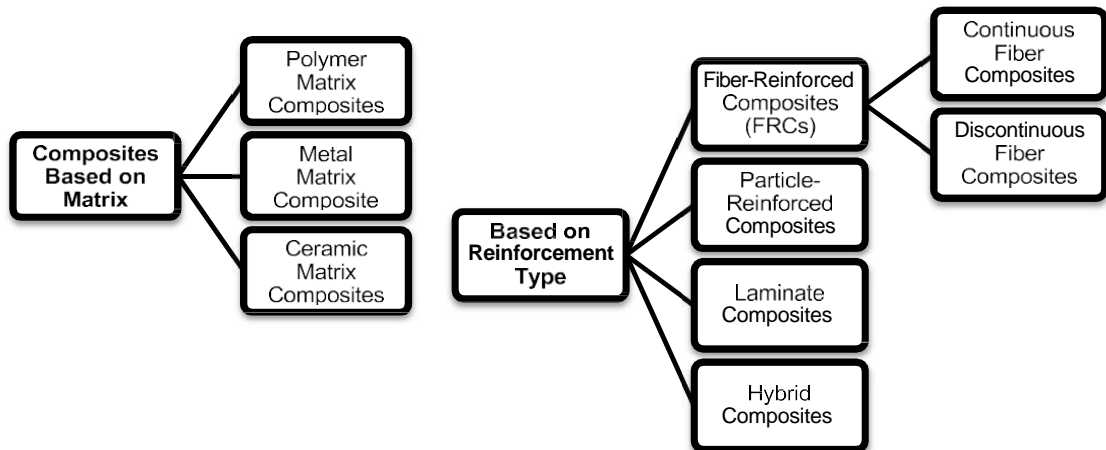


Figure 1: Composites Classification

#### Design and Nomenclature of Airplane Wings

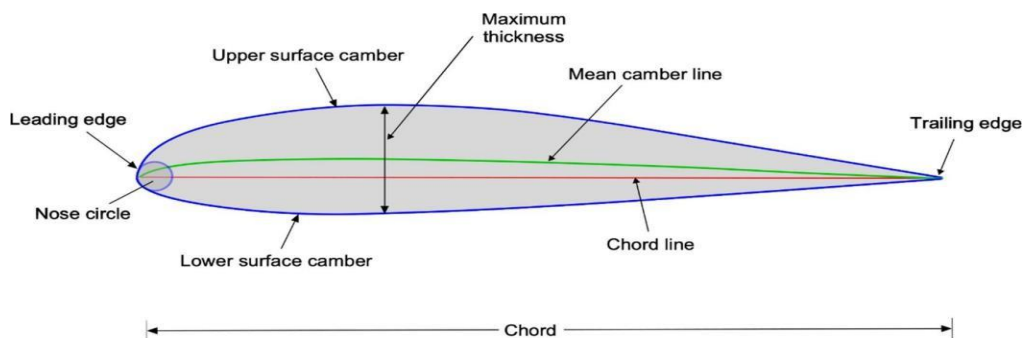


Figure 4: Basic Wing Geometry

#### Aerodynamic Analysis and Structural Design of the wing

The design and analysis of composite wings play a crucial role in aerospace applications, improving aerodynamic efficiency and structural strength while reducing weight. In this study, the wing profiles NACA 2412 and NACA 4412 are considered for modeling and meshing to evaluate their suitability for composite wing applications. The modeling process was carried out in CATIA, and meshing was performed in ANSYS 2025 R1.

#### Profile Generation

The airfoil profiles were generated using an airfoil plotter, which provided precise coordinates for both NACA 2412 and NACA 4412. NACA 2412 has a maximum camber of 2% at 40% of the chord length, while NACA 4412 has a higher camber of 4%, making it suitable for applications requiring greater lift at lower speeds.

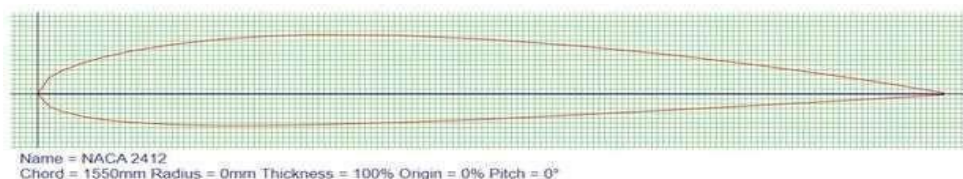


Fig 5: NACA 2412 Profile

The wing designed is simplified into a structure with only beams, ribs and skins. It adopts a double-beam structure with good bending and torsion rigidity to obtain a structural layout with high bearing efficiency.

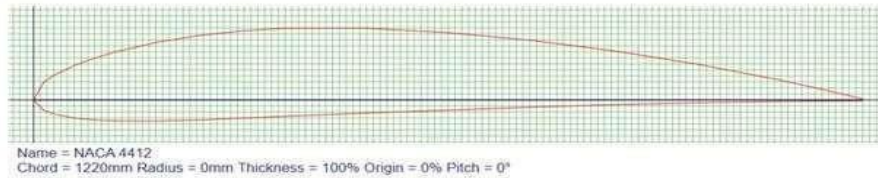


Fig 6: NACA 4412 Profile

### 3-D Model Generation

The 3D model for the NACA 4412 airfoil profile was created by first obtaining the airfoil shape from an airfoil plotter. This profile was then imported into CAD software, where it was extruded to a length of 5485 mm to generate a solid wing section.

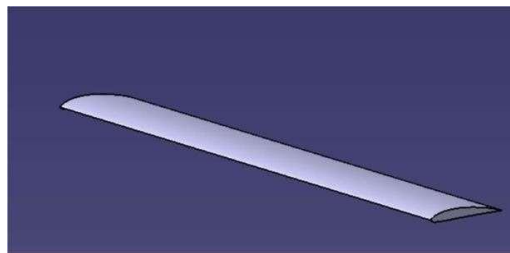


Fig 7: 3D Part NACA 2412

The 3D model of the NACA 2412 airfoil was developed using a similar approach. The airfoil profile was first obtained using an airfoil plotter and then imported into CAD software for further processing. The profile was extruded to a length of 5500 mm, ensuring that the aerodynamic characteristics of the NACA 2412 series were accurately maintained

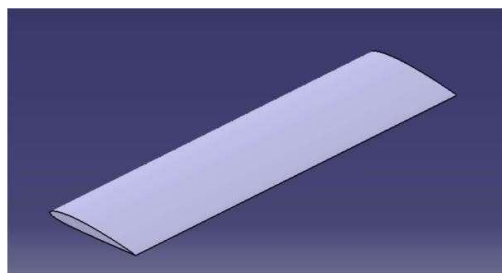


Fig 8: 3D Part NACA 4412

### Structural and Modal Analysis of Composite Wing

## II. STATIC STRUCTURAL ANALYSIS OF WING

For this analysis, a uniform pressure load was applied to the bottom surface of the wing, simulating the aerodynamic lift force experienced during takeoff and cruise conditions. Four different pressure values were considered, corresponding to:

The wing was fully constrained at the root, while the free end was allowed to deform naturally under the applied aerodynamic forces. The analysis was conducted for all three composite materials and the aluminium alloy to observe their structural response under identical loading conditions.

The key results from the static structural analysis include:

**Total Deformation (mm):** This measures the overall displacement of the wing under applied loads, providing insight into its flexibility and stiffness.

**Von Mises Stresses (Pa):** This evaluates the maximum stress levels in the material, ensuring that it does not exceed its yield strength, which could lead to failure.

**Strain Distribution:** This helps in understanding how the material stretches or compresses under aerodynamic loading, indicating its resistance to structural distortion.

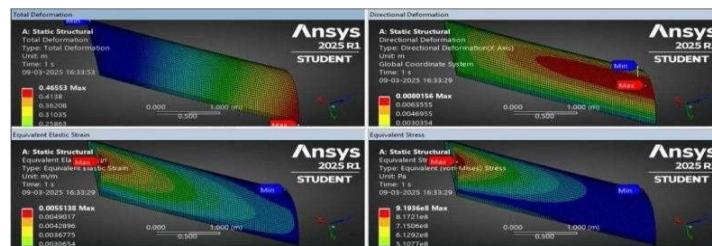


Fig 23: Epoxy 230 (GPa) take off for 4412

From the images, it can be observed that the deformation patterns vary according to the material properties. The maximum deformation consistently occurs at the free end of the wing, while the fixed end remains stable. Among the three materials, the Epoxy Carbon Woven (230 GPa) composite exhibits the highest total deformation, followed by the Epoxy Carbon UD (230 GPa) composite, with the Epoxy Carbon UD (395 GPa) composite showing the least deformation. This trend highlights those materials with higher stiffness experience reduced deflection under identical loading conditions.

FOR NACA 4412 CRUISE

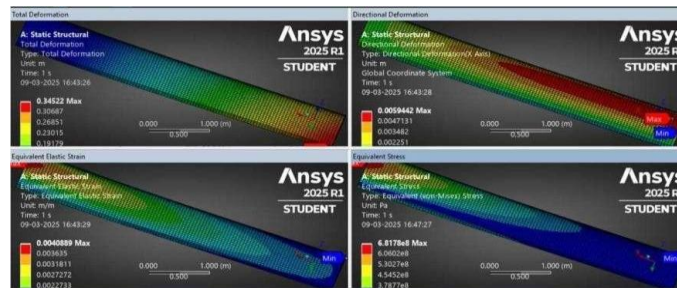


Fig 24: Woven Cruise for 4412

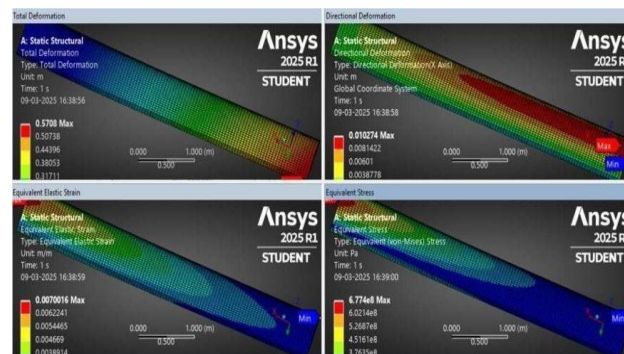


Fig 25: Epoxy 395 (GPa) cruise for 4412



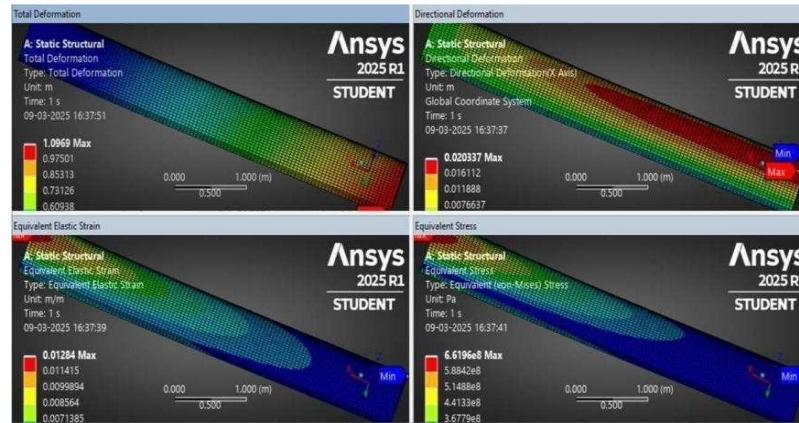


Fig 26 Epoxy 230 (GPa) Cruise for 4412

From the images, it can be observed that the deformation and stress patterns vary significantly among the materials under takeoff conditions. The Epoxy Carbon Woven (230 GPa) composite demonstrates a well-balanced structural response, providing an optimal trade-off between deformation and stress distribution. The total deformation is highest in the 395 GPa UD composite, followed by the 230 GPa UD composite, and lowest for the woven composite. This indicates that the woven composite exhibits superior stiffness and resistance to bending, making it a more stable choice for wing structures. The structural and modal analysis of the composite wing provided valuable insights into mechanical performance of composite materials compared to aluminum alloy. The modal analysis revealed variations in natural frequencies and mode shapes, indicating differences in material stiffness and vibrational behavior. The static structural analysis highlighted total deformation, Von Mises stress distribution, and strain characteristics under aerodynamic loading.

### III. ANALYSIS RESULTS FOR NACA 2412

#### VON MISES STRESS ANALYSIS FOR NACA 2412 WING (TAKEOFF CONDITION)

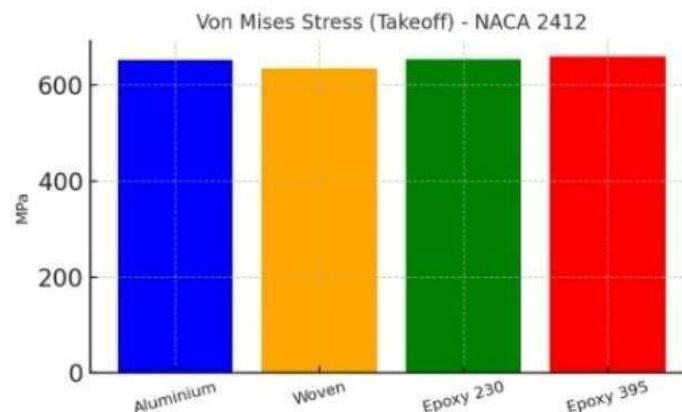


Fig 29: Stresses at Take Off 2412

The Von Mises stress analysis for the NACA 2412 wing under take-off conditions was conducted for different materials, including Aluminium Alloy (6061-T6), Epoxy Carbon Woven (230 GPa) Prepreg, Epoxy Carbon UD (230 GPa) Prepreg, and Epoxy Carbon UD (395 GPa) Prepreg. The results indicate that Epoxy Carbon Woven (230 GPa) Prepreg exhibits a lower Von Mises stress (634.65 MPa) compared to other materials, making it an excellent choice for structural integrity and durability. Its multidirectional fiber orientation effectively distributes the applied load, reducing localized stress concentrations. In contrast, Epoxy Carbon UD (395 GPa) Prepreg shows the highest stress (660.44 MPa), indicating a more brittle nature under load. The balanced mechanical properties of Epoxy Carbon Woven provide better damage tolerance and resilience, making it a favorable material for lightweight aerospace applications.

VON MISES STRESS ANALYSIS FOR NACA 2412 WING (CRUISE CONDITION)

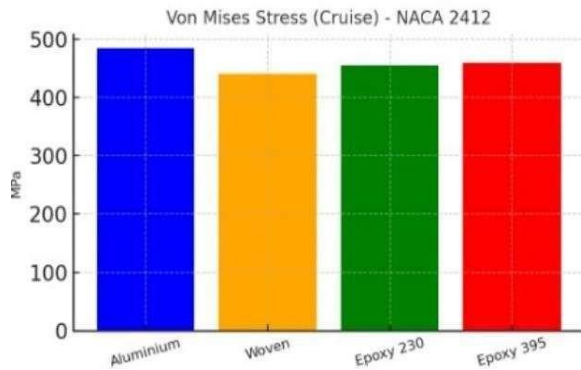


Fig 30: Stresses at cruise 2412

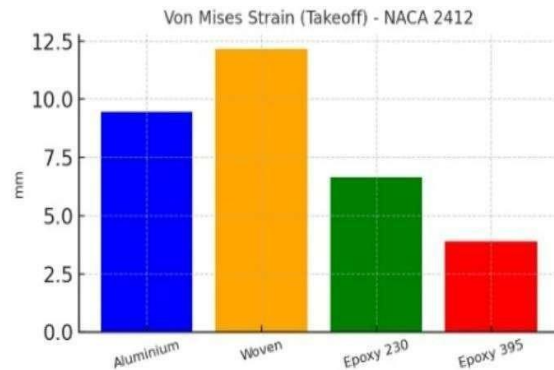


Fig 31: strain at takeoff 2412

VON MISES STRAIN ANALYSIS FOR NACA 2412 WING (CRUISE CONDITION)

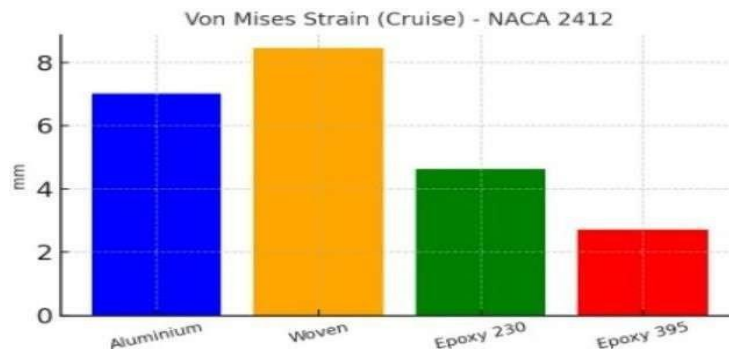


Fig 32: strain for cruise 2412

Another set of strain analysis under cruise conditions further reinforces the benefits of Epoxy Carbon Woven (230 GPa) Prepreg. While Aluminium Alloy (6061-T6) exhibits the highest strain, indicating excessive deformation, Epoxy Carbon Woven shows a well- balanced response, avoiding both excessive flexibility and extreme rigidity. Epoxy Carbon UD materials exhibit slightly higher strain than the woven composite, but their unidirectional fiber alignment makes them more prone to sudden failure under multidirectional loading conditions. The woven structure of Epoxy Carbon Woven provides uniform load distribution, reducing localized stress buildup and enhancing fatigue resistance.

VON MISES STRESS ANALYSIS FOR NACA 4412 WING (TAKE OFF CONDITION)

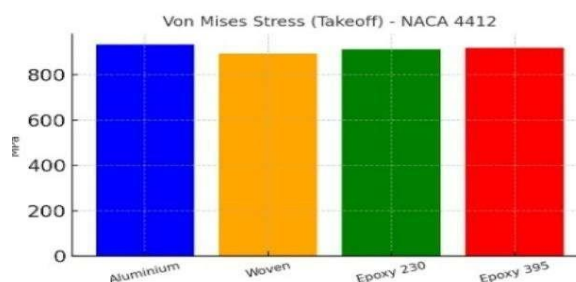


Fig 33: Stresses at Take Off 4412

VON MISES STRESS ANALYSIS FOR NACA 4412 WING (CRUISE CONDITION)

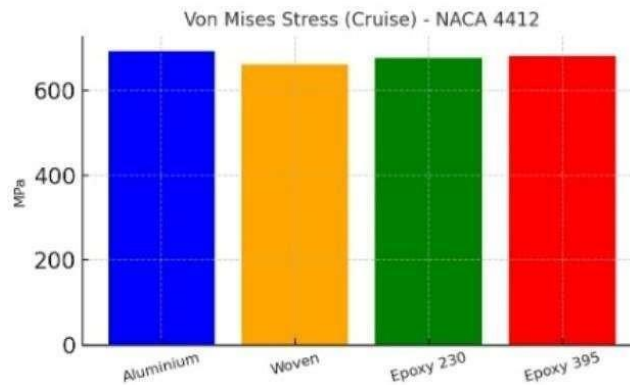


Fig 34: Stresses at cruise 4412

VON MISES STRAIN ANALYSIS FOR NACA 4412 WING (TAKEOFF CONDITION)

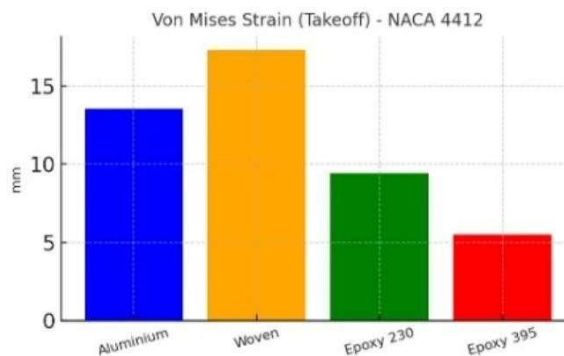


Fig 35: Strain at take off 4412

#### IV. CFD ANALYSIS

To evaluate the aerodynamic performance of the selected airfoil profiles, CFD analysis was performed on NACA 2412 and NACA 4412 under a uniform flow velocity of 30 m/s. The study focused on pressure distribution, lift, and drag forces, which are critical parameters for assessing wing efficiency.

The pressure contours illustrate the distribution of pressure over both air foils. The leading edge of both air foils experiences high pressure, while the upper surface shows a significant low-pressure region, ensuring effective lift generation. In the case of NACA 4412, the increased camber results in a higher-pressure difference, leading to greater lift production compared to NACA 2412.

Additionally, force calculations were performed to determine lift and drag values. The results indicate that NACA 4412 exhibits higher lift than NACA 2412, making it more suitable for applications requiring higher lift at lower speeds.

However, NACA 2412 shows relatively lower drag, making it favorable for efficient cruising conditions. The findings from this CFD study align with the structural analysis results, further justifying the selection of Epoxy Carbon Woven Prepreg (230 GPa) as the preferred composite material for the wing. This material provides a high strength-to-weight ratio, ensuring structural integrity while optimizing aerodynamic performance.



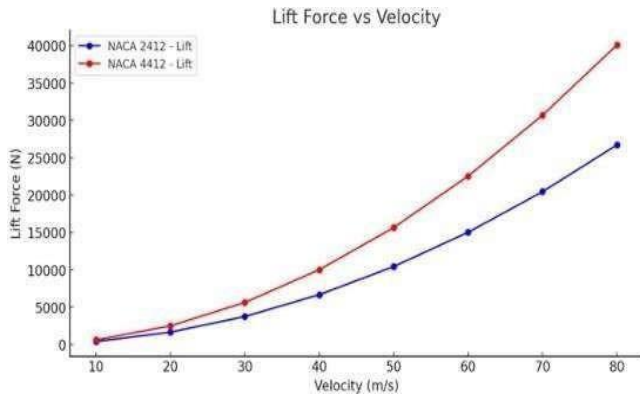


Fig 36: Lift vs Velocity

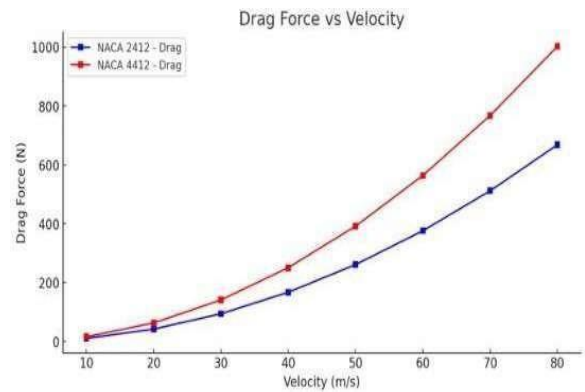


Fig 37: Drag vs Velocity

## V. CONCLUSION

The design and analysis of composite wings were conducted to evaluate the structural and aerodynamic performance of different materials and airfoil configurations. This study aimed to enhance the efficiency and durability of aircraft wings by utilizing advanced composite materials, particularly Epoxy Carbon Woven (230 GPa) Prepreg, which was identified as the most suitable material based on its superior strength-to-weight ratio and mechanical properties.

The static structural analysis confirmed that Epoxy Carbon Woven Prepreg exhibited minimal deformation while maintaining high stiffness and strength, making it an excellent candidate for aircraft wing applications. The modal analysis further validated its vibrational stability, ensuring better performance under dynamic loading conditions.

The CFD analysis of NACA 2412 and NACA 4412 air foils provided insights into their aerodynamic efficiency. The results showed that NACA 4412 generated higher lift, making it more suitable for applications requiring greater lift at lower speeds. However, NACA 2412 exhibited lower drag, ensuring better fuel efficiency. The pressure contours and force calculations confirmed the effectiveness of these air foils in aerodynamic performance.

Overall, the study demonstrated that composite materials, especially Epoxy Carbon Woven Prepreg, offer significant advantages over conventional materials like aluminum in terms of weight reduction, structural integrity, and aerodynamic efficiency. The findings validate the application of composite wings in modern aerospace engineering, contributing to improved fuel efficiency, performance, and sustainability.

The design optimization process demonstrates the significant benefits of using CFRP (M55j/914prepreg) instead of E - Glass,

resulting in a 38% reduction in weight when applied to the wing skin. Using CFRP in the ribs and spars also led to an 11% weight reduction. Beyond material choice, the research highlights the critical role of ply sequence optimization. Variations in ply orientation were shown to significantly influence von Mises stress and displacement. Specifically, the ply sequence [0/90/+45/-45/90/0] is identified as a configuration that yields better performance for composite wing design, effectively balancing structural integrity and weight efficiency. These findings provide valuable insights for optimizing composite wing designs in aircraft.

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