DESIGN, OPTIMIZATION AND FABRICATION OF UAV WING

A Final Year Project Report

Presented to

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

All across the globe, reduction in the use of Energy is becoming a necessity by each passing day. As fossil fuel reserves are depleting and demand of energy is increasing, so weight reduction is the technique to lower the energy consumption. The prime and foremost objective of this project is design, optimization, and fabrication of a UAV wing, where weight reduction is done by replacing ribs by hexagonal lattice structure while maintaining structural integrity to produce a fully functional prototype.

Two types of research were conducted; primary research includes Market Survey, Experimental Data and Consultation with Experts and secondary research which contains Research Papers, Journals and Online libraries, were employed to discern the significance of achieving this project. Extensive research is conducted along with relevant calculations (Load Calculation) to define the design specifications. Using these specifications, a 3D model of a UAV wing is developed employing solid modeling computer aided design software i.e SOLIDWORKS. Then the structural analysis is carried out using Finite Element Method Tools. The internal structure is replaced by lattice using Ntop and the model is optimized by changing lattice dimensions and FEA. The fabrication of UAV wings commenced through printing by 3-D Printer. In the end, experimental testing to check the stability of the developed wing is performed through wind tunnel and the results are documented.

ACKNOWLEDGMENTS

Firstly, we are deeply grateful to Dr. Aamir Mubashir, our supervisor, for his indispensable guidance and unwavering support throughout our project. Secondly, we appreciate the invaluable advice from Sir Ali Bin Naveed and Sir Asadullah. Thirdly, we thank our parents for inspiring us to exceed our own expectations.

Last but certainly not least, we extend our heartfelt thanks to SMME for their generous provision of resources and unwavering commitment to our success. Their support has not only facilitated the realization of our goals but has also empowered us to pursue our aspirations with resilience and conviction.

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ABBREVIATIONS

CO	Carbon Monoxide
CO2	Carbon Dioxide
NOx	Nitrogen Oxides
UAV	Unmanned Aerial Vehicle
IC	Internal Combustion
NACA	National Advisory Committee of Aeronautics
FEA	Finite Element Analysis
NTop	Ntopology Software

NOMENCLATURE

C_L	Coefficient of Lift
C_d	Coefficient of Drag
ρ	Density
V	Volume of Wing
A	Area of surface of wing

CHAPTER 1: INTRODUCTION

Motivation

The global usage of fossil fuels and batteries in UAVs is on the rise, while their reserves are dwindling. Moreover, commodity prices are escalating rapidly. Hence, it's imperative to seek a sustainable alternative, such as reducing weight by replacing conventional internal structures with lattice structures. Since less energy is required to power an object of lesser weight, a viable solution to this problem is weight reduction while maintaining structural characteristics. Based on empirical analysis, it's found that, on average, a commercial aircraft requires approximately 0.2 kg of fuel to transport 1 kg of weight over 1,000 km. And the average weight of an aircraft wing is 30ton approx. to 30000 and if we reduce the mass by 5000kg then we can save 1000kg of fuel for every1000km.

Furthermore, energy sources pose significant threats to the environment, notably global warming due to carbon emissions into the atmosphere and the extraction processes involved in obtaining battery chemicals from the earth. It is natural to go towards lightweight structures in the Future. Research is being conducted to make lightweight objects having long-lasting and cost-effective characteristics.

Problem Statement:

Design and optimized the lattice structure, to replace ribs of a UAV wing having NACA 2412 profile and to develop a working prototype of the UAV wing using PLA using 3D printers. The project revolves around the design of lattice structure i.e.choosing the lattice structure, its dimension. Followed by Analyzing section which ensures that the chosen lattice is best fit i.e. it reduced the weight while maintain structural strength as that of basic model. Then optimization and fabrication process willbe carried on at the end respectively. This project should employ the engineering knowledge we have gained and lead us through the intricate process of developing a complex engineering system, fostering our engineering and project management abilities. The outcomes derived from this project should assist us in identifying potential flaws in our approach, ultimately enabling us to overcome our limitations.

Objectives:

- **Design of CAD model and Load Calculations**
- **Structural analysis and design optimization using n-topology.**
- **Manufacturing of UAV wing using 3D-printing.**
- **Wing Tunnel Testing.**

Our first step is to develop a 3D model of UAV wing, from the chosen NACA 2412 profile based on the market research conducted. The model size is limited to manufacturing restraint. After the 3D model was completed, we have calculated loads that will act upon the UAV wing through theoretical calculations. N-topology stress analysis is utilized to assess the developed chassis under specified loading conditions and constraints. The Von Mises stress values obtained are then compared with the material's yield strength to determine the factor of safety. Additionally, the maximum displacement of the wing is measured and deemed satisfactory. Then optimization is carried on which is our main objective, to get the minimum while maintaining the strength of the basic model.

Then we will move on to fabrication. Fabrication will be done with the help of 3d printer and material chosen is PLA to make our prototype lightweight. Ultimately, the developed prototype will undergo experimental testing in a wind tunnel, replicating real-world operating conditions to assess and compare its performance. The findings from these experiments will be recorded, and recommendations will be provided to gauge the extent of success in achieving our objectives.

CHAPTER 2: LITERATURE REVIEW

With the increase in technological advances, UAVs have become a vital part of industries and sectors from agriculture and surveying to search and rescue. These are aircraft which can be remotely controlled or can fly autonomously through software and complex automation systems. UAVs typically consist of essential components: the airframe (body), propulsion system (electric motors, gasoline engines, etc.), control system (including onboard computers and sensors), communication system (for remote control or data transmission), and power source (usually batteries for electric UAVs). All of the above components serve a vital role in the manufacturing of Unmanned Aerial Vehicles, but the most vital one is its body better known as airframe.

The primary source of energy for an Unmanned Aerial Vehicle can be either an internal combustion engine or a battery source. An internal combustion engine uses fuel which is extracted from the ground in the form of crude oil and then distilled to make it usable. Lithium batteries require the naturally occurring element called Lithium which is drawn out of the ground using complex procedures. Both processes require energy, which is supplied through burning fossil fuels leading to an increase in pollution and decrease in natural resources. The primary constituents of these pollutants include carbon monoxide (CO), carbon dioxide (CO2), nitrogen oxides (NOx), and hydrocarbons. While recent progress in vehicle Emission After treatment systems is expected to mitigate these pollutants, the most readily reducible among them is CO2. Ultimately, the consequences encompass the greenhouse effect, glacier melting, diminished crop yields, weather fluctuations, as well as various other impacts yet to be fully understood.

In order to reduce the carbon footprint which is the main cause of all the pollution problems generating from fossil fuels, there can be two techniques; either the IC engines using fossil fuels be replaced by better alternatives or to reduce the usage of these fuels through increasing efficiency. Discovering better alternatives is a tedious task requiring research, development etc. What can be done is to increase the efficiency through weight reduction. Energy and weight are directly proportional to each other meaning more energy being required to move a vehicle of larger weight and vice versa.

Figure 1 Sustainable Development Goals

What is a UAV:

A UAV (Unmanned Aerial Vehicle), commonly known as a drone, is like a small airplaneor helicopter that doesn't need a pilot inside. It's controlled remotely by a person on the ground using a special controller, smartphone or through software-controlled flight plans or follow complex dynamic automation systems. Uavs can be used to do tasks like takingpictures or videos from the sky, delivering packages, helping with farming by checking crops, or even assisting in search and rescue missions. They're like flying robots that can go where it's hard or risky for humans to go, and they're becoming more and more useful in many areas of life. UAVs come in various shapes and sizes, from small handheld models weighing just a few grams to large military-grade drones with wingspans of several meters.

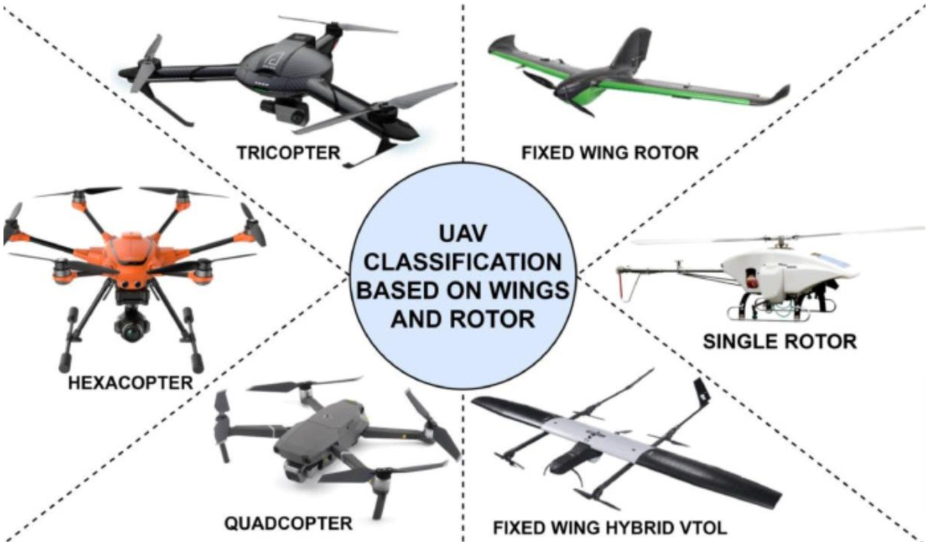


Figure 2 Classification of UAVs based on Wings and Rotors

What are UAVs used for:

Unmanned Aerial Vehicles (UAVs), or drones, have a wide range of uses across various industries and sectors. Here are some common applications:

- **Aerial Photography and Videography**
- **Agriculture**
- **Infrastructure Inspection**
- **Search and Rescue**
- **Mapping and Surveying**
- **Delivery Services**
- **Environmental Monitoring**
- **Defense and Security**
- **Disaster Response**
- **Scientific Research**

Airframe(body):

The most vital part of an Unmanned Aerial Vehicle is the airframe which consists of the fuselage and the wings attached to it. Fuselage can be considered as a hollow body which consists of all the electrical equipment and electronics while the majority of the weight for an airframe is the wings. The most conventional design for the wings is the ribs and spar design where the spars run along the length of the wing and ribs in between those spars along the width of the wing.

UAV Wing:

Despite the various styles adopted for aircraft wings throughout history, a fundamental design emerged early on and has persisted, in some variation, across most aircraft wings. This design incorporates a spar and numerous ribs to establish the airfoil shape, ensuring both longitudinal and lateral stability. In instances where necessary, a double spar may also be utilized to enhance structural robustness along the wing's length.. The following picture correctly depicts all the components of an aircraft wing.

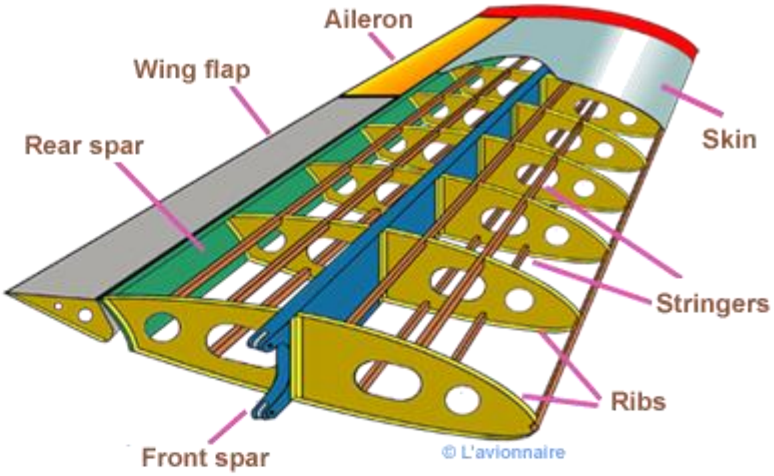
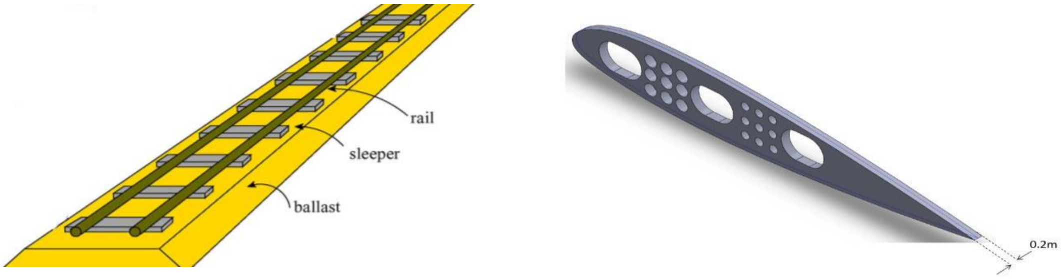


Figure 3 Conventional Wing Structure

A major contribution to the weight in the case of wing is its ribs which are made of solid material. Techniques can be used to reduce the weight of the wing.

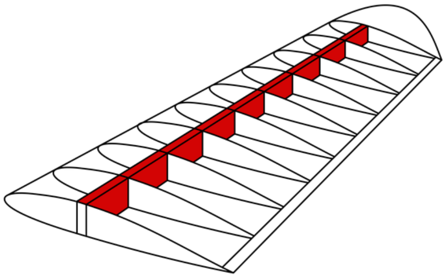
Ribs and Spars:

The internal structure of a wing in in the form of a railway line which includes the railway rail and the sleeper. In case of UAV wing the rail is given the name of spar which runs across the length of the wing while the railway sleepers are ribs in the internal structure of the wing.



Railway Line

Singular Rib



Wing Spar Highlighted in Red

Figure 4 Wing Components

Profile Used:

NACA (National Advisory Committee of Aeronautics) airfoil profiles were developed in the early 20th century due to their aerodynamic applications, especially in aviation. These profiles are characterized by numerical designations indicating their specific geometric shape. There are a number of types of NACA profiles. Here are some and their typical uses:

1. **NACA 4-Digit Series:**
    - These airfoils are defined by a four-digit number (e.g., NACA 2412).
    - The first digit represents the maximum camber in percentage of the chord length. The second digit denotes the position of maximum camber measured as a percentage of the chord. The last two digits represent the thickness-to-chord ratio in percentage.
    - Example: NACA 2412 has 2% maximum camber located at 40% of the chord length, with a thickness-to-chord ratio of 12%.
    - Uses: These airfoils are versatile and can be found in a wide range of applications, including general aviation, UAVs (Unmanned Aerial Vehicles), and small aircraft.
2. **NACA 5-Digit Series:**
    - These airfoils are an extension of the 4-digit series with an additional fifth digit.
    - The fifth digit represents the design lift coefficient of the airfoil.
    - Example: NACA 23015 has similar characteristics to NACA 23012 but is specifically designed for a higher lift coefficient.
    - Uses: Suitable for applications requiring higher lift coefficients, such as in some light aircraft and wind turbine blades.
3. **NACA 6-Series:**
    - These airfoils were designed for high-speed applications, particularly for transonic and supersonic flight.
    - They feature thin profiles optimized for minimizing drag at high speeds.
    - Examples include NACA 64Axxx and NACA 66Axxx.

    - Uses: Aerospace applications such as supersonic aircraft and high-speed missiles.

We have used NACA 2412 profile since it is generally used in Unmanned Aerial Vehicles. The NACA 2412 airfoil is a part of the NACA 4-digit series. Its designation:

- "24" indicates that the maximum camber is 2% of the chord length, and it's located at 40% of the chord length.
- The "12" signifies that the thickness-to-chord ratio is 12%.

So, the NACA 2412 airfoil is characterized by 2% maximum camber located at 40% of the chord length and a thickness-to-chord ratio of 12%.

Weight Reduction:

The idea of using lattice structures in wing designs suggests that replacing key parts of wings with lattice structures could potentially improve weight, strength, and cost. The main aim is to explore if these lattice structures can be used to reduce weight while increasing strength, although it's unlikely that they would be cheaper initially compared to current methods.

Lattice structures are naturally found in things like crystals at a molecular level, such as quartz, as well as in organic materials like wood and honeycombs. Honeycombs are a clear example of a structured pattern in nature, even though they're only 2D, while full lattice structures need a 3D arrangement. Honeycombs are a great example in nature because they're visible to us, helping us understand what's happening on a smaller scale within various materials.

The strength of many crystalline materials comes from their molecular lattice structures. The idea is to take advantage of these benefits on a larger scale within aircraft wing structures, particularly in light attack aircraft. Currently, only certain basic lattice designs, like triangular, cubic, hexagonal, and octagonal, can be efficiently made.

Examples of these structures can be seen below in Figures.

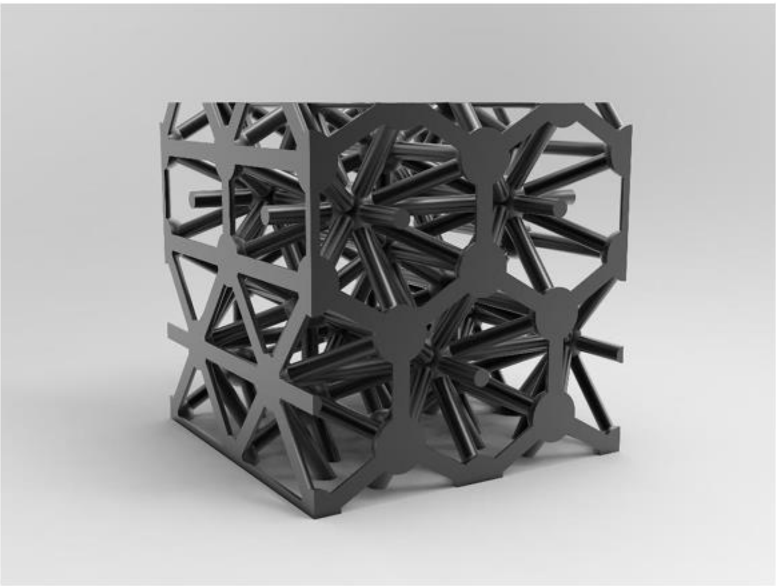


Figure 5 Triangular Lattice Structure

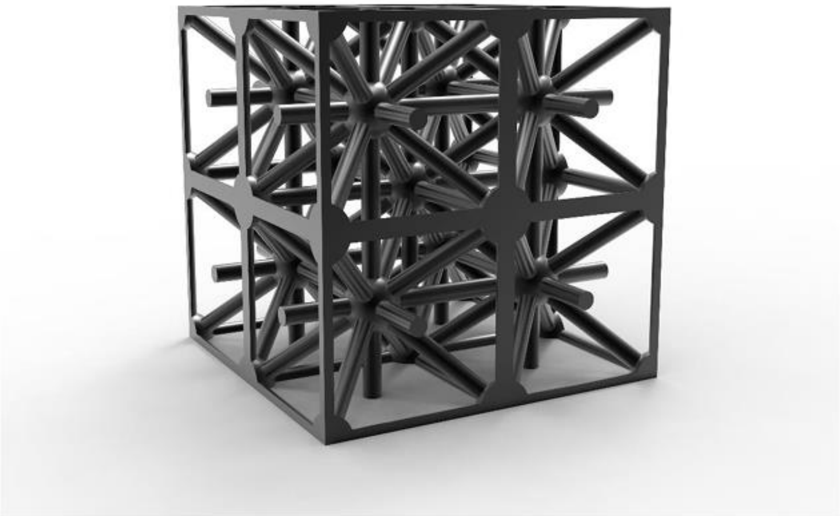


Figure 6 Cubic Lattice Structure

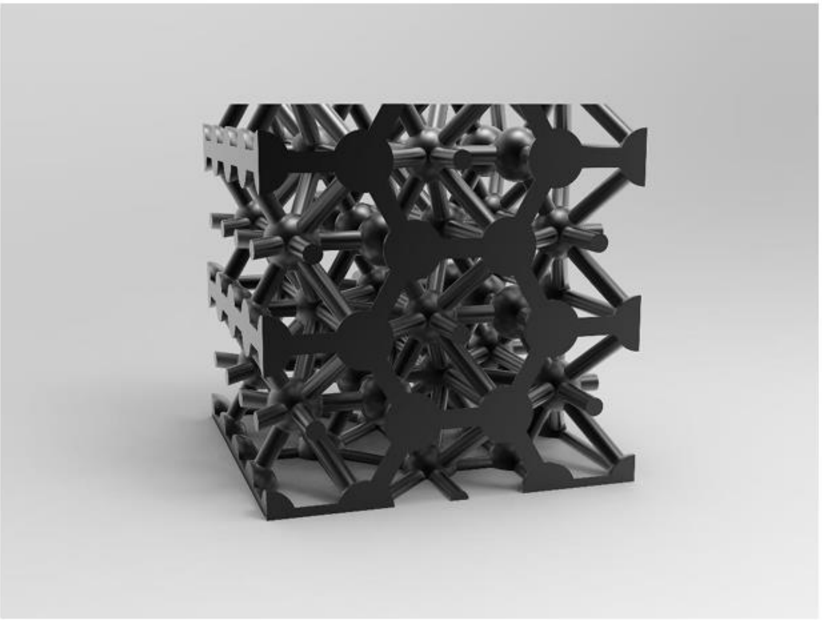


Figure 7 Hexagonal Lattice Structure

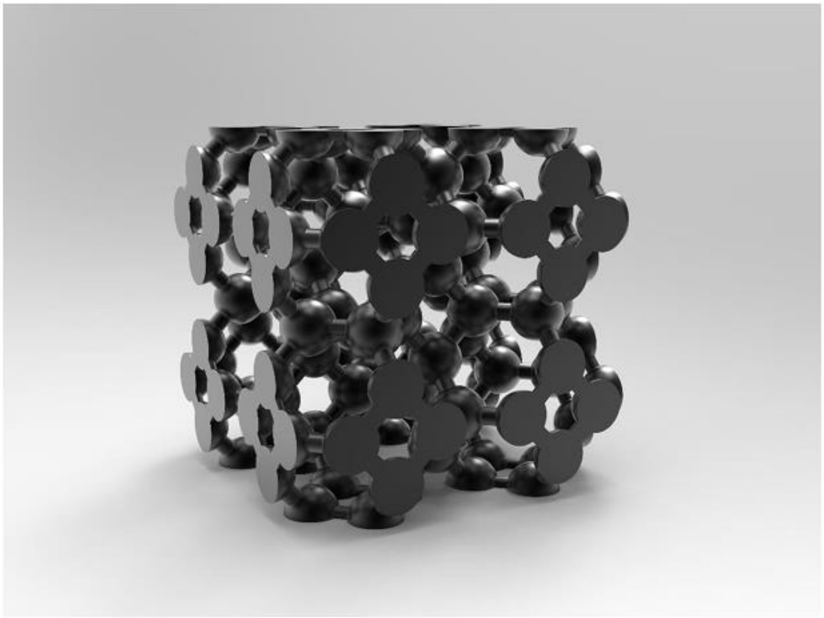


Figure 8 Octagonal Lattice Structure

There are clear distinctions directly related to their names when we examine these structures. These lattices are known as ball and strut lattices, owing to their sphericalshaped "ball" hubs connected by cylindrical struts. The triangular lattice forms a 3D triangular and hexagonal pattern, creating a robust connection between different sections. The cubic lattice is perhaps the most familiar, forming small cubes as the primary pattern. The hexagonal lattice is typically considered the strongest due to its high relative volume packing. This strength comes from the staggered ball pattern, where the balls in one layer lie between those in the next layer, resulting in both the highest volume packing and the strongest lattice.

However, the strongest lattice may not always be necessary, as the objective is to optimize wing structures for light attack aircraft in the most efficient manner. While it may exhibit strength in subsequent tests, it also tends to be the heaviest, requiring more material and time to produce, thus increasing costs.

Then there's the octagonal lattice, which, despite its organic appearance, leaves considerable open space between the balls and struts, creating large voids within the cell centers. Due to its increased voids and complexity, the octagonal lattice is the most labor-intensive to create, making it unsuitable for aircraft application. Because of its open structure and high material requirement, the octagonal lattice isn't suitable for the relatively budget-friendly light attack aircraft.

To better understand the fundamental structures of these lattices, the renderings in the figures maintain similar characteristics. Each lattice network has an overall cube structure measuring 10 inches by 10 inches by 10 inches, with each lattice cell set at 5 inches by 5 inches by 5 inches. However, the octagonal lattice defines its cells easily with small 3D octagons made up of 16 balls and struts. The triangular lattice forms a triangular prism, the cubic lattice forms a cube, and the hexagonal lattice forms a hexagonal prism. The balls in each lattice are 1.5 inches in diameter, while the struts are 0.5 inches in diameter. This feature isn't so much an optimization technique as it is a way to consistently test the structures with minimal alterations to their overall structure. With these sizing characteristics, it's easy to calculate not only the void volume in the structures but also the weight and volume of the material used for each.

CHAPTER 3: METHODOLOGY

Creating and refining the design of a UAV wing to minimize weight is a detailed process that demands meticulous planning and execution. To meet our goals within the specified timeframe, we've organized our tasks efficiently and formulated a master plan that's both effective and streamlined. Our systematic approach begins with identifying design requirements and then outlining the necessary steps to fulfill them. Below, we provide a detailed chronological account of the methodical approach we've employed to accomplish the project deliverables previously established.

Design considerations:

At the onset of any engineering endeavor, the initial step is to recognize and define the design considerations, which serve as the foundation for the design process. These considerations are shaped by various external factors such as customer requirements, prevailing market trends, and design limitations.

Weight and Size

In the development of a UAV wing, the weight and dimensions of the wing play crucial roles in influencing flight performance. Wings with increased weight demand more power, while larger size imposes design limitations. In our project, thorough research led us to design our model with a span length of 300mm. This choice aligns with the capabilities of our 3D printer, the Ultimaker S5, which offers a built volume of (320 by 152 by 154) mm.

Cost Effective:

For the developed UAV wing to be economically viable, it must be cost-effective to ensure competitiveness within the market. Regardless of the design's strength and efficiency, if it isn't economically efficient, it won't sustain itself in the market. One significant factor that drives up project costs is the absence of locally sourced parts. In our model, we've aimed to incorporate locally procured equipment and materials as much as possible to minimize the costs associated with prototype development.

Factor of Safety

Each mechanical part is provided with a factor of safety. As it is important for the component (which in our case is UAV wing) to withstand given loading. Factor of safety is applied due to

- Uncertainty in Material Properties:
- Unpredictable Loads
- Simplifications in Analysis
- Imperfections in manufacturing processes
- Materials degrade due to wear and fatigue.

Usage of hard materials in structural components and avoiding stress concentrations can greatly improve the factor of safety.

Data Collection:

Data collection will help in finalizing design specification. As we progress through our project stages—concept development, idea visualization, 3D models creation, testing, and refinement—we gather data from various sources. This includes both primary data, obtained through market surveys and expert consultations, and secondary data sourced from research papers, journals, and online resources. This comprehensive approach ensures informed decision-making, integrating technical excellence with market alignment and cost-effectiveness.

Design Specifications:

After design considerations we came to know that the span length is 300mm and from the market research conducted we came to know that average cruise velocity of UAV is 15 m/s and aerofoil profile used in UAV wing is NACA 2412. We also get to know that the normally ratio between span and chord is 6 so we choose chord to be 75mm. As we don't have any requirement of desired lift so we use this ratio, otherwise it can vary depending on the required lift.

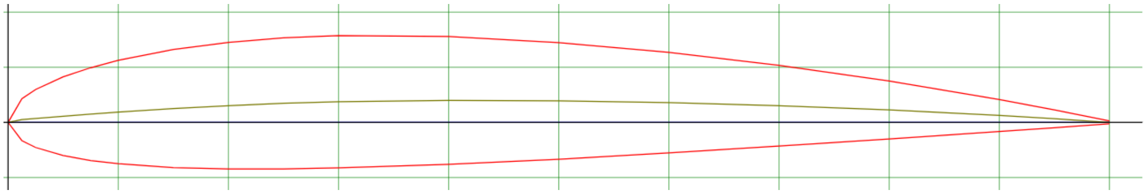
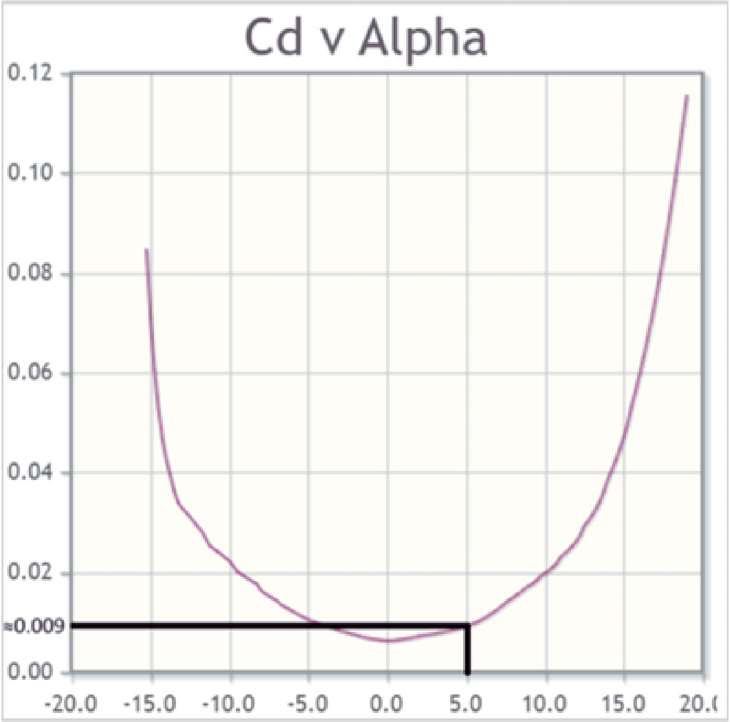


Figure 9 NACA 2412 Profile

The NACA 2412 profile has drag coefficient c_d=0.009 and lift coefficient c_L=0.8 at angle of attack of 5^0 which can be find from the figures. The UAV wing is design at this attack angle because it provides maximum ratio of c_L and c_d as the aim is to design wing for maximum lift.



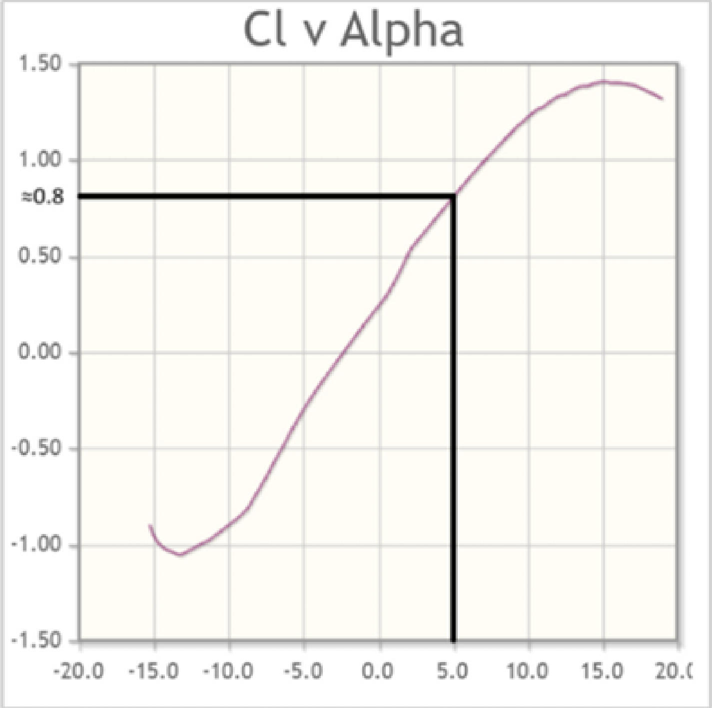


Figure 10 Coefficient of Lift and Drag for NACA 2412 versus Angle of Attack

Sr NO	Design Parameter	Value
1	Span	300mm
2	Chord	75mm
3	Aerofoil	NACA-2412
4	Drag coefficient	0.009
5	Lift coeffecient	0.8
6	Attack Angle	5^0
7	Cruise Velocity	15m/s

Table 1 Design Parameters

Load Calculations:

The main loading acting on the UAV wing is drag and lift force. As we know drag force is

$$Drag\ Force\ D = \frac{1}{2} c_d \rho V^2 A$$

$$Drag\ Force\ D = \frac{1}{2}(0.009)(1.23)(15)^2(0.3 * 0.075)$$

$$Drag\ Force\ D = 0.028N$$

As the drag force is acting on both side of the aerofoil so the drag force will be twice which will be 0.056N

As we know lift force is

$$Lift\ Force\ L = \frac{1}{2} c_L \rho V^2 A$$

$$Lift\ Force\ L = \frac{1}{2}(0.8)(1.23)(15)^2(0.3 * 0.075)$$

$$Lift\ Force\ L = 4.98N$$

Loads	Value
Lift Force	$4.98N$
Drag Force	0.056N

Table 2 Lift and Drag Force Values

Model Development:

Considering the design considerations for the UAV wing, we've arrived at a conceptual model that will serve as the foundation for our project. We will design model considering only ribs and spars in the internal structure of the UAV wing to minimize the complexities in manufacturing, so we can focus on our goal which is ultimately weight reduction. As the size of our model is finalized, we move on to the selection of other supporting systems which will constitute the model. These systems arevital to the operation and include ribs and spars.

3D model development:

The 3D model of the wing is developed in SolidWorks. We used rectangular tubes to form the spars. The curved end is used at end, to remove stress concentrationat corner. The reason of selecting this shape was having ease in 3D printing, so the part can be produced with least defects. The ribs will be same as that of NACA 2412 profile, sothat the spar shape shouldn't deflect permanently.

SolidWorks Model Development:

For CAD modelling of the wing we opted for a scaled down model of a UAV wing in SolidWorks. Scaling down helps in achieving quicker FEA results and analysis while maintaining the credibility of the obtained results. NACA 2412 profile was selected for the wing since it has diverse applications in UAV field.

First, we obtained the profile data of NACA 2412 from airfoiltools.com and imported it in SolidWorks to create the side profile of wing.

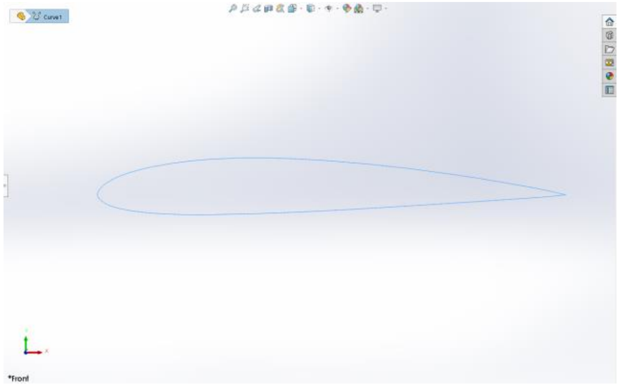


Figure 11 Outline of NACA Profile

After extruding the profile for a width of one rib which was chosen to be 10mm, we obtained one rib.

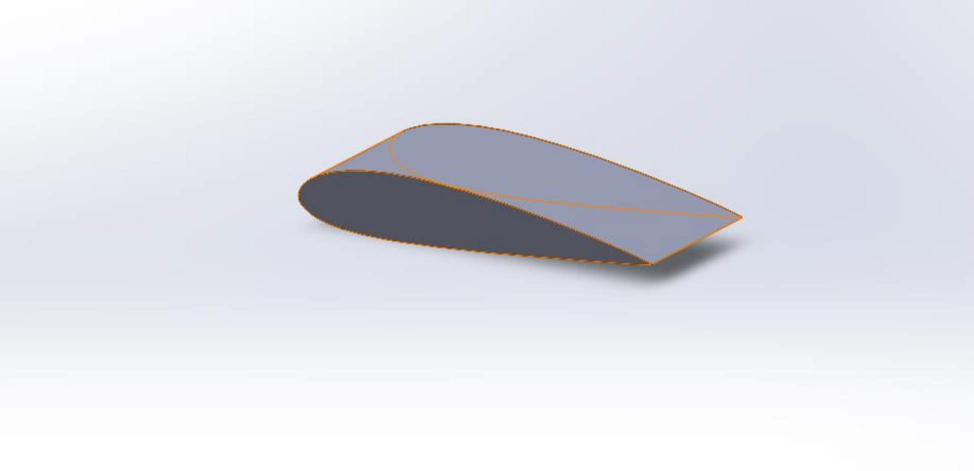


Figure 12 Extruded Naca Profile

Linear pattern feature was applied to get 8 ribs with a spacing of 70mm for the wing along the span as shown below.

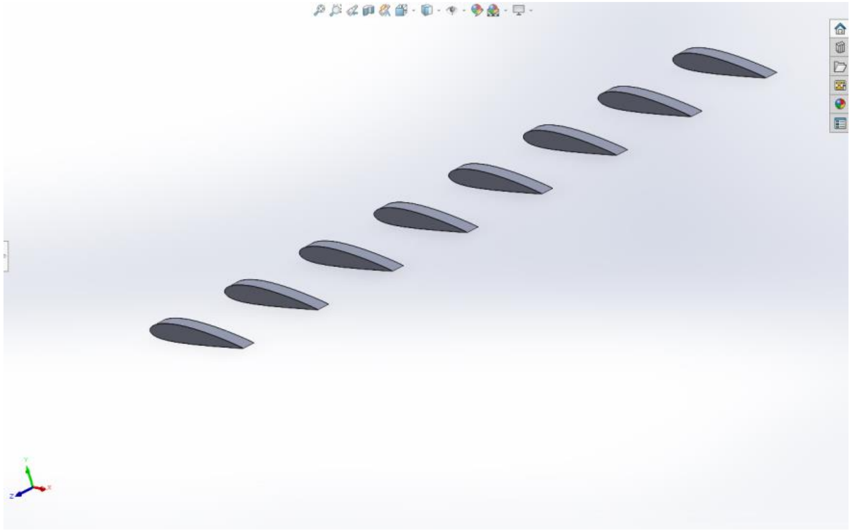


Figure 13 Application of Linear Pattern Feature

Rectangular spars were chosen for simpler analysis. First, a 9mm x 5.25mm hole was created through all ribs for spar 1.

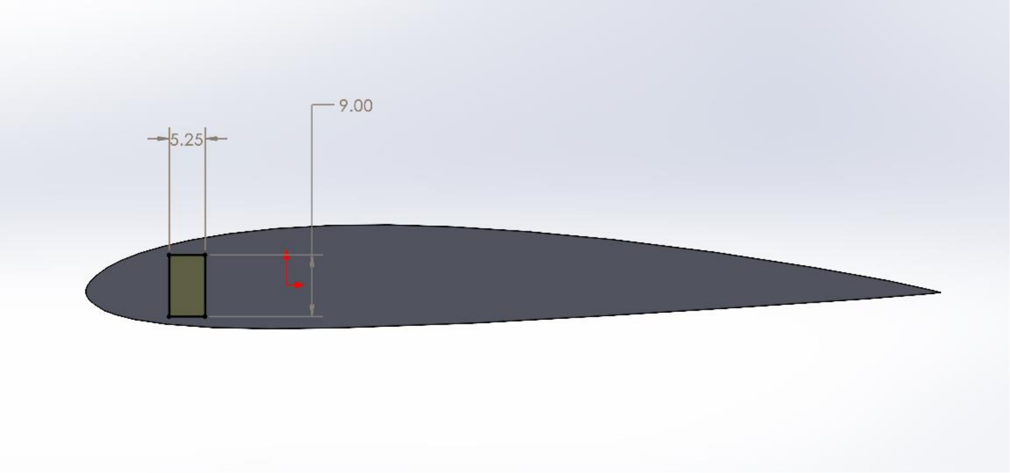


Figure 14 Hole for Spar 1

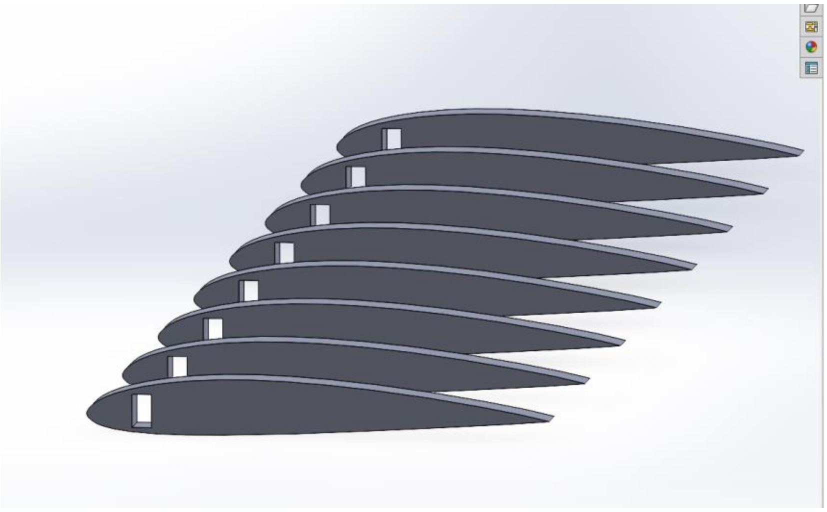


Figure 15 View of all Ribs with Spar 1 holes

For spar 2 we adjusted as 5.5mm x 5mm dimensions.

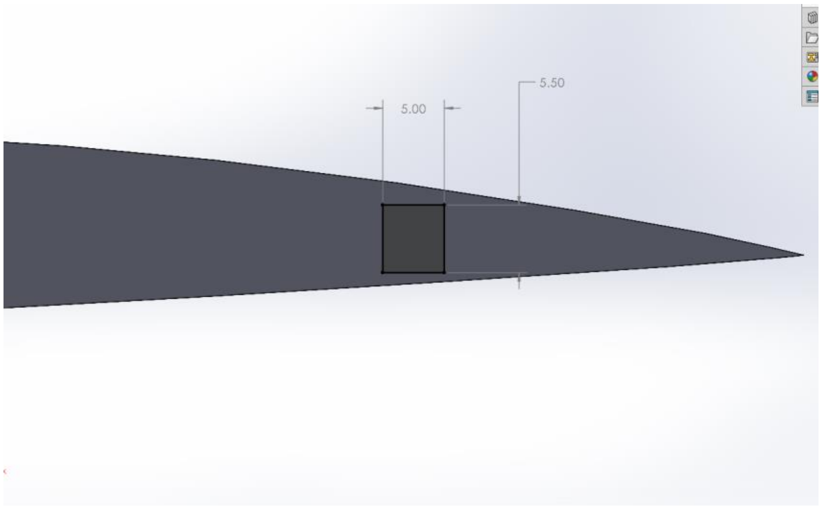


Figure 16 Hole for Spar 2

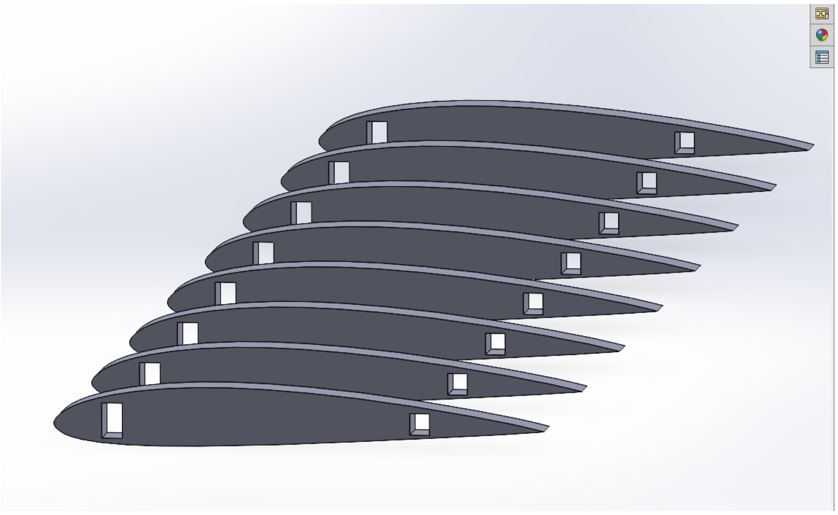


Figure 17 View of Ribs with Spar 1 and Spar 2

Figure 18 Ribs and Spar Design

Then the model was scaled in x-y plane for our need to make the chord 75mm. It is important to remember that the span to chord ratio here is taken to be 4 which is quite common in such applications.

Three lightening holes were introduced with these dimensions in millimeters. These are usually applied in many real-world cases.

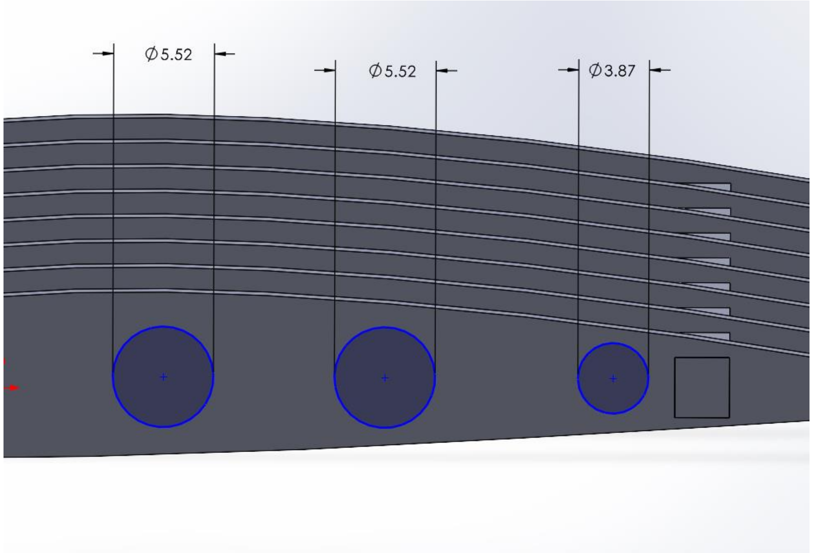


Figure 19 Ribs with Lightening Holes

This is the final internal structure of the wing.

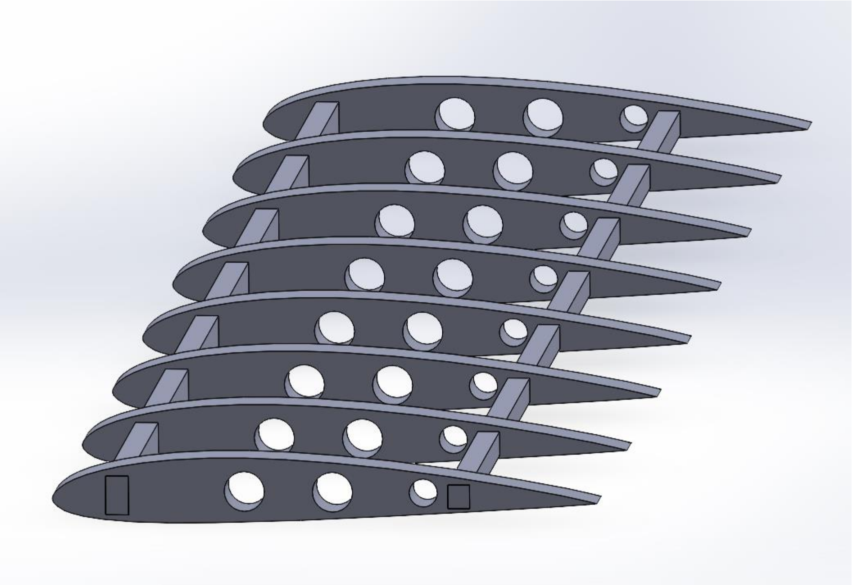


Figure 20 Finalized Structure

Later, we applied a 1mm thick sheet on all sides of the internal structure to get:

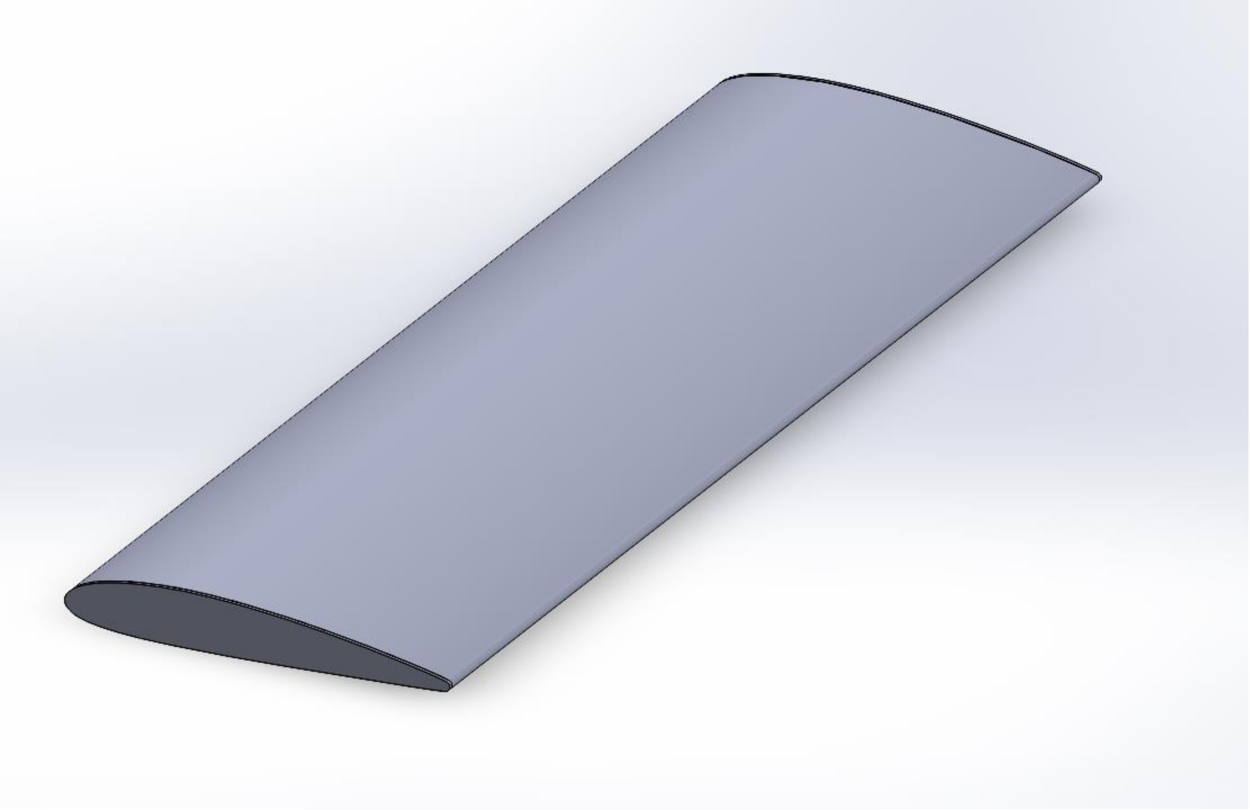


Figure 21 Wing with Internal Structure and Surface Sheet

Tabular Summary of Dimensions

Feature	Dimension (mm)
Chord	75
Span	300
Sheet Thickness	1
Spar 1 width	5.25
Spar 1 height	9
Spar 2 width	5.5

Spar 2 height	5
Hole 1 Dia	5.52
Hole 2 Dia	5.52
Hole 3 Dia	3.87

Table 3 Wing Features Dimensions

Material Selection:

Choice for material is based on the factors including lightweightness, other material properties, cost, availability and choice of material should also be 3D printed by 3D printers. Keeping in view our budget constraints and availability of materials, we have opted for Pla (Polylactic Acid). It has flexural strength of 40MPa.

Figure 22 PLA Material Spool for Ultimaker S5

ANALYSIS:

The analysis of our model consists of the Finite Element Analysis and the experimental testing will be done when the model is fabricated.

The stepwise summary of this analysis is given below.

Static Analysis:

Finite Element Model Generation:

To generate the Finite Element Model for our static study, we must undertake several steps, beginning with geometry development, followed by material definition, application of loads and constraints, and finally, mesh generation. The detailed step-by-step process is outlined below in chronological order.

Material Definition:

Once the model geometry is set, the subsequent step involves assigning a material to it. This process establishes the material properties, encompassing parameters like density, Young’s Modulus, and other relevant material characteristics.

Sr No	Material Properties	Values
1	density	0.00125g/mm^3
2	Yield strength	27Mpa
3	Young Modulus	4.1Gpa
4	Poison Ratio	0.35

Table 4 Material Properties with Values

Constraints:

To support the wing, fixed constraints are applied to the model. These constraints are strategically positioned to simulate real-life loading conditions on a wing. Specifically, they are applied to one side of the wing, mimicking the fixed end, akin to a wing's attachment to its fuselage in practical aviation scenarios.

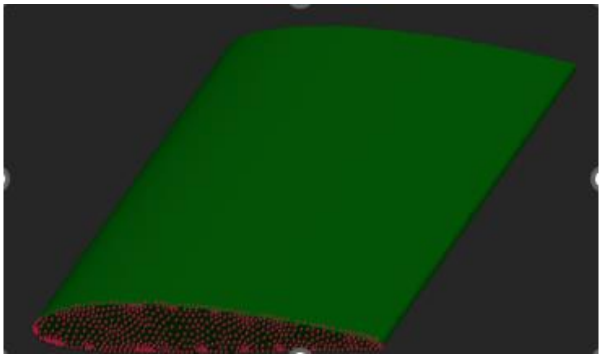


Figure 23 Fixed Side Shown in Red dots

Applied Loads:

A distributed load is applied on the top surface of the airfoil which will be drag force. Another distributed load is applied on the bottom surface of the airfoil which willbe drag force and the lift force as the net lift force direction is upwards. The magnitude ofthis load is calculated and shown in the section of loads calculation. The load distribution can be easily understood by referring to the figure provided below.

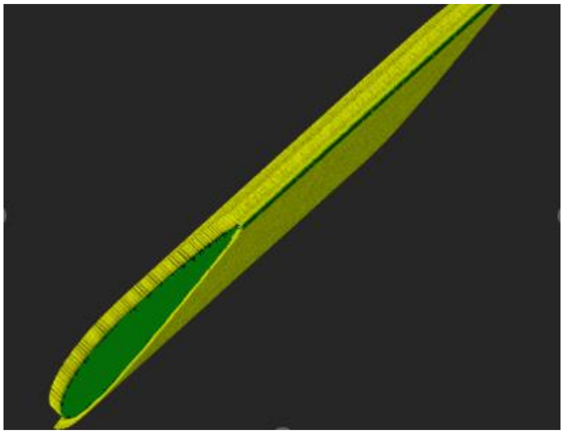


Figure 24 Load on Top and Bottom Surface

Mesh Generation:

In our research, we employ a physics-controlled mesh generation approach. Initially, we calculate benchmark results using coarse mesh elements. Subsequently, we systematically reduce the mesh element size to examine how changes affect convergence or divergence from the benchmark value. Furthermore, we utilize finer mesh elements at sharp edges and contours to address stress concentration areas.

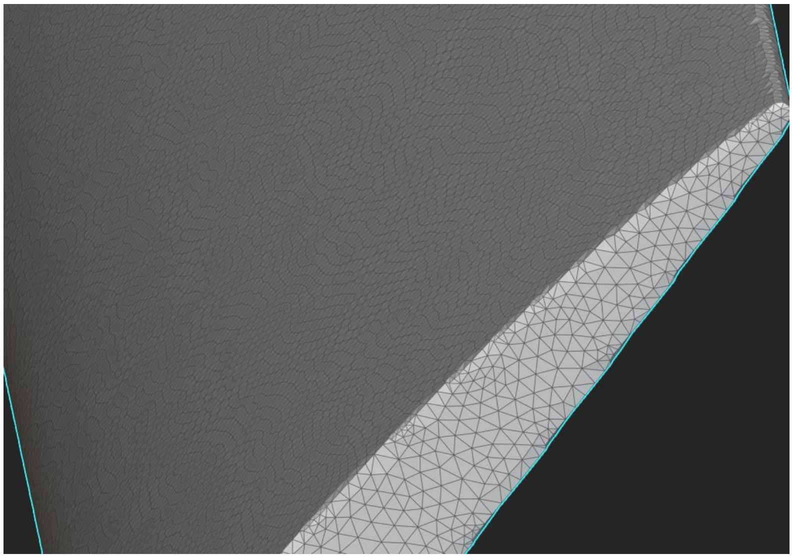


Figure 25 Mesh Pattern on Wing

Lattice Selection:

As we chose the method to reduce the weight is replacing the ribs by lattice structure from the research we have conducted. We came to know that the honeycomb hexagonal lattice structure is best used in wing application. Because as we know the major loading on wing is bending and some torsional loading so chosen lattice is best for this purpose. You can see the detailed reason of selection in table below.

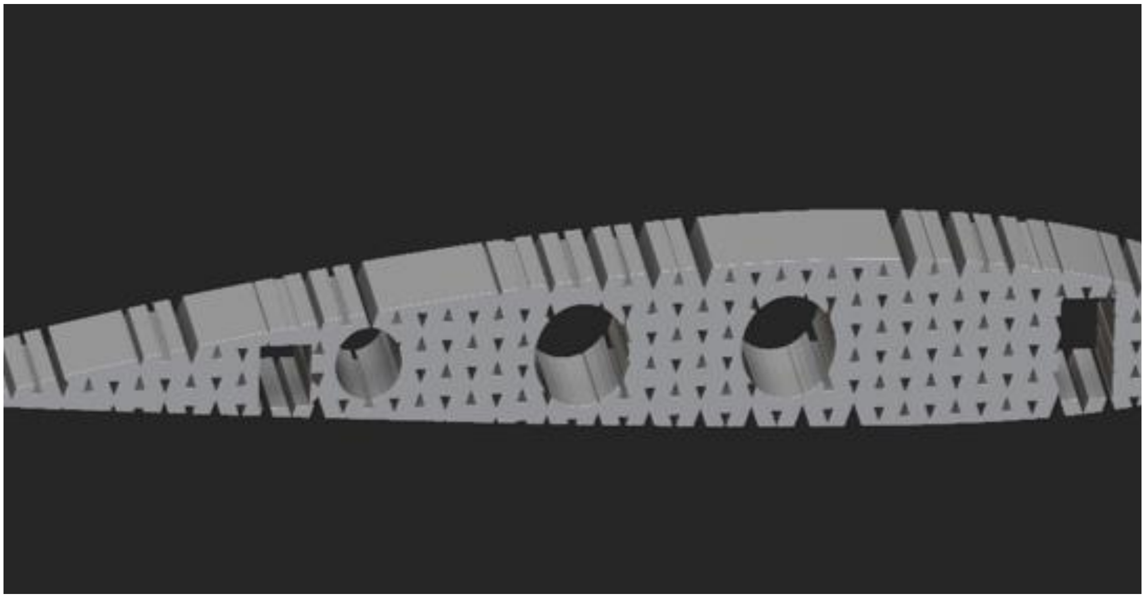
Lattice Structure	Properties
Hexagonal honeycomb	• Strongest along L-Direction • Best for Compressive and Shear Stresses
Re-entrant	• Low Ductility • Less Fracture Stress
Daimond	• High Stiffness • High Compression Resistance

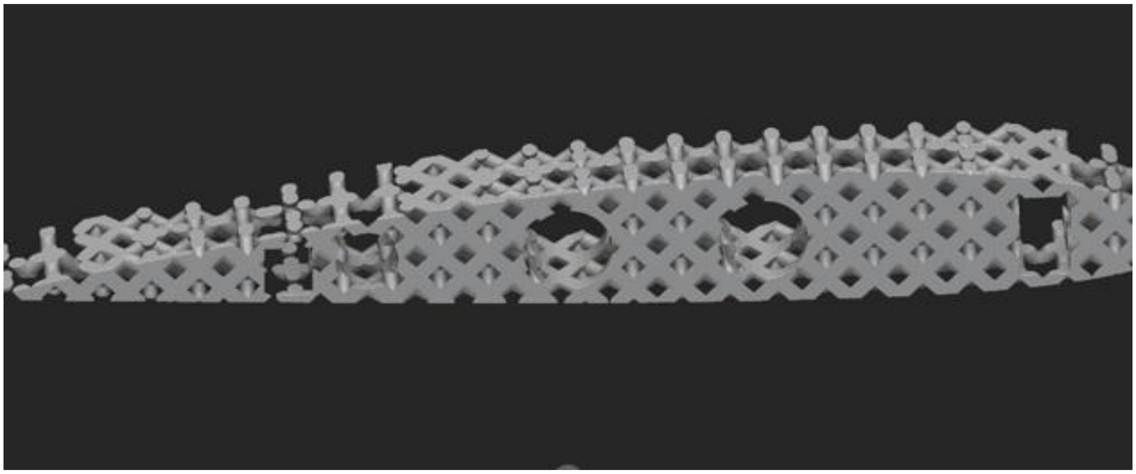
Table 5 Different Latice Structures and its Properties

Replacing Solid Ribs with Lattice Ribs:

In this step we will replace the solid ribs in the internal structure with lattices ribs to achieve our goal which is weight reduction. This process was not a one-step phenomenon, and it goes through several hits and trials to achieve a structure which will be of minimum weight and should have same strength as that of solid model. Different orientation of lattices and size of lattices were selected, and Finite Element Analysis and weight calculation was done for each trial to test that achievable strength is same as our basic model and have the least weight.

Different Lattice iterations are shown below to explain how the final lattice structure was selected.





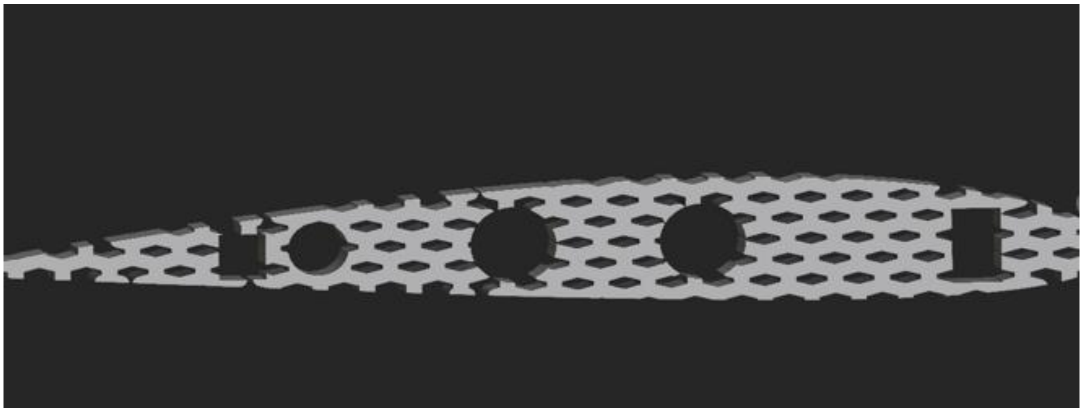


Figure 26 Lattice Iterations 1,2 and 3

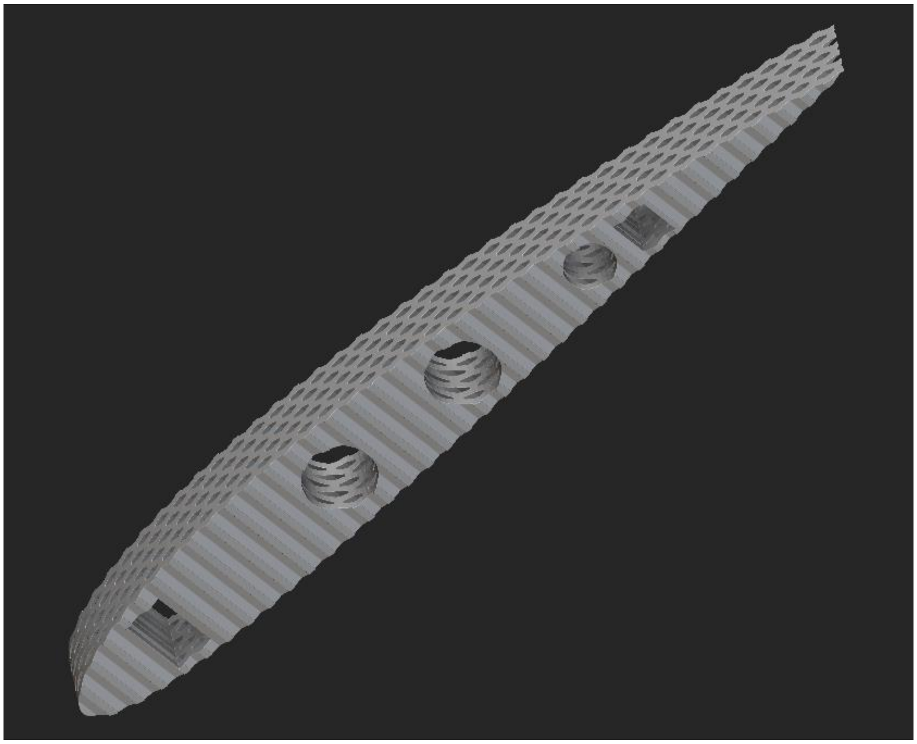


Figure 27 Finalized Lattice Structure

Lattice Density Variation:

To reduce further weight the density of lattice (i.e. lattice thickness and dimensions) was changed throughout the span of the wing. Greater density was observed near the support (due to greater stress concentration) and lesser density at the tip of the span (due to less stress).

The picture is shown below:

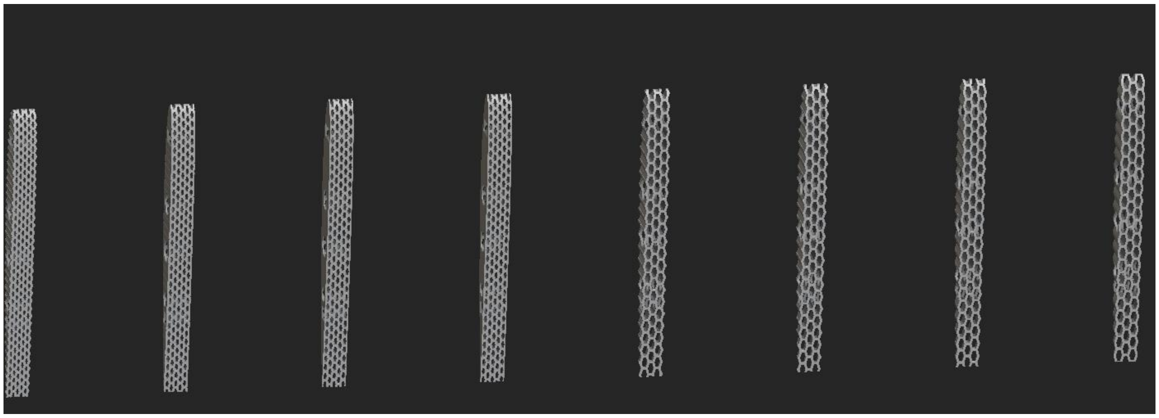


Figure 28 Lattice Density Variation Across the Wing

The left side shows the rib at the support and right side shows the rib at the far end of the wing.

Internal Cover:

One of the other techniques which was used to reduce weight was replace some of the internal part of the wing to lattice.

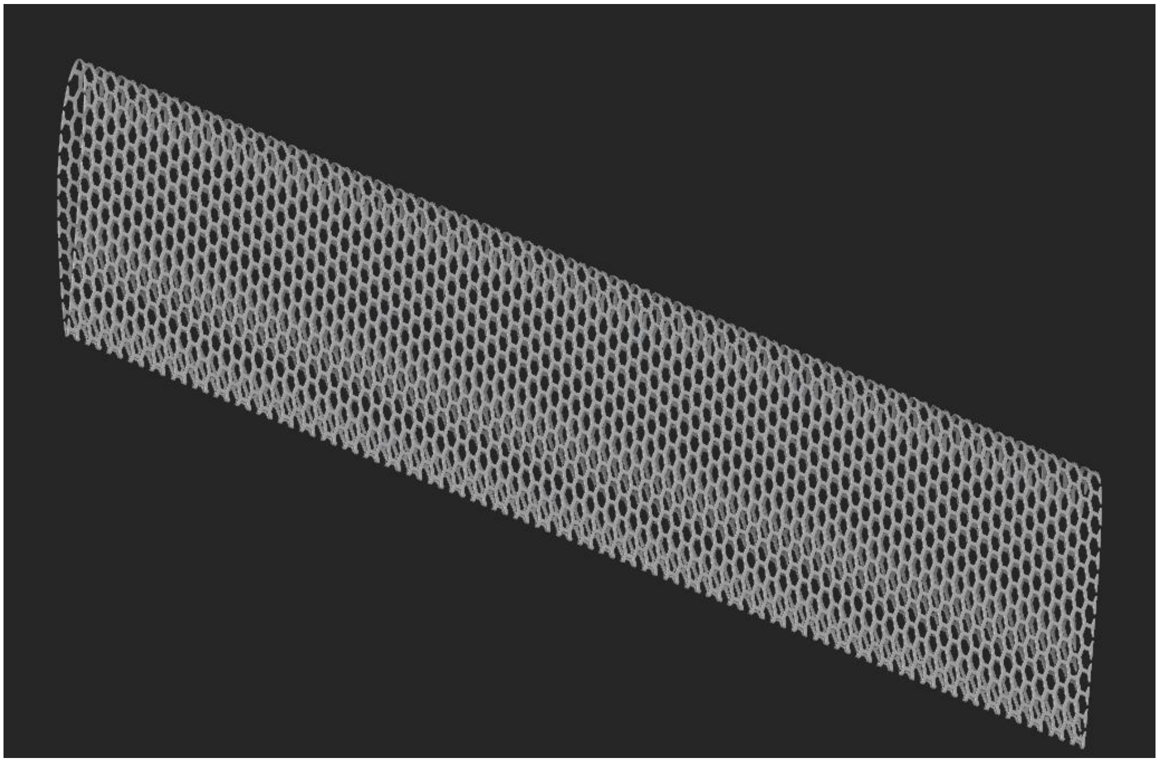


Figure 29 Internal Cover

Finite Element Analysis:

Again, FEA was performed on the model containing lattice and iteration was performed on the bodies containing lattice, so the structural strength and deflection should remain same as that of the solid model.

Manufacturing:

Manufacturing of wing is carried out by Ultimaker S5 R2, and the material used was PLA:

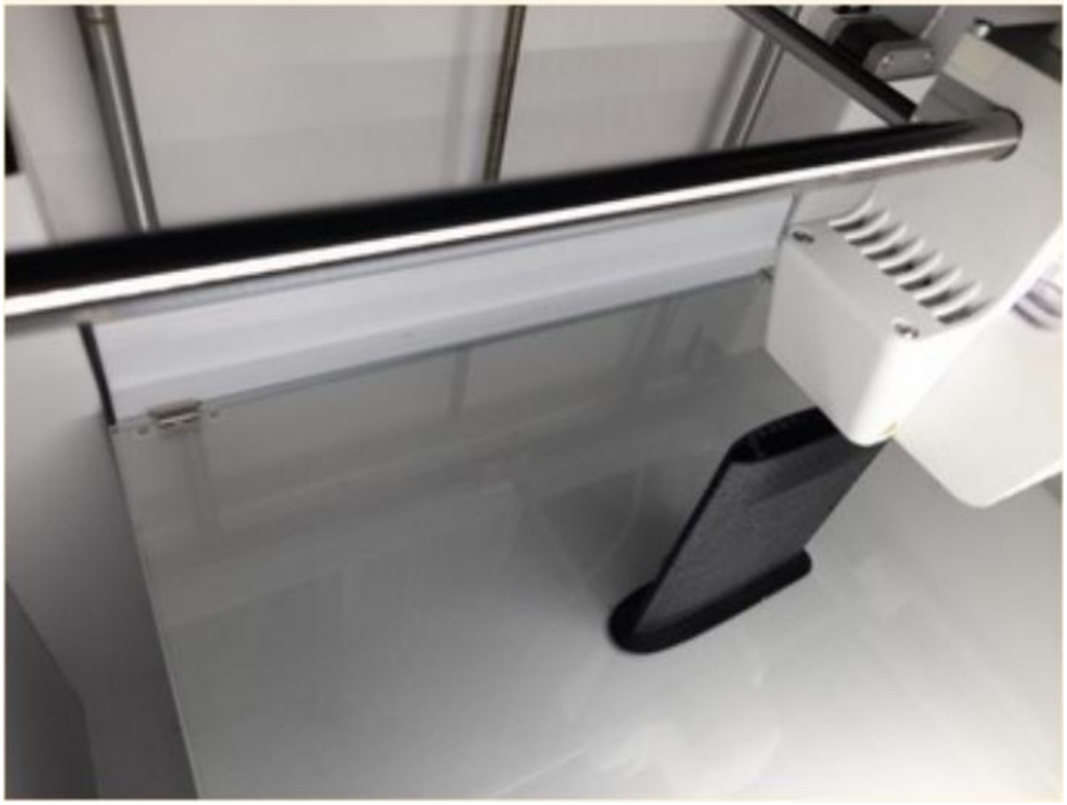


Figure 30 Ultimaker S5 R2

3 Point Bend testing:

The 3-point bend testing was performed on the weakest rib and the failure stress was measured and compared with the ultimate tensile stress, 2 samples were tested and the stress at which failure occurs was almost the same and were in the safe limit.

Figure 31 Three Point Bend Testing

Figure 32 3-Point Bend Testing Performed on Weakest Rib

Wind tunnel testing:

To test the whole wing some real-world environment is to be provided, so for this case wind tunnel testing is used, the tunnel dimensions were (18 by 18 by 36) inches. The attachment on which the mount (on which wing is fastened) is to be attached, is at the middle.

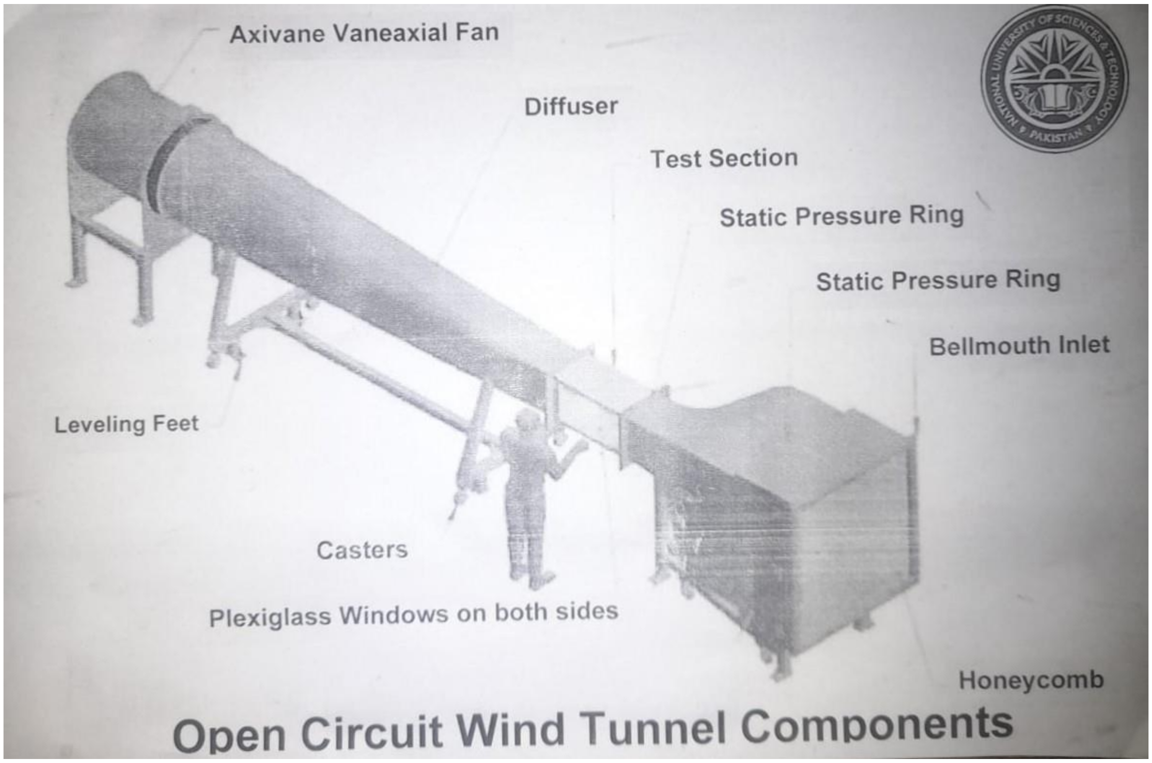


Figure 33 Open Circuit Wind Tunnel

So, at one side there is a space of 9-inch 230 mm and our wing is of 300m so the mount was designed in such a way so the wing can be placed inside the tunnel

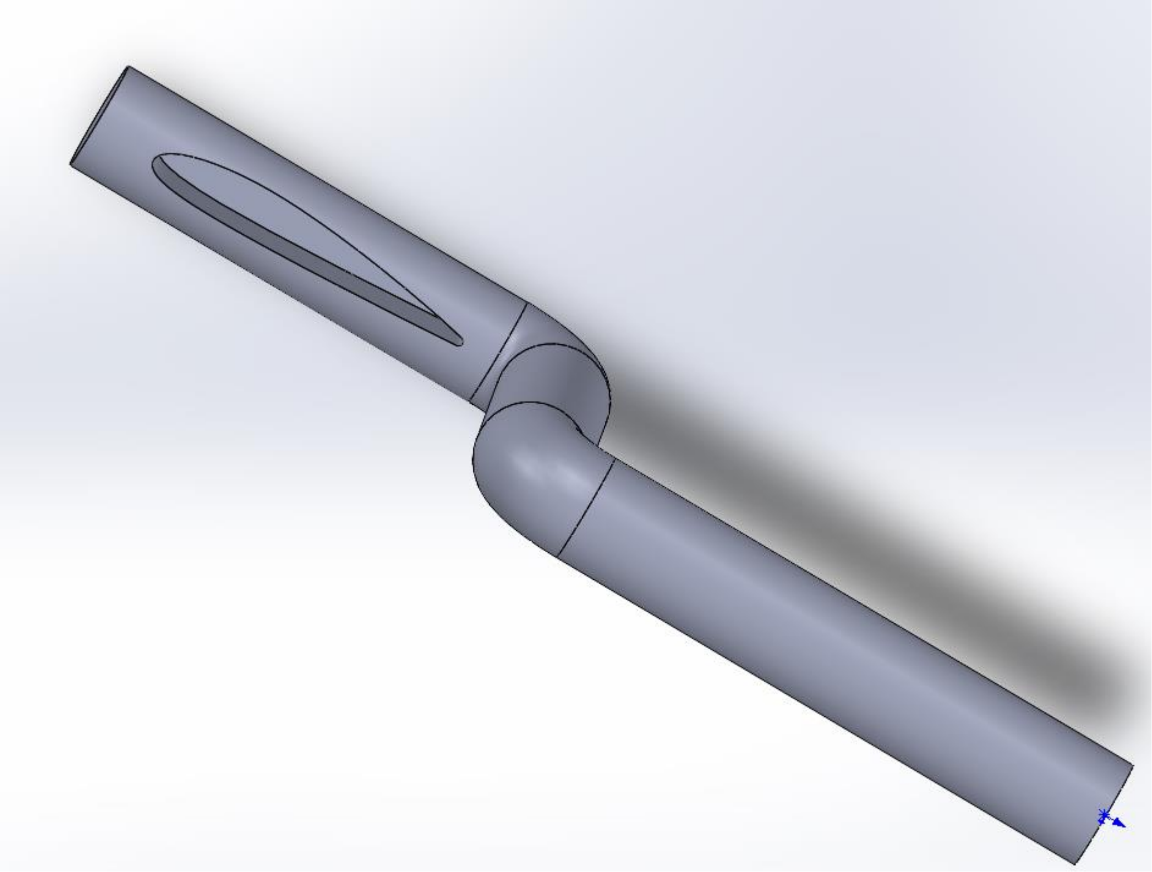
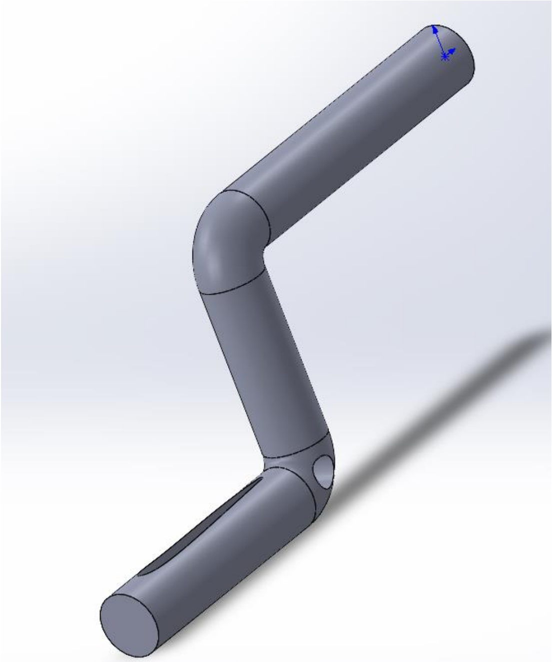


Figure 34 Support for Mounting Wing in Wind Tunnel

This is the reason why mount is not straight. The airfoil shape groove is given inside it so the airfoil can be attached to it.

The hole was given beneath the mount (and support was inserted in it, which rest up to the ground) so that the failure of mount due to torsion should not occur.



The attachment of the wind tunnel is to be attached to the mount through the annulus shown:

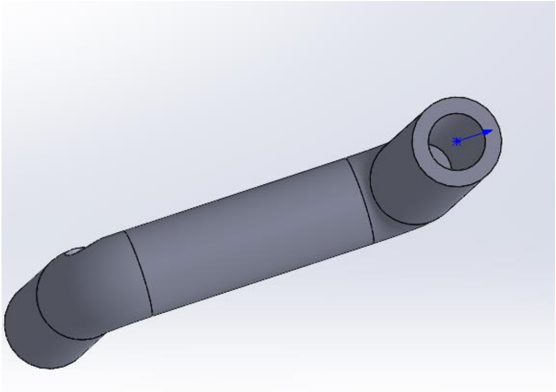


Figure 35 Wind Tunnel Rod Inserted in circular hole highlighted.

The whole mechanism was installed in the wind tunnel and testing was done.

CHAPTER 4: RESULTS AND DISCUSSIONS

The wing underwent a vertical load of 4.98N to simulate lift, along with a horizontal force of 0.056N representing drag, in addition to its own weight, all under specified constraints. The analysis aimed to determine the von Mises stresses resulting from this loading. It is crucial that the maximum von Mises stress remains below the yield strength to prevent chassis yielding caused by the applied load.

Our result and discussion section will comprise of two sections. First will show that stresses on the solidworks solid model will be less than the yield strength of the PLA(Polylactic Acid) material.

And the other section will confirm that the structural integrity of the final model in which solid ribs were replaced by lattice ribs is same as that of our basic model.

First Section:

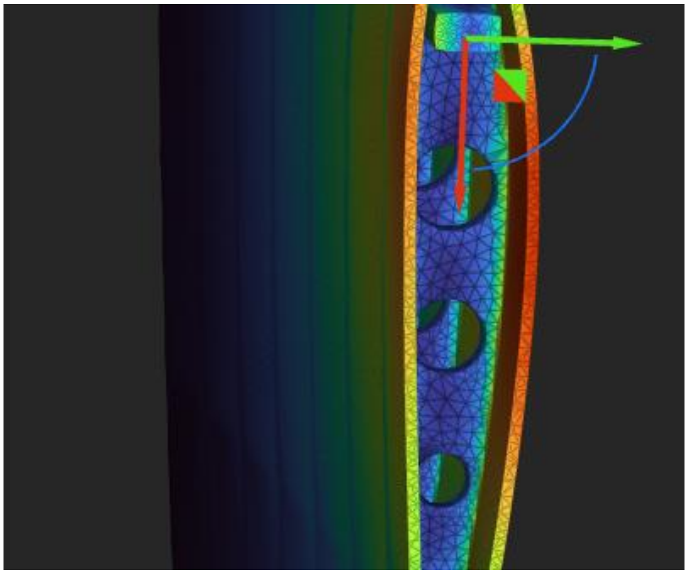


Figure 36 Cross-Sectional View of Solid Rib and Spar Model

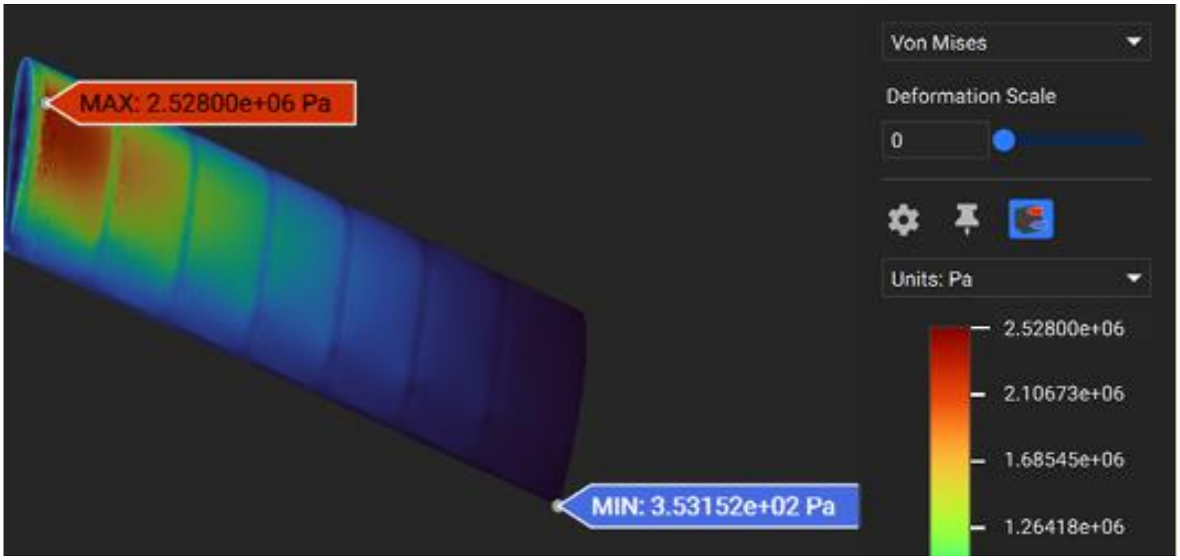


Figure 37 Von Mises Stress Result

The maximum and minimum stress were found out to be 2.53Mpa and 353Pa, while the total mass of the basic model was 89g.

Discussion:

From the results of the von mises stress it is clear that the maximum stresses are less than the yield strength i.e wing will not yield on application of loading. The maximum value of stress is 2.53MPa which is less than yield strength of 27MPa. The factor of safety is 10.6

Second Section:

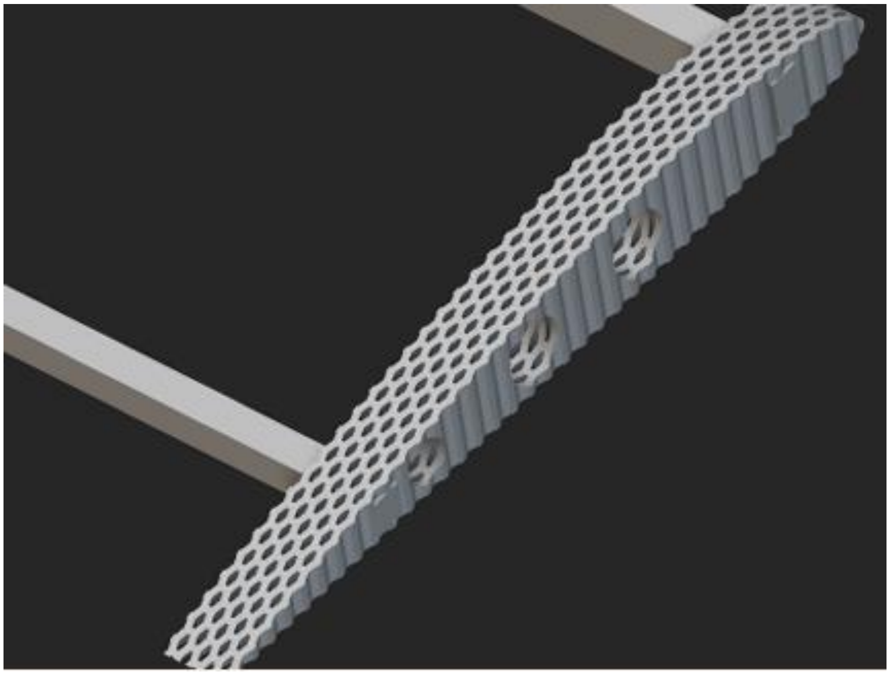
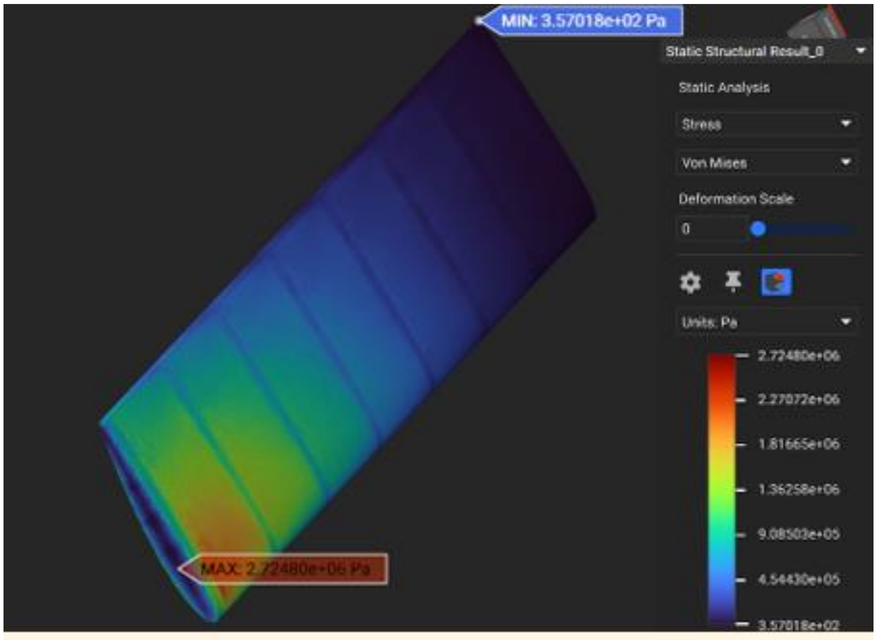


Figure 38 Rib with Honeycomb Lattice Structure



Static Structural Result_0

Static Analysis

Stress

Von Mises

Deformation Scale: 0

Units: Pa

Figure 39 Von Mises Stress Result

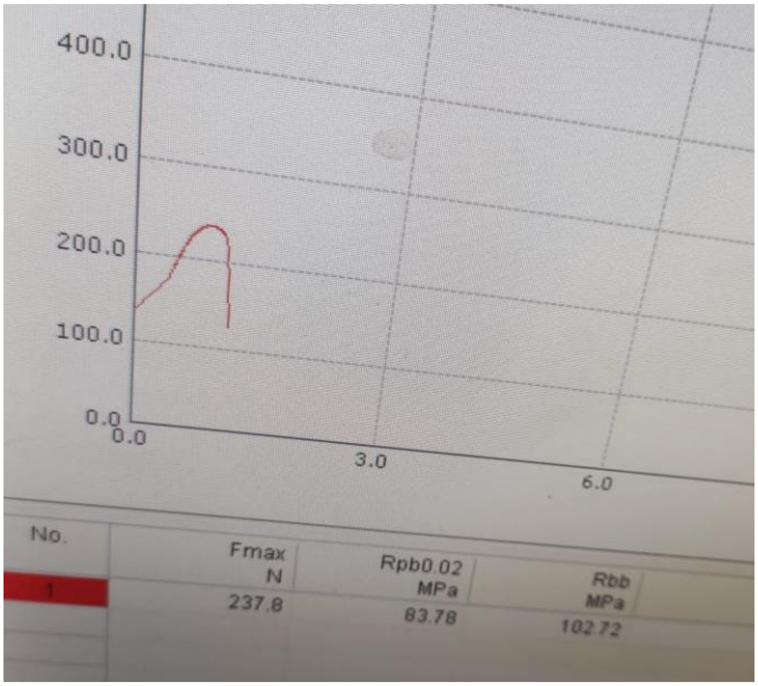
Discussion:

The maximum and minimum stress were found out to be 2.72Mpa and 357Pa, while the total mass of the optimized body was 70g, resulting in weight reduction of about 22%

While the stresses were almost same as that in previous section indicating that the structural integrity was almost same while weight is reduced.

Results of 3 Point Bend Testing

The rib was tested in the 3-point bend testing machine and the load at which failure occur is 238 N and corresponding stress was calculated which was 10 Mpa which is greater than the stress in our FEA analysis so our design will sustain the required loading



No.	Fmax N	Rpb0.02 MPa	Rbb MPa
1	237.8	83.78	102.72

Figure 40 Results of 3-Point Bend Testing

Results of Wind Tunnel Testing:

As we design the wing for the speed of 15m/s, so for testing we have provide it with the same speed in the wind tunnel and we achieved the 4.5N equivalent force which is almost equal to the lift force calculated theoretically (4.98N) and both the wing remain structurally intact.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

In this project we design, optimized and manufacture a UAV wing . The supporting system of the vehicle were integrated, and a fully functional prototype was fabricated and tested. The basic goal was to reduce the weight of the UAV wing which was done with the help of replacing lattice ribs with solid ribs. Our findings in this project will not only contribute to the promotion of using this technique, but it will also help to figure out the major hurdles in its development.

The major findings of the project are as follows.

- A solidworks model of the UAV wing was developed.
- FEA static analysis was performed on UAV wing for design validation.
- For yielding criteria, Von Mises stresses were measured. Maximum von mises stress for given loading case were found to 2.53MPa which is far below the yield strength of material used in our wing i.e 27MPa
- The mass of the basic model was 89g.
- The solid ribs were replace with hexagonal honeycomb ribs
- The resulting model was optimized to achieve the minimum weight while ensuring the maximum stress lies in the same region as that of solid ribs model.
- FEA static analysis was again performed and the resulting von misses' stresses was 2.72Mpa.
- The mass of the optimized model was 70g resulting in a decrease of 22% reduction of weight.
- The manufacturing is done with the help of a 3D printer.

- Wind tunnel testing is done to verify the design and target specification.

Our projects meet the required characteristics which is weight reduction. However, the manufacturing process is limited to small scale parts as the design is complex, so it takes time and much of the material removal which also increases cost. And if we use 3d printing it has size limitation and cost.

Our project sheds light on the possibility of introducing this weight reduction technology. It opens new barriers to discussion on the adoption of this technology while studying their impact and potential contribution for the betterment of future industry.

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