Toronto Metropolitan University

AER507 Materials and Manufacturing

Glider Design

Final Report

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Table of Contents

List of Tables

List of Figures

Introduction

The objective of this project is to design and fabricate a composite wing glider. This project aims to familiarize students with the design and manufacturing processes by making students fabricate the glider using the method of their choice, with a few restrictions. Firstly, the wing must be a NACA M22 airfoil, with a wingspan of 29.5 inches and a chord length of 4 inches. The fuselage must be made of wood and 29.5 inches long and less than 2 inches wide. The tail must also be made of wood and its surface area must be less than 30% of the wing area. The maximum payload, including the wing, must be less than 200 g.

The main design goal is to maximize the payload-to-weight ratio. This is the ratio of the total payload divided by the weight of the wing. In order to achieve this goal, the wing must be made as light as possible, compared to the rest of the glider. In order to achieve a longer flight duration, the lift force must be maximized while minimizing the drag force, as there will be no thrust to counteract the drag force. This report will talk about various designs and manufacturing processes, and the selection criteria. In the end, one design and manufacturing process will be selected which best suits the project requirements.

Glider Theory

A glider is a fixed-wing aircraft that is supported in flight by the dynamic reaction of the air against its lifting surfaces, and whose free flight does not depend on an engine.[1] The glider comprises three main components.

One, the empennage – which includes the entire tail plane consisting of fixed control surfaces, such as horizontal and vertical stabilizers and movable control surfaces, such as rudder and elevator.

Second, wings could be high mounted, low mounted or mid mounted. The span of the wing is comparatively larger than other aircrafts which results in a higher aspect ratio. This improves a glider's lift to drag ratio enabling it to fly long ranges without an engine. Usually a dihedral angle for a glider is obtained by raising the tips of the wings 1/8 inch of every one inch of the wingspan. A proper dihedral angle has a dominant effect on the aircraft's stability. Along with the dihedral angle, a tapered wing is a planform found in various gliders. This is to increase the stability and reduce the overall drag as compared to a rectangular wing.

Lastly, the fuselage of a glider is small since there is no luggage compartment and the cockpit is small but can only carry at most 2 people. Landing gears are another main part of the fuselage. A glider usually has a main landing gear which retracts to reduce the drag on the fuselage and a tail wheel.

[1] "Glider (aircraft)," *Wikipedia*, 20-Oct-2020. [Online]. Available: https://en.wikipedia.org/wiki/Glider_(aircraft). [Accessed: 03-Dec-2020].

Glider Design

1. Design Objective.

The overall objective of this design process was to construct a glider having a high flight range to weight ratio. This was achieved through maximizing the payload – to weight ratio. While designing the glider we mainly aimed at having a Lightweight design which would be easy to manufacture and at the same time meet all the structural requirements. The Glider was designed and assembled in CATIA V5 in 4 parts: fuselage, wings, horizontal stabilizer, and vertical stabilizer. The final design was selected from the 3 design iterations presented in the design selection section.

2. Design Constraints.

Following are the glider parameters kept in mind while designing the glider.

- Airfoil shape, span, and chord – NACA M22, 29.5 in, 4 in.
- Glider length and width – 29.5 in and less than 2 in.
- Horizontal stabilizer area – less than 30% of wing area.
- Total payload including wing – 200 g.
- Wing loading profile – 200 g/span.
- No ailerons, rudders, elevator, and other kinds of control surfaces allowed.
- No additional propulsion methods.

The wing of the glider is required to produce enough aerodynamic forces to keep the glider as long as possible in the air. Thus, to optimize the M22 Airfoil wing with as long as possible glide, a dihedral angle of 3 degree was introduced along with a tapered wing to maintain aircrafts stability.

3. Design Selection.

Various design possibilities are explored in the following design iterations. Apart from these, designs such as canard wing, V-tail empennages and low mounted wing designs were researched. Some of these and following designs ended up being more complex and time consuming than the others to manufacture. Thus, some trade-offs were made in order to complete the glider under the design constraints. All the design iteration figures below are not to scale. All the designs are time and signature stamped as to show the flow of design and authenticity progress.

- Design 1.

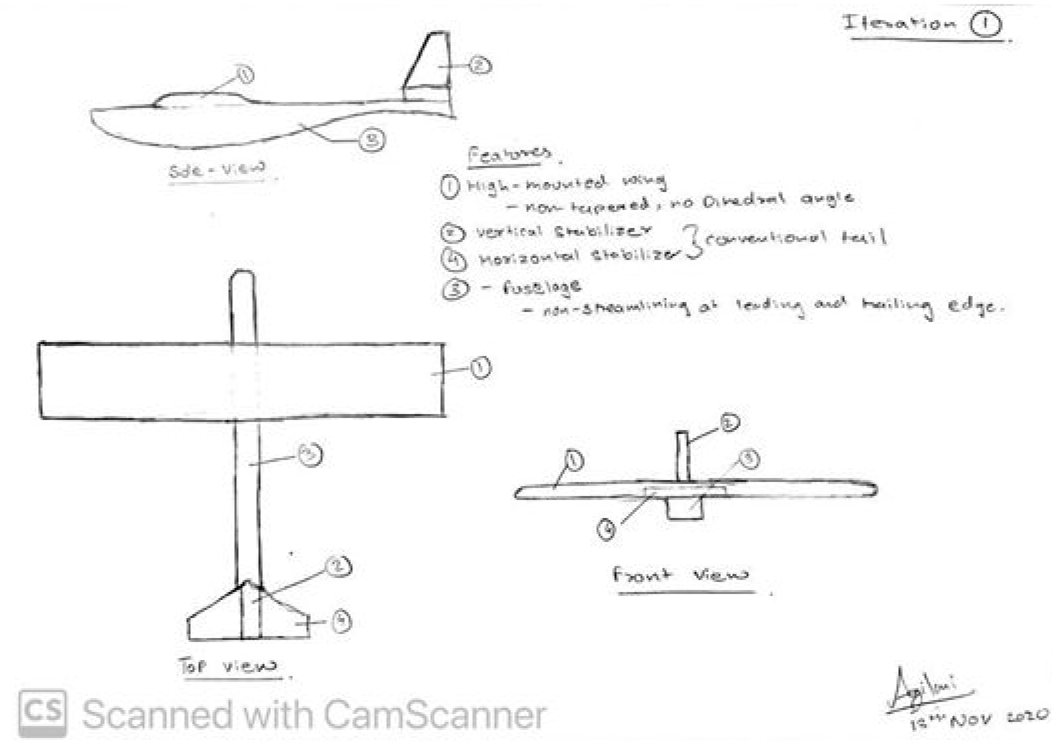

Figure 1: Design Iteration 1.

The above design iteration was inspired from traditional gliders. Its features include a high mounted wing design which has a rectangular cross section with no induced dihedral angle. The vertical and horizontal stabilizer makes the empennage on the glider which was inspired by conventional designs. The fuselage cross section from the top view looks like a solid block of foam material with no streamlining shape edges.

- Design 2.

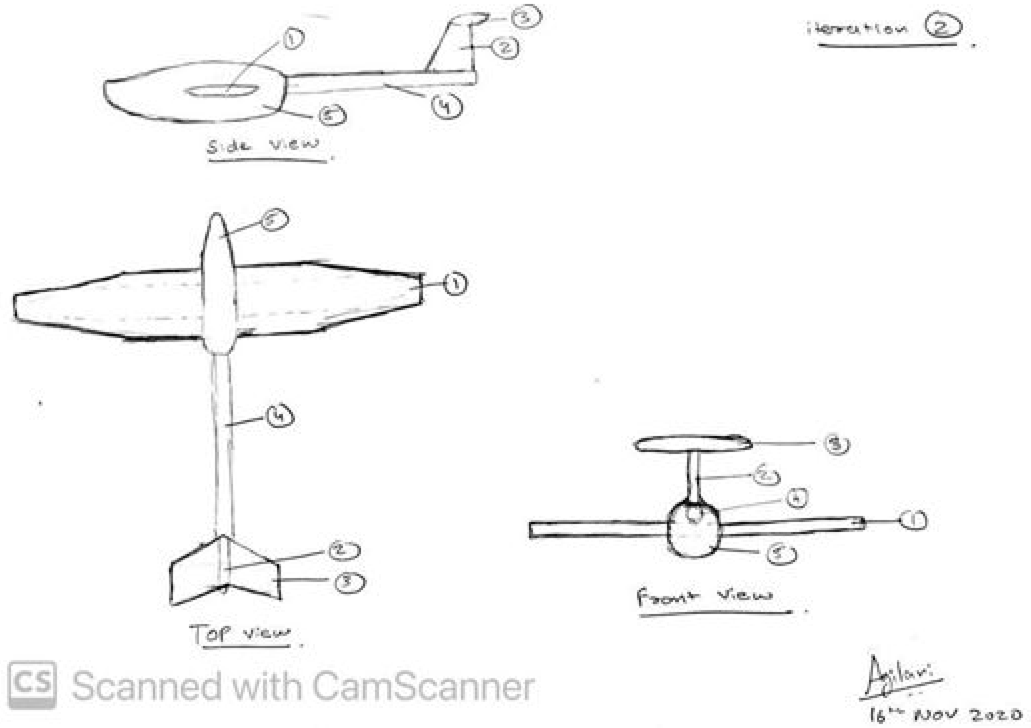

Figure 2: Design Iteration 2.

The above figure illustrates the second design iteration featuring a mid-wing and a T-tail empennage design. The wing cross-sectional area does not follow a rectangular planform as in design iteration 1. It is based on a semi tapered planform design allowing for greater stability and less drag. The T-tail empennage features a sweep horizontal stabilizer. As seen in the figure, the fuselage ends just after the wing's trailing edge. A boom rod is used to connect the fuselage and empennage together, which is a very effective lightweight design practice.

- Design 3.

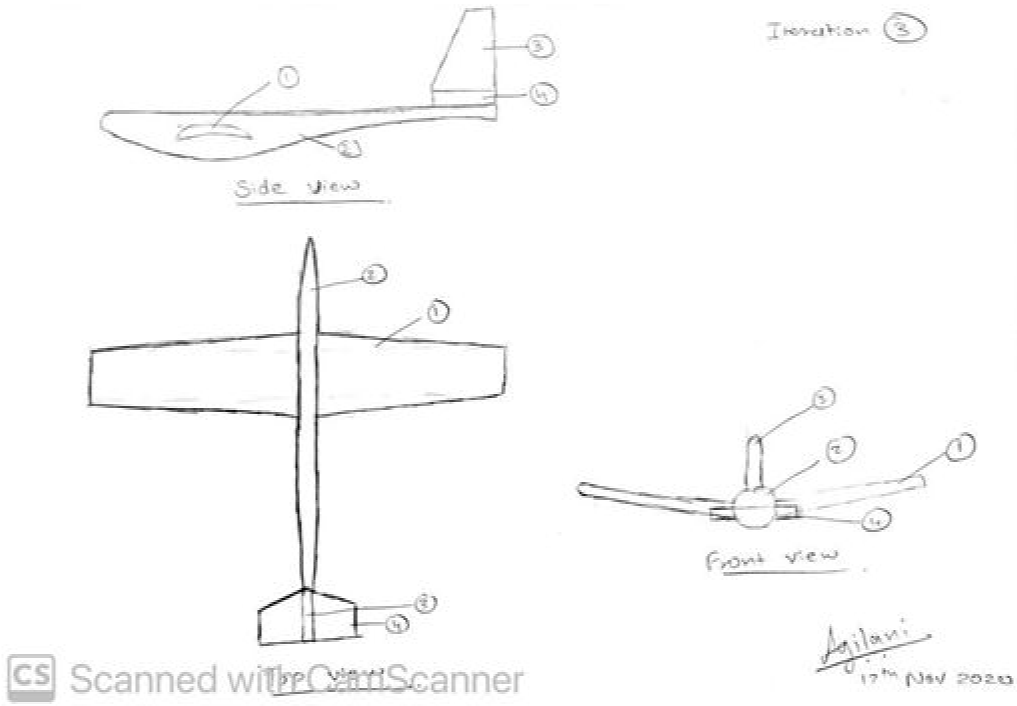

Figure 3: Design Iteration 3.

The above design iteration was chosen for the project. It features a mid-mounted wing with tapered wing planform. The wings are assembled at a dihedral angle with increased stability for the glider. The tail design is similar to the first design iteration, following a conventional empennage design. The fuselage follows a streamline like shape, converging at nose and tail ends. This design was selected because it not only focuses on one aspect of design constraints. The design follows an aerodynamic shape inspired by existing designs, which makes it efficient but light weight. The theoretical lift to drag ratio increases when compared to the above to iterations.

4. Design Analysis.

The glider design consisted of sketching the planforms for wing, fuselage, and empennage. As one of the constraints, the wingspan, chord and the Airfoil shape were given. Keeping in mind the other constraints a Catia model for each part was designed for the final design which was selected for the project. The fuselage had converging leading and trailing area design, which directly relates to the total volume reduction. Another advantage concerns flow dynamics creating lesser friction drag. This design was inspired by a fish's converging nose. We found that having ribs in the fuselage made the design much lighter but also compromised the structural integrity, hence a solid fuselage made from Styrofoam was chosen to enhance the loading capacity.

The composite wing is designed as a non-fixed component for the glider of which the Airfoil, shape and size were predetermined. The wings for this design iteration were assembled as a mid-wing at the half height of the fuselage and 1/3 of fuselage length. Surely, it is more difficult to assemble a mid-wing than a high or low mounted wing, but a mid-wing is more streamlined and has less interface drag than a high or low mounted wing. After the manufacturing process the wings were cut in half and assembled at a dihedral angle to increase the glider's stability. Along with it, the wing cross-section from the top is not a rectangular planform. A tapered wing plan form was used to reduce the drag generation. No twist angle and winglets were introduced for the wing as it was not a necessary parameter to consider since it was a very difficult and tiring manufacturing and assembling process. As further explained in the manufacturing process, Airfoil ribs were designed, and combined with spars to make up a structural skeleton for the wing. This reduced the wing's mass and increased its structural strength.

The main idea behind the tail and fuselage was to develop the best design for gliding that was possible to manufacture in the timeframe given. The empennage comprises a horizontal and a vertical stabilizer. There are no movable control surfaces due to design constraints. The empennage is designed as a conventional tail plane. A conventional tail provides appropriate stability and is much more lightweight than a t-tail design. A non-swept vertical stabilizer was used due to manufacturing feasibility, which was a compromise for the additional moment arm for the tail plane. The t-tail design, in the second design iteration, is very effective at small angles of attack, as the angle of attack increases the horizontal stabilizer is in the way on the wing's downwash causing it to stall before the wing. This design iteration was intended without the landing gears as it was one of a design constraint in our favour. Since, there was a significant reduction in overall drag and mass of the aircraft.

Measurements such as the centre of gravity, mass and area for each component were examined to assemble the components. Any discrepancy was stabilized with additional mass blocks at the required place. These measurements were completed in CATIA from which the wing analysis was finished using the equations explained in the glass.

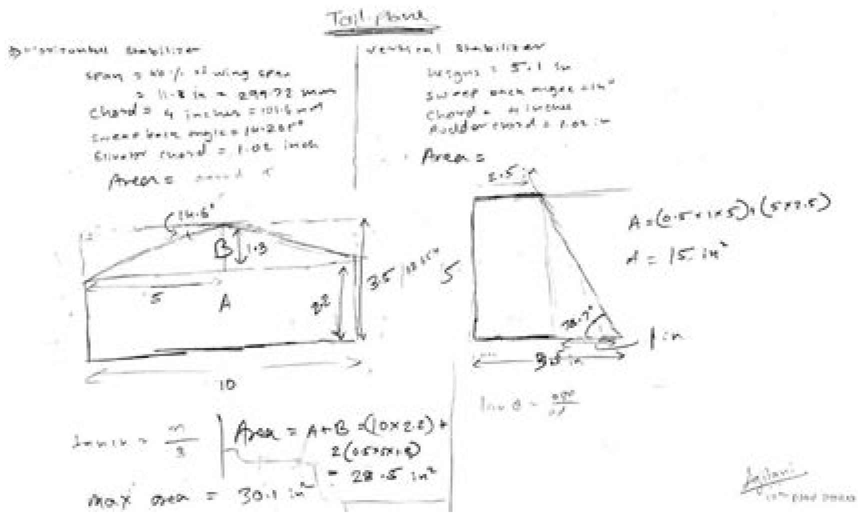

Figure 4: Rough Design of Glider Empennage.

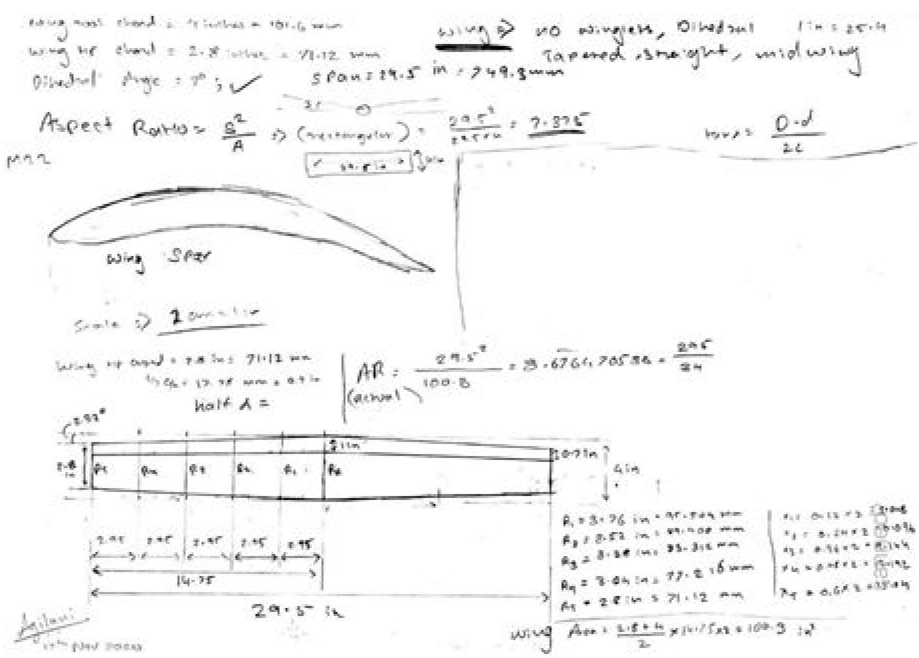

Figure 5: Rough Design For Glider Wing.

The above two figures illustrate a rough design sketch. The first figure entails the empennage measurements and rough area calculations. The second figure is a rough detailed design of the wing. It shows the location of spars and wing skeleton design. The Airfoil is based on the given M-22 from the NACA Airfoil database. Prints for final designs, by hand and in CATIA, are illustrated in the appendix section.

Manufacturing design

The mold of the NACA 0015 airfoil design was created using CATIA. One mold for the top skin of the airfoil was designed and another mold for the bottom skin of the airfoil.

There are two methods that can be used to manufacture the wing molds. The first method is to 3D print the mold using Selective laser Sintering (SLS). The second method is to use wood in CNC milling to produce the mold. These two methods will be discussed and compared in detail in the following sections

Method 1: 3D printing the Molds.

- The design of the mold is produced in a CAD software (CATIA) and transferred to a 3D printer
- A thickness of 0.25 mm is added to molds. This is done so that the material loss due to sanding and smoothing of the mold is taken into account.
- Material is added to the mold layer-by-layer.
- After mold is produced, the surface rubbed thoroughly with sand paper.
- This manufacturing process is fairly slow and expensive but the output accuracy is extremely High.

Method 2: (Wood) CNC Milling.

- The design of the mold is produced in a CAD software (CATIA) and transferred to a CNC milling machine.
- A block of balsa wood, 1120X150X125 (mm), is cut in half using the shearing tool, for top and bottom mold each. A power hacksaw can also be used to cut the wooden piece.
- The shearing tool is set to the appropriate cutting force.The shearing tool The cutting force required for shearing is given by 0.7*(TS)*t*L. TS is tensile strength, t is thickness and L is length.
- The new dimensions of the balsa wood is 1120X150X62.5 (mm).
- The piece that is cut is placed in the CNC milling machine and the machine is turned on, with the mold file already fed into it.
- Material has to be removed from the surface of the block so that the mold of the top skin can be produced.
- In the face milling operations, surface contouring is used. This tool has a ball end mill (cutter).
- The cutter (ball end mill) is rotating clockwise.as the feed moves forward.
- The chips that are being removed during the milling process are vacuumed using an electronic appliance such as a vacuum cleaner.

- After the removal of material is done through the milling operation, the mold is taken out and the product is rubbed with the sanding paper and polished. The route sheet was modified to a polishing task.

After the mold is made from either of the above mentioned processes, the next step is to drill holes on the sides of the molds so that a bolt and a screw can be used to close the top and bottom mold when placed on top of each other. The steps of producing the holes are detailed below.

- Drilling consists of producing a hole in a material with a tool called twist drill.
- Eight holes with a diameter of approximately ⅜ inch is made along the the length of each mold.
- The holes are made such that they overlap each other precisely.
- To close the molds, 3 inch carriage bolts are inserted from the bottom and a nut is placed on top and rotated clockwise to seal the molds securely.

Composite wing manufacturing.

Composites are materials that are made up of either two or more distinguishable materials. Many composite materials exist that are distinguishable, such as carbon fiber and fiberglass. Other composites that are not distinguishable include cement, concrete and plastic mouldings.

There are a couple of ways to manufacture the composite wing. Based on the materials that were available, below are the steps that were observed during the composite wing assembly process.

- Two molds were used, one for the top skin and the other for the bottom skin. Carbon fiber was used for the top skin and clear fiberglass for the bottom skin.
- The main apparatus that were used are listed below
    - Carbon Fiber Cloth 2.9oz/sqyd
    - Glass Fiber Cloth 2.0oz/sqyd
    - Glass Fiber Strips 1.6oz/sqyd
    - Polyurethane Foam 2lb/cu ft
    - Epoxy Hardener MVS-464
    - Epoxy Resin MVS-410
    - 19 Minute Pot Life
    - Scissors
    - Squeegee 3, 2 and 1.5 inch wide
    - Mold for top and bottom skin
- A 50 g shot of polyurethane foam was poured into the mold and allowed to settle and form.
- The mold was opened after removing all the bolts and the halves were separated.
- The foam was carefully extracted from the mold and was checked for any voids.

- The excess part of the foam was cut using a knife/box-cutter and the flashing was removed.
- The edge of the foam was then sanded upto the parting line.
- The foam was then cut using laser cutting. This was done to reduce weight and to allow fiberglass ribs to be formed.
- The final foam core weighs 15.0 grams
- The molds are waxed thoroughly using a circular motion to reach all pours. The wax was allowed to haze over before buffing.
- The total weight of the fiber material is recorded to be 23.0 grams. The foam core is
- All loose strands from the fiber cloths were cut off.
- The fiberglass is placed on the bottom mold and excess cloth is cut off and kept aside for later use of ribs.
- 46 grams of epoxy was prepared using Epoxy Hardener MVS-464 and Epoxy Resin MVS-410 and were stirred thoroughly.
- The epoxy is poured along the length of the fiberglass and carbon fiber cloth that is placed on the bottom mold and top mold respectively.
- The epoxy is distributed evenly as a thin layer over the molds using the squeegee. The fiberglass cloth is fully wetted out and transparent. Carbon fiber cloth is also wetted out.
- The glass strips are placed along the parting line of the mold.
- The foam core is then placed on top mold firmly
- The cloths are placed directly on the opposite of the rib on the bottom mold so that the cloths absorb some of the epoxy.
- The glass strips are taken out from the bottom mold and folded over the ribs using two squeegees. This process completed the lamination process.
- Any material that was over the bolt holes was removed.
- The bottom mold was placed over the tob mold and the 3 inch carriage bolts are inserted from the bottom with nuts closing the two molds together from the top. A 3D printed tool was used to tighten the bolts.
- The layup was left overnight.
- The next day, bolts were removed and the two molds were separated carefully.
- The flashing was separated from all around the the mold
- The excess material of the wing was trimmed with a diamond blade circular saw.
- 3 mm of material on the trailing edge is left and 1 mm on the leading edge.
- The wing was then sanded down with 120 Grit Sandpaper to remove the high spots.
- The final weight of the wing was recorded to be 60 grams.

Different Composite Wing Manufacturing Methods.

Other possible methods of making a composite wing include the use of materials such as kevlar or metals like steel. Instead of a one long piece of carbon fibre for the top of the wing, smaller cut pieces of carbon could be used in compression or injection molding [ ]. The advantage of this method is that the chopped carbon fibre is more resistant to corrosion, fatigue and creep. The stiffness and specific strength is also increased. The disadvantage of this method is that there is a chance for the airflow over the airfoil would become turbulent and the end result of the product would not be smooth as it is expected with a single piece of carbon fibre [ ].

Another method to manufacture the composite wing is to use a hybrid system. This system would use a laminate having layers of carbon fibre sandwiched between two layers of metal alloys. The advantage of this method is that the fatigue life is better and the specific strength and specific strength is higher. The disadvantage is that the weight of the composite wing would increase significantly. The flight time of the glider would be decreased due to the increased weight.

Fuselage and Empennage Manufacturing.

- The fuselage for the chosen design is made out of Blue SF polystyrene.
- The design for the fuselage is transferred to the foam CNC router. The process of the material removing is similar to the one described in the sections above.
- The fuselage consists of an in-built holding mechanism that helps to hold the vertical and horizontal stabilizer together with liquid synthetic adhesive glue (Epoxy)
- The vertical and horizontal stabilizers were made using Blue SF polystyrene and a CNC machine was used.

Assembly Process of Glider.

1. Main Design.

The steps that were taken to assemble the glider and make it ready to fly are described in detail. The manufacturing of the fuselage and the attachment of the wings to the fuselage is also discussed.

- The area of the mid-section of the wing was approximated and was used to cut out a slot in the fuselage to slide the wing through it. A metallic blade with a width of 4 mm was used so that a smooth curve can be made.
- After the wing was slid through the slot, the wing was adjusted so that the span of the wing is equal on either side of the fuselage for balance.
- Liquid synthetic adhesive glue was used to stick the wing onto the fuselage in the right place.

- The horizontal stabilizer was slid into the holding mechanism ang glued using epoxy. The length of the horizontal stabilizer was precisely marked to b equal on both sides for balance.
- Then the vertical stabilizer was inserted on top of the horizontal stabilizer was was glued using epoxy.
- The glider was made sure to have almost negligible rotation about the roll axis.
- Lastly, to balance the weight of the empennage, 2 holes were drilled into the fuselage near the nose-tip with a drilling tool so that bolts and nuts could be added to balance the weight if needed

The main Assembly design is compared with other potential assembly designs to understand the advantages and disadvantages of the chosen system better. The processes will be compared using decision making matrix and critical path analysis.

Potential Assembly Design 2.

Lathe machine was used to produce the fuselage in this method. Lathe consists of rotating a shaft against a tool while the tool's position is controlled. It is mostly used for shafts with a circular cross section. The spindle on the lathe rotates. The spindle is rotated by an electric motor via a system of belts.

- A bamboo rod is used as the fuselage. Using CNC machining, a flat surface is made on the bamboo stick at places where the wing and empennage would be placed.
- At the nose-tip of the glider, threads are made so that nuts can be added to counterbalance the weight of the empennage.
    - Using blue dye, the length is marked for threading distance.
    - Using a lathe machine, the threading is done.
- After the threads were made, the wing was attached to the flat surface of the bamboo stick and would be glued using epoxy. The empennage that would be made out of foam would also be attached to the flat surface of the rod that is on the trailing end.

Potential Assembly Design 3.

Riveting and Laser cutting would be utilized to produce the fuselage and this assembly method. The fuselage would be joined with the vertical stabilizer. This material used in the laser cutting tool would be Corrugated B_flute (cardboard). This method also includes riveting to hold the empennage together. The steps are as follows

- The shape of the fuselage with the vertical stabilizer would be sent as a readable file to the laser cutting machine.
- Balsa strips are attached along the length of the glider to reinforce the structure and to add surface area for the wings and horizontal stabilizer to be added.
- The wing and horizontal stabilizer is fixed using elastic bands.
- The Vertical stabilizer is riveted onto the horizontal stabilizer

    - The supports are L-shaped 3D printed with a 3 mm hole on each side
    - Using a bucking bar and a hammer, riveting would be done 4 times in total to secure the empennage.
    - The type of rivet used would be a tubular rivet, this is done to add minimal weight to the glider.
- Finally, to counterbalance the empennage weight, pieces of balsa wood would be glued to the nose-tip using epoxy.

The integrity and strength of the wing is inspected by dropping it from 3 feet. If the wing drops successfully without breaking, it is dropped again from a height of 6 and 11 feet respectively. The design of the wing is tested by doing a flight test. The objective was to have maximum flight distance. If the flight distance was less than 10 meters, the wing would be redesigned by considering the max flight distance of other competitors.

Table 1: Decision Making Matrix.

Rating: 1 worst - 5 best				
Selection Criteria	Weight (100%)	Main Assembly Design	Assembly Design 2	Assembly Design 3
Light Weight	12.5%	5→0.625	4→0.5	2.5→0.3125
Ease of Manufacturing	12.5%	5→0.625	3.5→0.4375	2→0.25
Structural Integrity	12.5%	3.5→0.4375	4.5→0.5625	4→0.5
Ease of Repair	12.5%	3→0.375	4.5→0.5625	2.5→0.3125
Max Range	125%	5→0.625	3→0.375	3→0.375
Materials Availability	12.5%	5→0.625	4→0.5	3→0.375
Equipment Availability	12.5%	5→0.625	5→0.625	3.5→0.4375
Cost of Manufacture	12.5%	5→0.625	2.5→0.3125	2→0.25
Total Score	100%	4.5625	3.875	2.8125

By comparing the assembly process, cost of manufacture, materials available .etc, it can be observed that the most efficient way to design and manufacture the glider is using the Main Assembly Design. This is because in Design 2, there is use of technical equipment like lathe machines and the cost of manufacture is increased significantly. Design 3 consists of riveting and laser cutting. Riveting adds weight to the glider and the method is time consuming. This is one of the reasons why Design 3 was voted last.

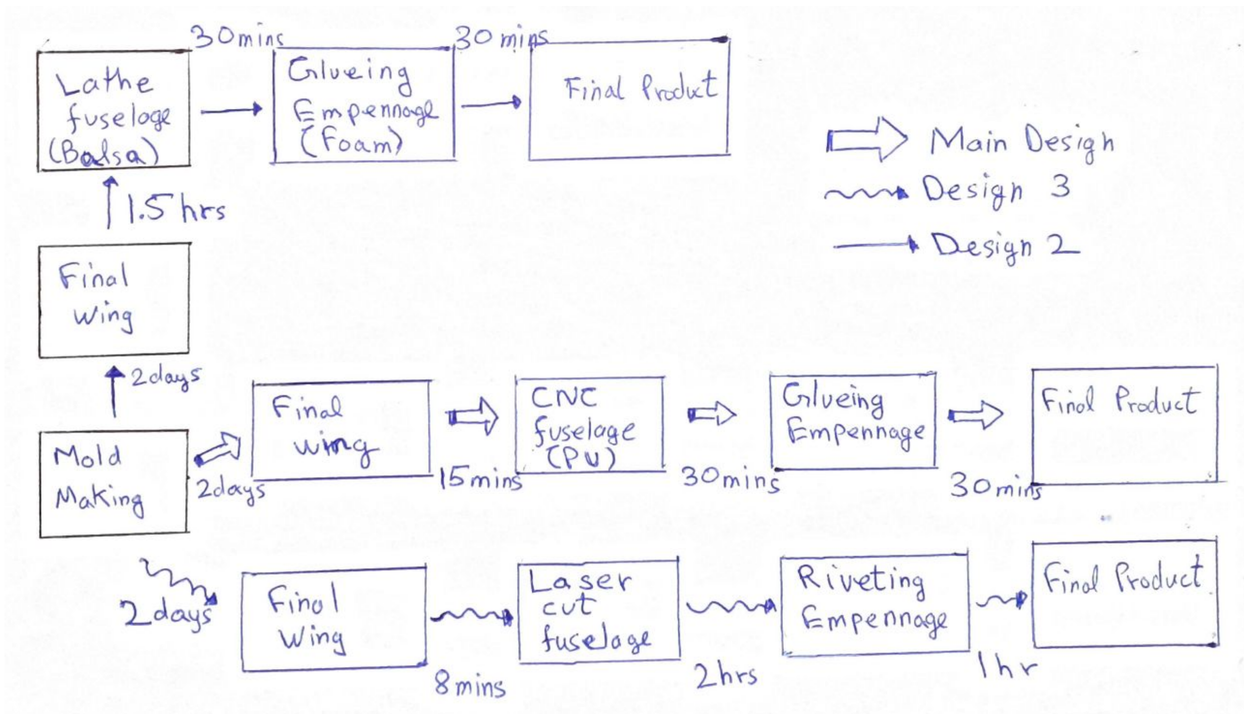

Figure 6: Critical Path Analysis on Time for three Methods

Wing Analysis

Table 2 displays the various types of materials to use for the given components of the glider design project. The materials selected were based off of the given weight and its characteristics towards the given component. After finalizing the decision, we concluded that the materials suitable for the composite wing would be fiberglass and carbon-fibre, whereas for the fuselage and tail plane it would be Blue SF Polystyrene.

Table 2: Material Selection for the Components.

Material/Item	Purpose		Weight
	Used for	Considered for	
Balsa		Tail plane	0.019 g/cm^2
Depron Foam	Airfoil skeleton	Fuselage, Tail plane	0.0137 g/cm^2
Coroplast		Airfoil Ribs	0.0975 g/cm^2
Blue SF Polystyrene	Fuselage, Tail plane		0.0255 g/cm^3
ABS Solid Bar	Wing Spars	Tail Boom	1.1 g/cm^3
Carbon Tube		Tail Boom and wing Spars	8.75 g each
Fibreglass and Carbon-Fibre	Composite Wing		50-60 g

The glider design contains four major components which are the vertical stabilizer, the horizontal stabilizer, the fuselage and the wing. The vertical stabilizer and the horizontal stabilizer are the vertical and horizontal components of the Tail plane. The total weight of the glider must not exceed 200 grams and must have a wingspan of 29.5 in (74.93 cm) which was a requirement for the project.

The total weight of the glider was calculated which depended on the type of materials it was using as well. The mass, area and volume of the glider was calculated from the software CATIA which was used for designing the glider. Table 3 displays the results of the mass, the total mass, volume and area of the four major components in a better visual representation.

Table 3: Mass, Area and Volume of the Components used.

Components	Mass (g)	Area (m^2)	Volume (m^3)
Fuselage	23.2305	0.112	9.114×10^{-4}
Horizontal Stabilizer	5.661	0.041	2.225×10^{-4}
Vertical Stabilizer	3.672	0.028	1.439×10^{-4}
Wings	60	0.136	7.9935×10^{-4}
Total Mass	92.5635 g		

The software CATIA provided us with the mass and volume for the given components of the design. Based on those properties we were able to calculate the density for each material. The modulus of elasticity was also calculated and can be found online as well [1,2,3]. Calculations are demonstrated in the appendix section of the report for a better understanding.

Table 4: Properties of the Materials selected for the Glider Project.

Materials	Density (g/cm^3)	Modulus of Elasticity (GPA)
Blue SF Polystyrene	0.0254	1.65
Fiberglass	2.11	51.7
Carbon- Fibre	1.6743	100

To determine specific strength, forces and moment of the wing various calculations took place. The wing was taken into half size as a cantilever beam. Using the design method, forces and moment were determined from the cantilever beam. We were able to calculate Tensile Strength and Specific Strength from formulas found through Stress Analysis. Figure 6 portrays the free body diagram for the cantilever beam which is half of the wing. The cut a-a free body diagram is also displayed in figure 6 for a better understanding. Table 5 lists all the results obtained from the cantilever beam calculations. All calculations are displayed in the appendix section for a better understanding.

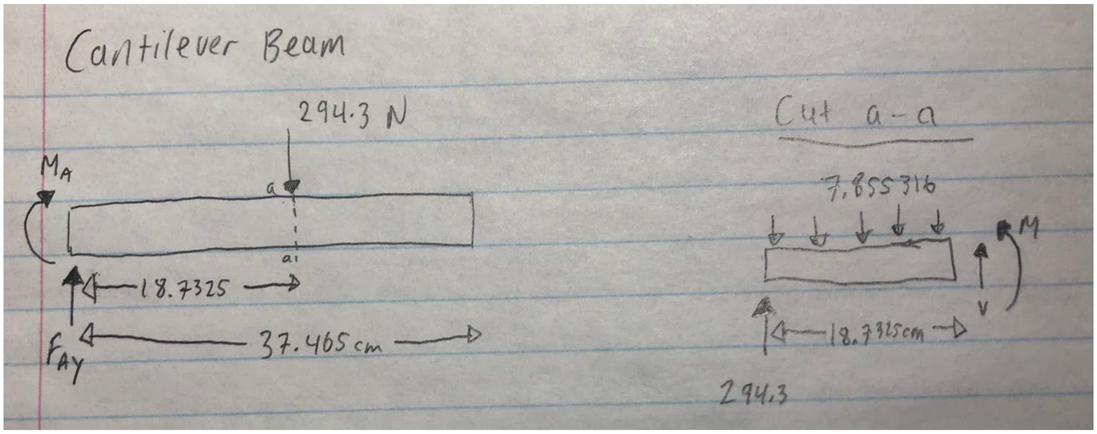

Figure 7: Visual Representation of the Cantilever Beam for Half of the Wing.

Table 5: Values found from implying Stress Analysis using a Cantilever Beam.

Properties	Results
Force Applied (F_{AY})	0.29 N
Moment	0.055 N.m
Moment (Cut a-a)*	0.04135 N.m
V (Cut a-a)	0.14715
Moment of Inertia	0.980 cm^4
Stress (σ)	29.5 kPa
Tensile Strength	276 Pa
Specific Strength	72.89 Pa

In order to achieve the goal for payload to weight ratio was all based on how to design the wing and which materials to use. In table 2 it portrays that we used ABS solid bar for the wing spars and fiberglass and carbon fibre for the composite wing component. All these materials helped reach our goal of making the weight as low as possible for the glider. After various calculations the payload to weight ratio was determined to be 1.54. Calculations are shown in the appendix section for a better understanding.

Discussion

In order to achieve the main goal of maximizing the payload to weight ratio, we had to design a wing that was as light as possible, while maintaining structural integrity and satisfying the structural requirements. We decided on using ABS solid bars for the wing spars in order to minimize the weight and maximize the strength of the airfoil. The material weighed in at 1.1 g/cm^3.

As shown in the composite wing manufacturing section, 3 methods were taken into consideration for the actual manufacturing process of the composite wing. One of the methods considered was to use a hybrid system where we would sandwich two layers of metal alloys by carbon fibre. This would result in a stronger airfoil, at the cost of minimizing the weight. Since the main goal was to maximize the payload to wing weight ratio, this idea was scrapped. Instead, we opted to construct the wing using carbon fibre, fibreglass, and polystyrene since all these materials are lightweight. This resulted in a wing that was 60 grams in weight. The total payload was 92.5635 grams, which would result in a payload-weight ratio of 1.5427725.

When deciding upon the manufacturing process, a decision-making matrix was used. In this matrix, there were 8 criteria that were considered. We weighed each one to be equal, resulting in each to be 12.5% of the final decision. This meant that we did not prioritize the weight over the cost specifically. Instead, we left them both equal and we decided upon a final design based on the other aspects. However, out of the 3 designs we considered, the chosen one had the best ratings for weight and cost compared to the other two designs. Often, lighter materials are more expensive than their heavier counterparts, especially when they both have similar strength. In order to make up for expensive material costs, we decided to make up for it through the manufacturing process. For example, when creating the mold for the airfoil, we decided to forgo the 3D printing option as that was more expensive. Instead, we created the mold out of wood, using CNC milling.

Using the airfoil characteristics charts (Figure 17 in appendix), a very rough approximation of the lift force can be made. Depending on the angle of attack, the corresponding lift coefficient can be determined and used to calculate the lift force. This is a rough estimate because the exact angle of attack and velocity when the glider is thrown cannot be determined. However, the velocity can be estimated by testing test flights of the glider and approximating the average velocity using the distance travelled and flight time. The angle of attack would have to be visually estimated. Using this information, the lift force can be calculated, providing a rough idea of the lift force generated by the airfoil. For more accurate results, the wing would have to be tested in a wind tunnel.

As seen in the airfoil characteristic charts, for the ratio of lift to drag Vs. angle of attack, as angle of attack increases the lift to drag ratio also increases showing a proportional relationship. After the angle of attack of 4 degrees, the drag forces become more dominant eventually leading to glider stalling. By inspection, the stall angle was found to be at 16 degrees angle of attack. The Theoretical range for the glider was found to be approximately at 9 m, using the data from the graph and CATIA. This range is very imprecise considering there were no errors accounted for. Errors such as optimal launching angle and force, dihedral and taper wing impact, etc.

Creating the wing itself in Catia was simpler than the actual fabrication part, in the sense of achieving certain aerodynamic goals. This is because a computer can make the perfect surface/shape based on the user input. During the fabrication process, there are many uncertainties that must be accounted for. For example, when designing the mold, the sanding of the surface must be taken into consideration, so the mold would be slightly bigger in order to accommodate for the excess material that would be removed. In addition, the sanding is done by hand which may lead to imperfect surfaces due to human error. This might lead to minor flaws in the surface which can affect the aerodynamic performance. Another source of performance weakening would be the assembly of the glider. The adhesive would have to be smoothed out when applied in order to maintain a smooth surface. Any bumps and other imperfections in the crevices of the glider can hinder the performance. Practicing caution and precision when assembling the glider helped limit these potential performance impairments.

References

1. *Overview of materials for Polystyrene, Extrusion Grade*. [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=1c41e50c2e324e00b0c4e419ca780304. [Accessed: 03-Dec-2020].
2. *D-Glass Fiber, Generic*. [Online]. Available: http://www.matweb.com/search/DataSheet.aspx?MatGUID=3984c45fd4a449dfbfa4909d2a9060df. [Accessed: 03-Dec-2020].
3. *Overview of materials for Epoxy/Carbon Fiber Composite*. [Online]. Available: http://www.matweb.com/search/datasheet.aspx?matguid=39e40851fc164b6c9bda29d798bf3726. [Accessed: 03-Dec-2020].
4. "Glider (aircraft)," *Wikipedia*, 20-Oct-2020. [Online]. Available: https://en.wikipedia.org/wiki/Glider_(aircraft). [Accessed: 03-Dec-2020].
5. "Determining dihedral angle?," *The Rocketry Forum*. [Online]. Available: https://www.rocketryforum.com/threads/determining-dihedral-angle.144967/. [Accessed: 03-Dec-2020].
6. *NACA M22 AIRFOIL (m22-il)*. [Online]. Available: http://airfoiltools.com/airfoil/details?airfoil=m22-il. [Accessed: 03-Dec-2020].
7. "The Glider Empennage, Powerplant, and Landing Gear," *Flight Literacy*, 06-Apr-2020. [Online]. Available: https://www.flightliteracy.com/the-glider-empennage-powerplant-and-landing-gear/. [Accessed: 03-Dec-2020].
8. N.A.C.A. Langley Aeronautical Lab., "NACA Technical Report 352 - Large-Scale Aerodynamic Characteristics of Airfoil as Tested in the Variable Density Wind Tunnel", Langley Field, VA, 1931. http://ntrs.nasa.gov/search.jsp?R=19930091421

Appendix

Calculations.

Glider Properties

- ➢ Wing weight: 0.5886 N
- ➢ Half of wing weight : 0.2943 N
- ➢ Wingspan = 74.93 cm
- ➢ Half of wingspan = 37.465 cm
- ➢ Thickness: 1.05 cm
- ➢ Wing Area: 0.065 m^2
- ➢ Uniform distribution on cantilever beam = $\frac{0.2943}{37.465*100^{-1}}$ = 0.785533
- ➢ Glider Weight: 0.908 N
- ➢ $(\frac{C_l}{C_l})_{max}$ = 18.75

- Determining density for Blue SF Polystyrene from the fuselage component. The same equation was used for determining the other materials used

$$\rho = \frac{m}{v} = \frac{23.2305}{911.4} = 25.5\ kg/m^3$$

- Calculations for force F_{AY}

$$F_{AY} = 0;\ F_{AY} - 0.2943 = 0 \rightarrow F_{AY} = 0.2943\ N$$

- Calculation for Moment on cantilever beam

$$M = 0;\ -M - (0.2943 \times 0.187325) = 0 \rightarrow M = -0.05512974\ \text{N.m}$$

- Calculation for V on cut a-a

$$-V + 0.2943 - 0.785533(0.187325) = 0 \rightarrow V = 0.14715\ N$$

- Calculation for Moment in the cut a-a

$$M = 0;\ -M - (0.785533)(\frac{0.187325^2}{2}) + 0.2943(0.187325) = 0 \rightarrow M = 0.0413473107\ \text{N.m}$$

- Calculation for Moment of Inertia

$$I = \frac{1}{12}bh^3 = \frac{1}{12}(10.16)(1.05^3) = 0.980\ cm^4$$

- Calculation for Stress

$$\sigma = \frac{M\bar{y}}{I} = \frac{(0.05512974)(0.00525)}{0.980*100^{-4}} = 29533.78\ \text{Pa}$$

- Calculation for Tensile Strength

$$Chord\ Length\ =\ 4\ inches\ \rightarrow 10.16\ cm$$

$$A = b \times h = (10.16)(1.05) = 10.668\ cm^2$$

$$Ts = \frac{F_{max}}{A} = \frac{0.2943}{10.668*100^{-2}} = 275.87176\ \text{Pa}$$

- Calculation for Specific Strength

$$\rho_{fiberglass} + \rho_{carbon-fibre} = 2.11 + 1.6743 = 3.7843 g/cm^3 \rightarrow 3784.3 kg/m^3$$

$$S = \frac{Ts}{\rho} = \frac{275.87176}{3784.3\ kg/m^3} = 0.07289\ \text{KPa} \rightarrow 72.89\ \text{Pa}$$

- Theoretical Range

$$Range = \sqrt{\frac{W}{0.5} * C_l * \rho * s} * \frac{C_l}{C_d * W} = \sqrt{\frac{0.91}{0.5} * 1.3 * 1.225 * 0.065} * \frac{18.75}{0.91} = 8.94\ m$$

- Payload to Wing Ratio

$$Payload\ to\ Wing\ Ratio = \frac{Total\ Payload}{Wing\ Weight} = \frac{90.5635}{60} = 1.54$$

Glider CATIA Model and Detailed Design.

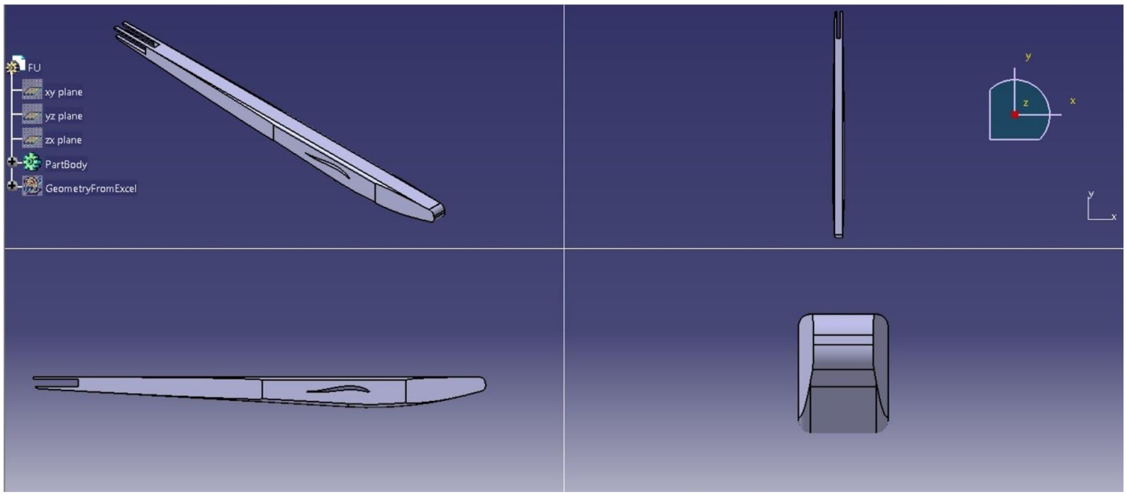

Figure 8: Fuselage CATIA Model.

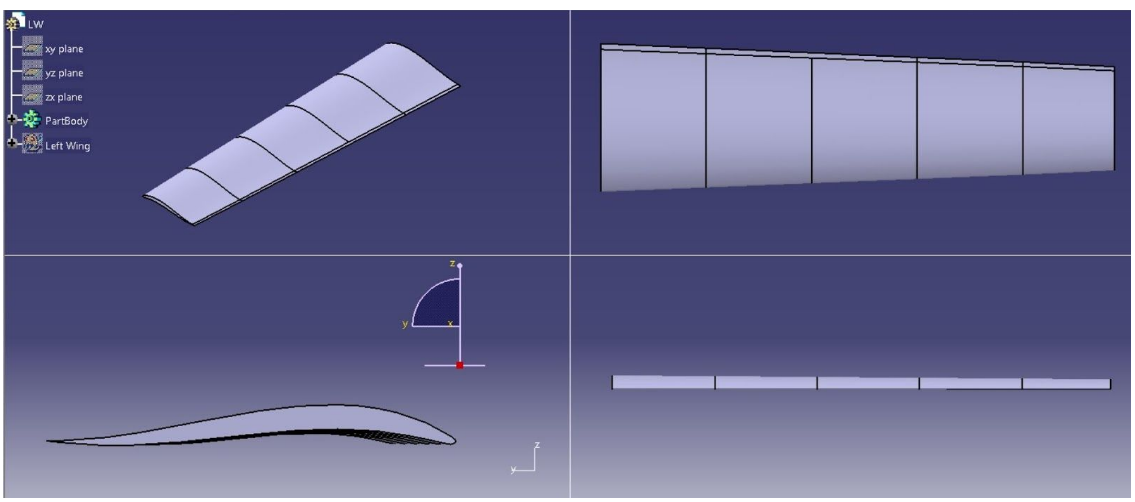

Figure 9: Left Wing CATIA Model.

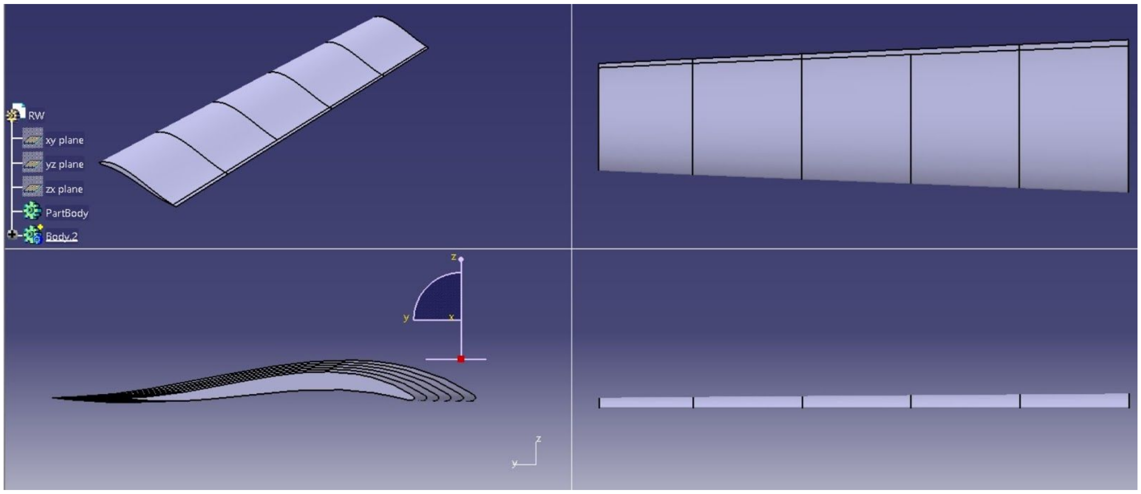

Figure 10: Right Wing CATIA Model.

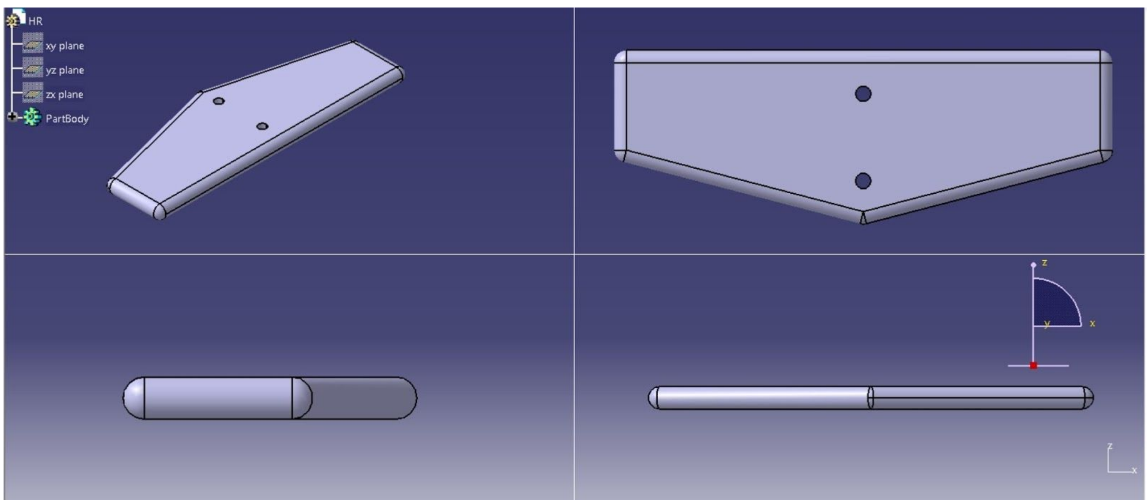

Figure 11: Horizontal Stabilizer CATIA Model.

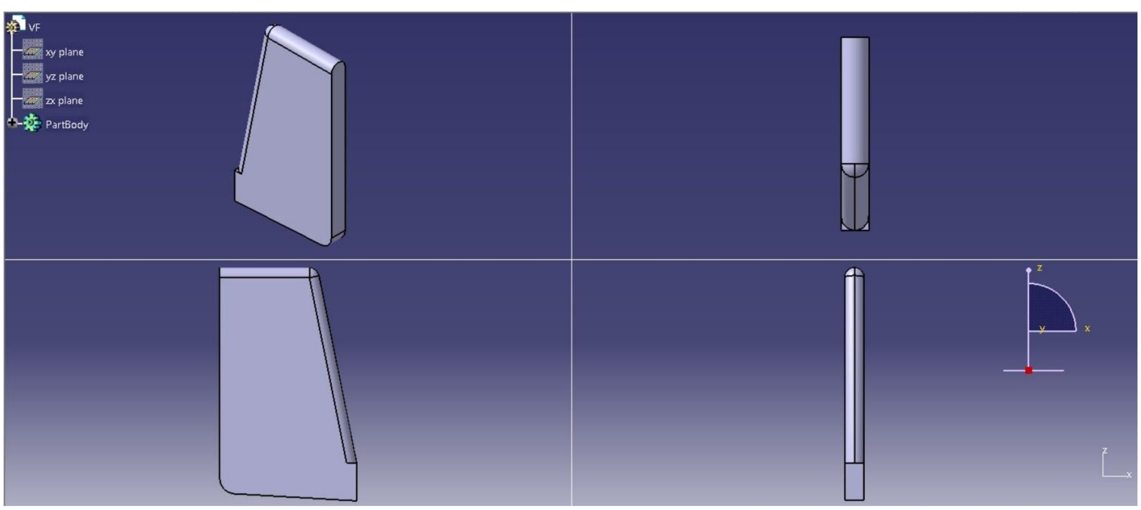

Figure 12: Vertical Stabilizer CATIA Model.

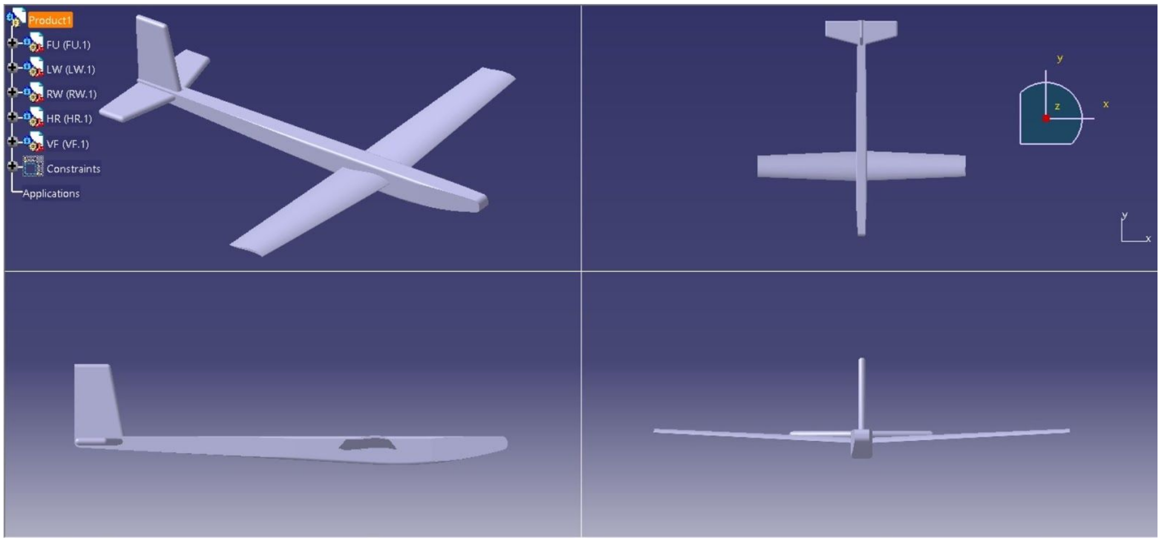

Figure 13: Assembled Glider CATIA Model.

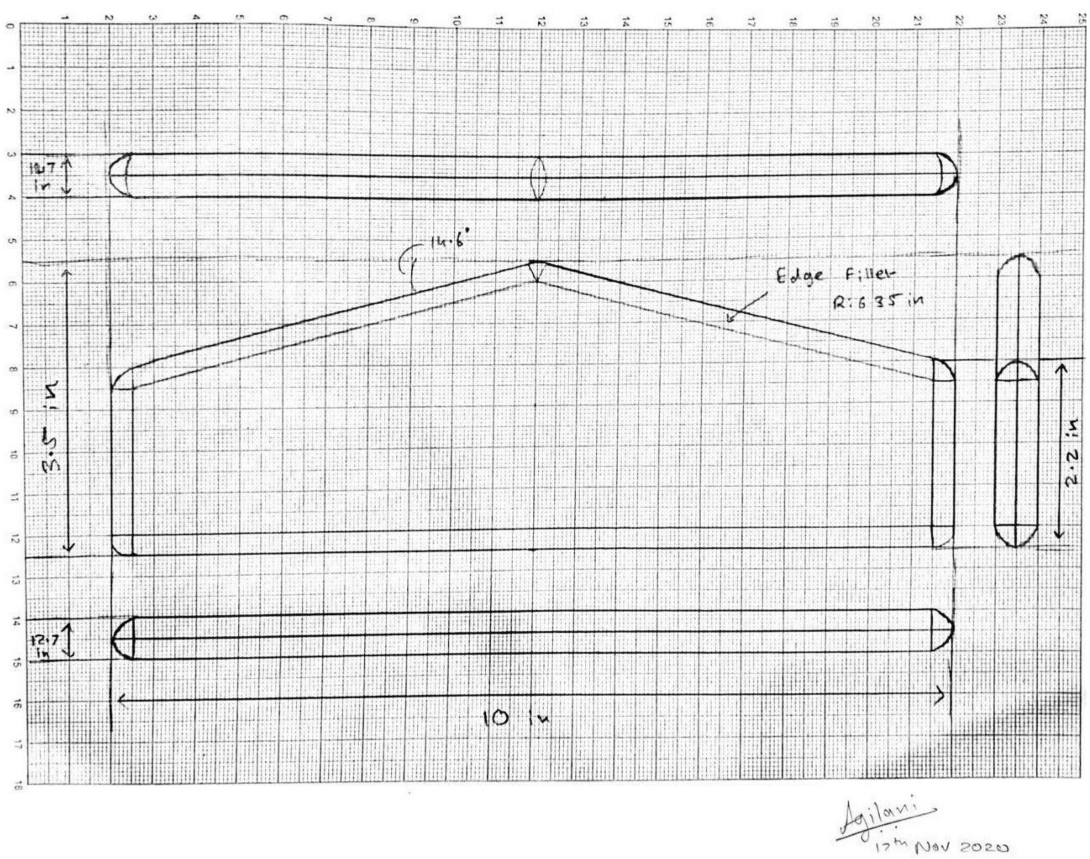

Figure 14: Detailed Design of Horizontal Stabilizer on Graph Paper.

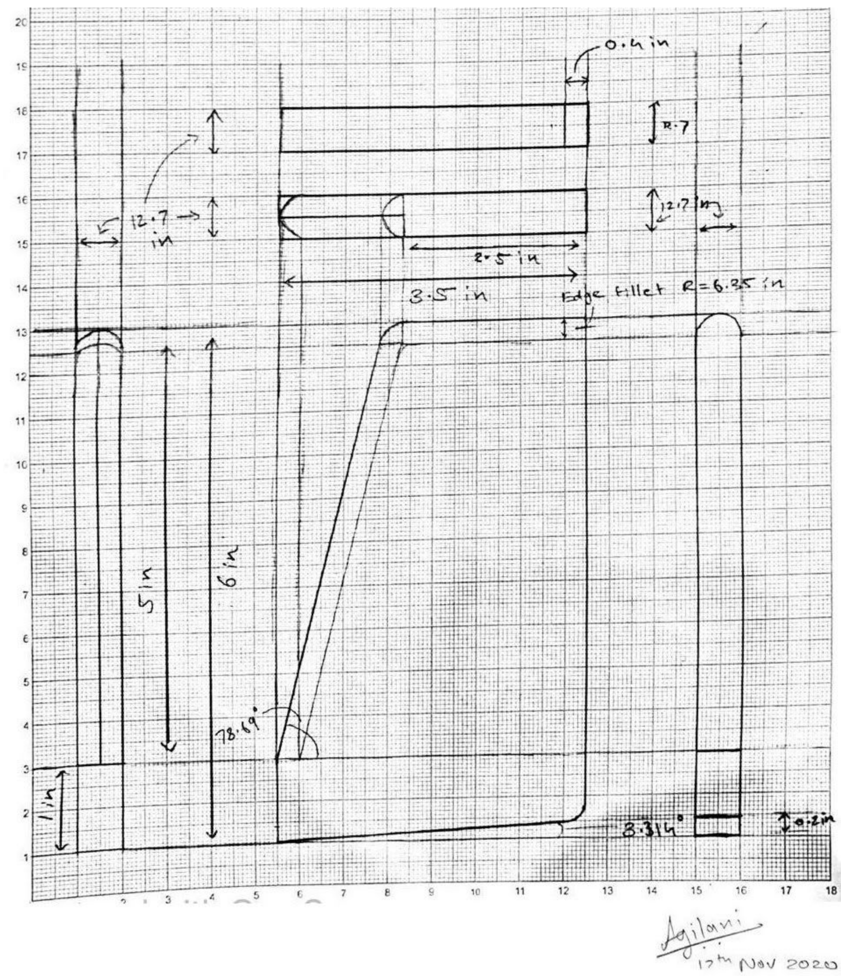

Figure 15: Detailed Design of Vertical Stabilizer on Graph Paper.

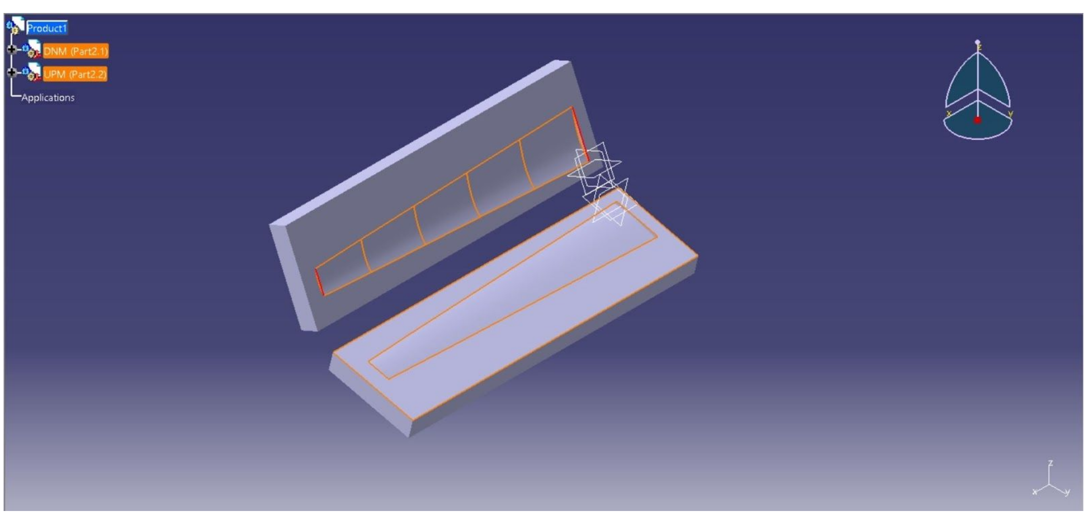

Figure 16: Left Wing Mold CATIA Model.

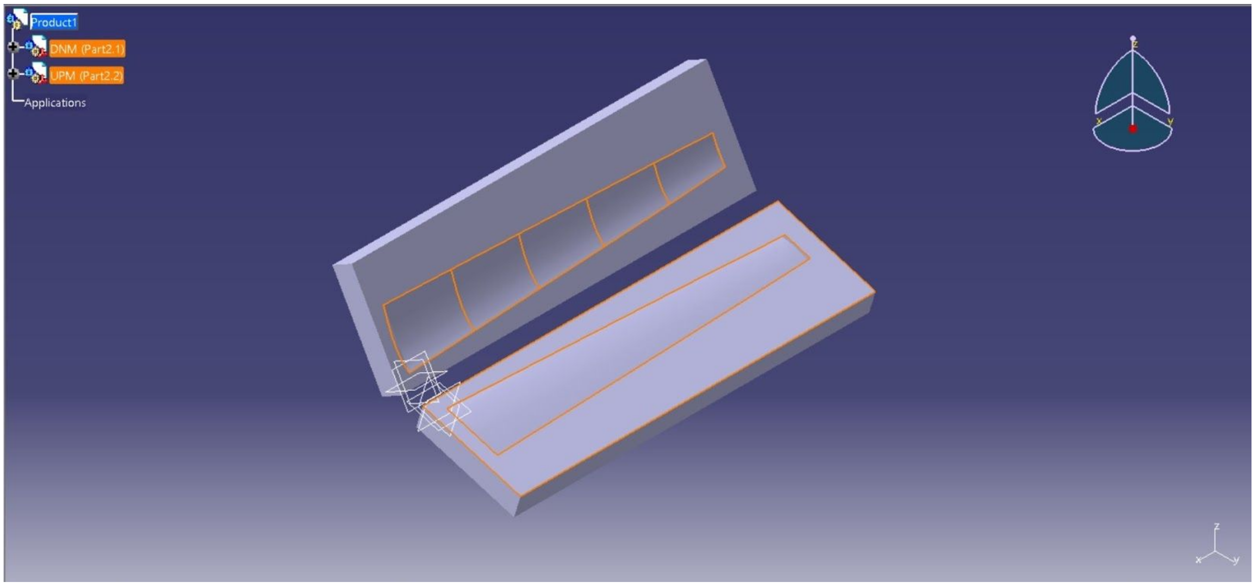

Figure 17: Right Wing Mold CATIA Model.

N.A.C.A. M-22 Airfoil Data.

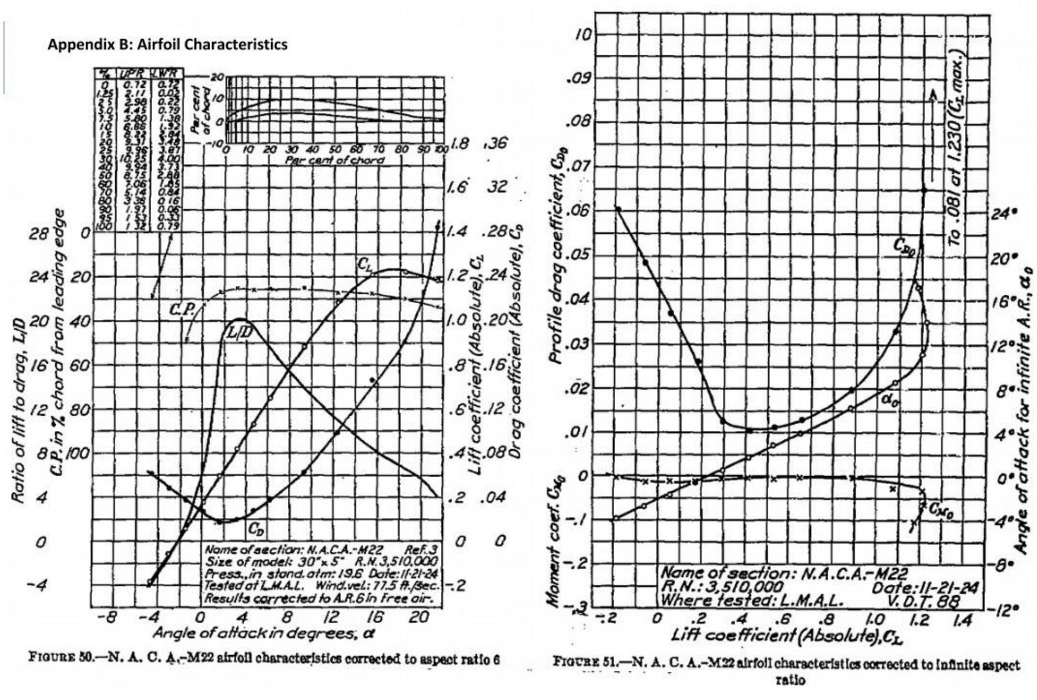

Figure 18: N.A.C.A. M22 Airfoil Characteristics.

Work Distribution

First Name	Last Name	Section	Work Distribution%	Signatures/ Initials
Ibrahim	Khan	1	25%	I.K
Aziz-U-Rahman	Arsalah	2	25%	A.A
Aman	Gilani	1	25%	A.G
Harshil	Panchal	1	25%	H.P

Rubric:

Student Name:				
Lab #:	**Section #:**		**TA:**	
Component:	**Excellent**	**Good**	**Needs Improvement**	**Grade**
Introduction				
Formatting				
Technical Writing				/1.5
References				
Procedure				
Formatting				/0.5
Technical Writing				
Results				
Formatting				/0.5
Content				
Calculation				
Formatting				
Sample Calculations				/1.5
Accuracy				
Discussion (Questions)				
Formatting				
Technical Writing				/3.0
Questions				
Conclusion				
Formatting				
Technical Writing				
Error Analysis				/3.0
Conclusion				
Overall:				/10