Senior Design Project Report

CSE/EEE 499

Hybrid Electric Aircraft

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ELECTRICAL AND COMPUTER ENGINEERING

NORTH SOUTH UNIVERSITY

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Agreement Form

We take great pleasure in submitting our senior design project report on “Hybrid Electric Airplane” This report is prepared as a requirement of the Capstone Design Project CSE/EEE499 A & B which is a two semester long senior design course. This course involves multidisciplinary teams of students who build and test custom designed systems, components or engineering processes. We would like to request you to accept this report as a partial fulfillment of Bachelor of Science degree under Electrical and Computer Engineering Department of North South University.

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ABSTRACT

To put it briefly, our aim is to harness the power of wind as we fly. One of the most significant guiding principles of today's transportation technology is to make the machines we use more efficient. The cornerstone for today's transportation tech is 'green' where we leave as little a carbon footprint as we can and thus make our existence on the planet more sustainable.

Keeping this in mind we have decided to take the idea of renewable energy and sustainability to the air transportation sector. Air transportation is one of the wonders of modern science. Since the days of Ikarus, human beings have relentlessly strived to fly higher, easier and with more comfort. As we progress in the sector of flight, there is a demand to make it more sustainable by reducing fuel consumption, reducing noise levels and on top of that kindle the indomitable human spirit of innovation by bringing something new to an existing idea.

The problem areas are lowering fuel consumption and reducing noise levels. We have decided to tackle the above issues by looking at two existing schools of thought. The 787 Dreamliner delegates its batteries to power the electrical systems and only uses chemical fuel to power the jet engines. It is thus quieter and has a smaller carbon footprint. Secondly, the electric motors are very quiet. Thirdly, an aircraft battles tremendous air resistance as it flies. From these three ideas we have decided to build a hybrid-electric aircraft.

The aircraft will take the idea of electric aircrafts and merge it with the idea of producing energy from wind resistance. There are obstacles. Betz' law shows us that the efficiency of wind turbines is 59.6%. Moreover, the battery technology of today is nowhere near capable of powering an airliner for the entirety of its flight. So compromises have to be made. In order to make it possible, we have decided to power the flight motors with charged batteries and generate energy with a turbine that is mounted on the front of the aircraft. The front turbine will generate energy by principles of electromagnetic induction that is used in a wind turbine.

EXECUTIVE SUMMARY

This report outlines the project scope and definition of a micro-class radio controlled (RC) airplane as well as the design process and fabrication considerations taken into account in the construction of a RC airplane. Further included is the implementation of hybrid technology on it. Students form groups of five, from which each team is to develop a project management plan for the completion of the project. These plans include subtasks, as well as the time required from completion, along with the designated person assigned to the task. This also includes the allocation and management of the resources necessary for project's realization.

This project is to be completed within a period of seven months whilst maintaining a budget cap of Tk. 30000. The budget not only covers the fabrication of the RC airplane, but also any form of testing and analysis to be performed over the course of executing the project.

The project team initiated the project by outlining a set of design objectives to which any subsequent design analysis results will be compared to. These objectives were based on the following premises; maximizing lift, minimizing drag and minimizing airplane weight. The major team objective is to achieve a payload to total weight fraction of 2-2.5 kg; as this is the main factor that is being measured for competition purposes. Needless to say, the early phase of design required that background research be performed in order to obtain a sound knowledge base in regards to RC airplane design principles as well as any other aerodynamic principles that apply to scaled-down airplanes that experience low Reynolds number flight conditions.

Upon completion of the research phase, it was determined that the RC airplane design should implement a low taper ratio, large wingspan and a large wing area. Using the preliminary research and objectives, it was decided that the group would proceed with flying wing or delta style design due to its excellent lift to drag ratio and general benefits with respect to generating lift in comparison to other airplane designs.

The project team then proceeded to perform computational fluid dynamics analysis and aerodynamic analysis using SolidWorks and XFLR5. This analysis allowed the team to conclude that the design being utilized is mostly stable both laterally and longitudinally. At this point, it was concluded that the design was suitable for manufacture.

The data collected was used to create a prototype in order to determine potential areas of concern before actual fabrication began. After the prototyping phase, the actual model was constructed and balancing tests were performed to optimize the positioning of the electronic components and confirm static stability. To conclude the manufacturing phase, the components were tested to ensure that the propulsion system and control surfaces were functioning.

NOMENCLATURE

AWING	Wing Area	b	Wing Span
AR	Aspect Ratio	λ	Taper Ratio
CLIFT	Coefficient of Lift	CDRAG	Coefficient of Drag
P	Density of Air	V	Craft Airspeed
w	Load	l	Lift
L	Length	M	Moment
CG	Center of Gravity	E	Young's Modulus
I	Area moment of Inertia	θ	Deflection Angle
v	Deflection	σ	Bending Stress
Y	Amplitude of Vibration in Y axis	LB	Rolling Moment
NB	Yawing		

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

The aviation sector is actively seeking after progressive design ideas to further alleviate the ecological effect of air travel. This is somewhat a consequence of increasing pressure on the industry from the government and various organizations to lessen outflows, regardless of the increase in air traffic. The forceful targets set by NASA and the EU (for example the Advisory Council for Aviation Research and Innovation in Europe has an objective of a 75% decrease in CO2 discharges and a 90% decrease of NOx emanations by 2050) cannot be accomplished through marginal enhancements in turbine innovation or aircraft design. Instead, disruptive technologies and more innovative aircraft must be considered.

Hybrid electric aircraft are being weightily considered as one of these revolutionary design concepts. Such aircrafts require a substantial increase in on-board power generation capability, from 1.5 MW on a current state-of-the-art more-electric aircraft (i.e. the Boeing 787), to 25 MW upwards for a hybrid electric aircraft. This requires significant development both in the design of appropriate aero-electrical power systems and in the development of appropriate technologies to enable these aero-electrical power systems to be realized within a reasonable time frame.

There are multiple approaches that are being taken ranging from pure electric aircrafts to hybrid electric and all the way to delegating auxiliary electrical systems to Lithium batteries to make this concept a reality. As a result of all the available methodologies, both technical and conceptual, consensus on what is a hybrid electric aircraft has become an elusive issue.

2 CONCEPTUAL DESIGN

2.1 AERODYNAMIC RESEARCH [1, 2, 3, 4]

2.1.1 LIFT& LIFTING BODIES

Lift is defined as a mechanical force generated by a solid object moving through a fluid. Essentially, lift is the force that opposes the weight of the airplane allowing the airplane to achieve flight. A lifting body is any part of the plane that generates lift. Although lift can be generated by every part of the airplane, the majority of the lift acting on an aircraft is generated by the aircraft's wings.

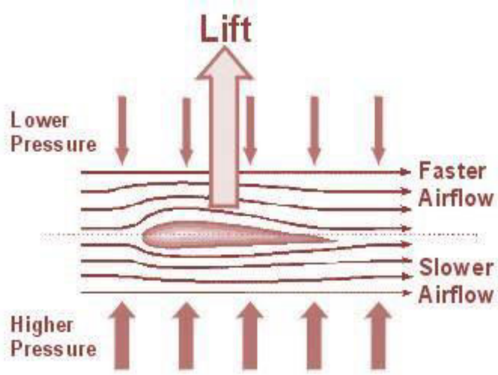


Figure 1 : Lift Acting On a Body

2.1.2 WINGS

The wing is designed to slice the air, the flowing fluid, into two streams; one that flows over the wing, and the other flowing under it. In standard design, the wing geometry and orientation are designed such that the air flowing on its topside has a greater velocity than the air flowing underneath. This is important because the higher velocity air stream exerts less pressure on the wing than the lower velocity stream beneath it, this pressure difference results in the upward acting force referred to as lift.

The lift acting on the RC airplane is a crucial part of ensuring that the design is capable of carrying the maximum payload with the given engine size. Thus, it is important to assess the various factors that influence lift on an airplane. Lift is affected by the angle of attack, wing loading, wing geometry, the speed at which the airplane travels through the fluid, and the properties of air. All of these can be influenced by design considerations with the exception of the air properties. The wings angle of attack has a direct correlation with the potential lift generated; however, it will also affect the amount of drag the body generates in an equivalent proportion. With a greater angle of attack, the wing will generate more lift; however, it should be noted that there is a "useful" lift. Useful lift refers to a situation in which most the force generated by the wings acts on the airplane body more in the vertical plane as opposed to the horizontal plane, this is where the wing geometry and orientation come into consideration.

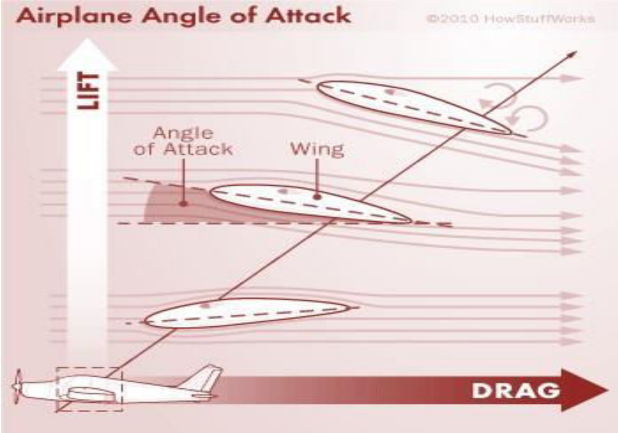


Figure 2: Wing Orientation and Lift and Drag Generation

The wing profiles on most aircrafts are typically in the shape of airfoils, as shown in the figure below. Airfoil shape is important as it will affect the lift generated. The lift generated is determined by the flow turning on the trailing edge of the foil – with greater flow resulting in a greater lift. Most RC airplanes employ a Clark Y type airfoil; it is used due to its flat bottom design, high camber, efficient lift to drag ratio and the fact that it is easily constructed. It also offers predictable and gentle stall characteristics.

Figure 3: Clark Y Airfoil Outline

The thrust, generated by the propeller and hand launch, is important to offset the effect of drag as a result of variances in wing geometry and orientation. This allows a greater angle of attack to be utilized in the design. It will also affect the velocity at which the craft body moves through the fluid, and as such, affects the maximum amount of lift that the plane can generate. The thrust generated by the plane requires optimizing the propeller design to ensure that the motor is being used in the most efficient manner to generate the most thrust.

Wing loads are a very important design consideration. It is a ratio of the aircraft weight to wing area; units are typically in oz/ft^2 [3]. It is important because;

I. Wing loading is the only indicator of how "heavy" an aircraft is. The actual weight of an aircraft has relatively little meaning in determining how well the plane will fly.

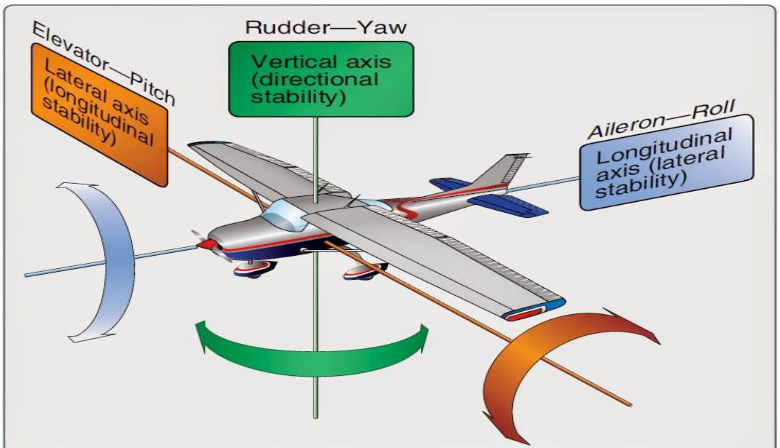
II. The lighter the wing loading, the slower the aircraft can take-off, fly and land. It will also have a better climb.

Increasing the wing area are will reduce the wing loading and allow the aircraft the benefits of being "lighter". Lift is a function of the lift coefficient (C_{LIFT}), wing area (A_{WING}), air density (ρ) and airspeed (V) as shown in the formula below;

$$Lift = C_{LIFT} \times \frac{\rho \times V^2}{2} \times A_{WING}$$

2.1.3 PLANE CONTROL SURFACES

There are four mechanisms that control the flight of an aircraft; flaps, ailerons, elevators, and a rudder. Airplanes make the use of flaps or slats to change the shape of their wings and tails. In our model we have used flaps as an elevator, negating the need to use a rudder. The purpose of the flaps and slats is to alter the amount of lift and drag, ultimately controlling how the airplane flies. Flaps are located on the back of the wing and are used during take-off and landing to adjust the shape of the wing. The flaps extend downward from the trailing edge to cause more lift during take-off. The change in shape also increases drag that assists in slowing down for landing. Ailerons are located closer to the end of the wing and are used in opposition so that one wing will create more lift than the other. This allows the plane to bank or roll either left or right. The rudder and elevators are stabilizers located on the tail of an airplane. Elevators, located on the horizontal part of the tail, are deployed to make the plane go up or down.



Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Roll	Longitudinal	Lateral
Elevator/ Stabilator	Pitch	Lateral	Longitudinal
Rudder	Yaw	Vertical	Directional

Figure 4: Flight Control Surfaces Move the Aircraft around the Three Axes of Flight

2.1.4 PARAMETERS

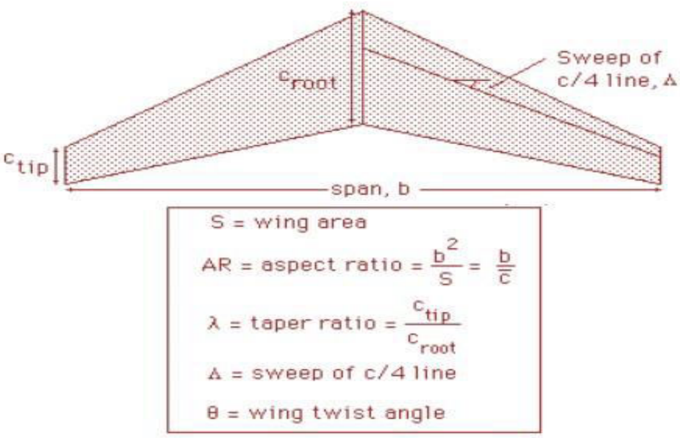


Figure 5: Typical Wing Design Parameters

WINGSPAN

Wingspan refers to the end-to-end length of the aircraft from one edge of the wing to the other. Deciding the wing span is one of the most basic decisions to be made in the design of a wing. It is best to utilize the largest wing span consistent with structural dynamic constraints. This should reduce the induced drag directly and create more lift.

It is important to note that as the wing span is increased, the wing structural weight also increases, from which the weight increase offsets the induced reduced drag. However, it is difficult to reach this point.

ASPECT RATIO

Aspect ratio has two general definitions. It can be defined as the ratio of the wing span (b) to the mean wing chord (C), but is commonly defined as the ratio of the wing area (A) to the wing span squared. The formulaic representation is shown below;

$$\text{Aspect Ratio} \quad = \frac{b^2}{A} = \frac{b}{C}$$

Aspect ratio is a major factor determining the dimensional characteristics of the ordinary wing as well as its lift-drag ratio. There are generally two options available for selecting aspect ratios; one can design a low aspect ratio wing or a high aspect ratio wing. Increasing aspect ratio results in an increase in lift experienced by the craft at a given angle of attack. It will result in changes to the wing lift distribution by intensifying the effects of all other parameters. An increase in aspect ratio with constant velocity will also decrease the drag the aircraft experiences, an effect that becomes more apparent with higher angles of attack. This will improve the performance of the wing when in a climbing attitude.

Low aspect ratio wings have nearly elliptic distributions of lift for a wide range of taper ratios and sweep angles. It takes a great deal of twist to change the distribution. Very high aspect ratio wings generate more lift but are quite sensitive to direction changes in flight. Also, a higher aspect ratio also has the effect of a higher rate of lift increase, as angle of attack increases, than lower aspect ratio wings.

Aspect ratio has an effect on the lift curve, that is to say, a high aspect ratio wing will have a higher maximum lift coefficient, but will also have a lower stalling angle of attack than a low aspect ratio wing that employs the same airfoil shape.

In ultra-lightweight planes, a higher aspect ratio is typically employed. Most ultra-lightweight planes typically have an aspect ratio between 5.5 and 8 and light general aviation aircraft between 7 and 9, averaging around 7.5. This is the range in which the project testing will be focused on.

TAPER RATIO

The taper ratio can be in either planform or thickness, or a combination of the two. It is defined as a ratio expressing the decrease from wing root's chord length (C_{root}) to wing tip's chord length (C_{tip}). The formulaic expression is shown below:

$$\text{Ratio} = \frac{C_{tip}}{C_{root}}$$

The taper ratio is important for design consideration as it can affect the weight of the wing. A lower taper ratio will typically result in lighter wings, leading to a smaller load on the engine. Also, increasing the root chord of the plane will create more space to accommodate a landing gear. A short tip chord length; however, can result in a reduced lift coefficient and unacceptable stall characteristics hindering the reduction of the taper ratio.

Essentially, the design goal is to keep the taper ratio as small as possible without creating excessive variation in the lift coefficient or poor stalling characteristics.

SWEEP

Sweep can be defined as the slant of a wing, horizontal tail, or other airfoil surface. It is typically employed for its effect on drag as it permits a greater lift coefficient without drag divergence. However, it has negative impacts on stall, increases the wing loading and destabilizes the airplane. It is best employed with lower aspect ratio planes.

WING TWIST

Wing twist refers to an aerodynamic feature added to aircraft wings to change lift distribution along the wing and the lift coefficient distributions. It has a positive effect on pitching moment and a little effect on trimmed drag, but also increases the structural weight of the craft. This is a design element to be employed on a situational basis in RC airplane design, as it might prove more harmful than beneficial.

DIHEDRAL AND ANHEDRAL

Dihedral and anhedral refer to the angle that results from slanting the wing by raising (dihedral) or lowering (anhedral) the wing tip with respect to the wing root. The dihedral is primarily used to counteract rolling and make the plane more laterally stable. Anhedrals are primarily used to counteract naturally occurring dihedrals.

MULTI-BLADE OPTIONS

Two-bladed propellers are commonly used because they are relatively efficient and easy and cheap to produce but sometimes an RC airplane may require more blades, particularly in situations utilizing multiple engines driving the plane. Generally, more blades are utilized in designs as the increased number of blades allows for smaller diameter propellers to be used. Essentially, one can get a similar amount of thrust to a larger diameter propeller by employing more blades.

However, it is important to note that adding more blades decreases the overall efficiency of the propeller because each blade has to cut through more turbulent air from the preceding blade, in fact a single bladed propeller is the most efficient but is more difficult to construct due to the need to create a balancing counterweight on the other side of the propeller cap to offset the weight of the blade.

2.2 MATERIAL RESEARCH [5]

The ideal RC aircraft frame is lightweight, inexpensive, strong and durable material. Research into material used in RC aircraft construction revealed that the most common materials used are reinforced Depron foam, aluminum bar, carbon fiber rod, and wood; the most popular being Depron foam and bass wood. Given that Depron foam is fairly inexpensive and lightweight, it will be the primary type of material used.

One key advantage of Depron foam over balsa wood for model airplanes lies in the ease with which it can be shaped with a sharp knife or a razor and also the fact that it can be used in comparatively large sizes– a desirable condition for model planes which have to maintain their aerodynamic settings for flying and stability.

There are three cuts of Depron foam and each is best used in construction of specific plane part.

- **Tangent Cut:** is ideal for fuselage sheet covering, wing leading edges, forming tubes and flexible spars.
- **Quarter Grain Cut:** Ideal for wings, tails, wing ribs, wing trailing edges, and fuselage formers.
- **Random Cut:** is a substitute for the other two cuts.

In using Depron foam wood, it will be necessary to reinforce the wood depending on its application. The current consensus is that the Depron foam will be reinforced with glue.

2.3 DESIGN CONCEPT GENERATION

To facilitate design process, the team decided on and set areas of focus for the design. These foci were at the background of each design and they are as follows:

I. **Maximize Lift**:
   a. Reduced wing loading
   b. Wing shape & geometry (Applying wing design aspects from background research)

II. **Minimize Drag**:
   a. Higher aspect ratio
   b. Plane Geometry

III. **Maximize Thrust:**
   a. Proper motor sizing & Propeller dimensions' selection

IV. **Minimize Weight**:
   a. Material Selection
   b. Design implementation considerations. Utilizing wireframe structures, trusses and avoiding thick solid parts as much as possible.

3 HYBRIDIZATION

In layman's terms, 'hybrid electric' signifies two different sources of power, and on aircraft this means being propelled by kerosene and an electric battery. Being able to move these traditional jet engines allows designers much greater creativity.

3.1 RESEARCH [6]

Hybrid-electric aircraft have gas turbine engines which drive electrical generators to power electrically motor driven fans. Depending on the variant of hybrid-electric aircraft being considered, thrust may be provided via a combination of gas turbines and electrical propulsors, or only via the electrical propulsors. This design philosophy is not new, and in fact is commonly found throughout industry in rail, marine and electric vehicles. Within these sectors electrical propulsion has been shown to have a number of benefits, including:

- Improved efficiency, particularly at part load
- Use of excess power generation for power supply to auxiliary loads such as pumps or pressurization systems
- Greater flexibility in location of electrical loads
- Reduced volume of machinery
- Reduced vibration and noise

In principle the overall structure of a hybrid electric aircraft could be similar to conventional tube and wing designs (although more novel blended wing body aircraft or tilt rotor designs are being considered), with gas turbine engines used for electrical power generation for driving electrical propellers. An example of a hybrid-electric aircraft design concept for a nine passenger regional aircraft is shown in Figure 1. For this type of aircraft, it is claimed that electric propulsion and autonomy technologies can decrease total operating costs (by up to 30%).

Figure 6: NASA SCEPTOR Hybrid Concept

A standout amongst the most critical points of interest related with hybrid electric aircrafts is the flexibility in configuration and operation. For example, the electric propulsion can be utilized continuously throughout flight or for specific sections of the flight plan where the power demand is higher. Furthermore, there is the possibility to incorporate energy storage systems alongside the gas turbine driven generators in order to enhance system performance. The inclusion of such systems also introduces a level of inherent redundancy.

Moreover, hybrid aircraft represent an opportunity to increase aerodynamic efficiency. By means of propulsors integrated into the body of the aircraft, Boundary Layer Ingestion (BLI) can be effectively used to re-energise the wake behind the aircraft, reducing drag. This stipulates the placement of the propulsors typically towards the rear. Some designs seek to further exploit this effect by placing propulsors on top of the fuselage so that the aircraft itself forms a sound barrier. Thus the use of hybrid electric propulsion offers improvements in efficiency and noise reduction – the two of which are key objectives for next generation aircrafts.

Be that as it may, huge difficulties do exist for the realization of hybrid electric aircraft given the substantial upscaling of electrical generation and distribution on-board.

The efficiency of aircraft is far more sensitive to weight than other applications where hybrid technologies have been utilized. Generally electric components struggle to match the power density of their mechanical equivalents (particularly at higher power levels) and therefore any potential weight penalty which comes with the addition of electrical components must be offset by the subsequent gains in efficiency and reductions in noise in future hybrid electric designs.

Hybrid electrical propulsion also inherently adds losses to a system through the intermediate use of electrical power. The efficiency of the electrical-mechanical power conversion and the electrical distribution system, as well as the size of associated systems to deal with these losses (e.g. the thermal management system), will have a significant bearing on the feasibility of any hybrid electric aircraft design.

Beyond these two fundamental issues lie a range of electrical technology and integration issues.

3.2 PREVIOUS WORKS ON HYBRID POWER SYSTEMS

- Zunum Aero, backed by Boeing and JetBlue, is working since 2013 on a family of 10-to-50-seat hybrid electric regional aircraft. On 5 October 2017, Zunum launched the development of a 6-to-12-seat aircraft with its powertrain installed on a testbed and flown in 2019. Aiming to fly in 2020 and be delivered in 2022, it should lower operating costs by 40–80% to reach available seat miles (ASM) costs of a 78-seat Dash 8-Q400. [7]

- On 28 November 2017, Airbus announced a partnership with Rolls-Royce and Siemens to develop the E-Fan X hybrid-electric airliner demonstrator, to fly in 2020. [8]

- The 1,300-shp GE Catalyst could be used in hybrid-electric propulsion: in late 2016, General Electric modified a GE F110 fighter turbofan to extract 250 kW from its HP turbine and 750 kW from its LP turbine, supported by the USAF Research Laboratory and NASA, developed and tested a 1-megawatt electric motor/generator with GE Global Research, and tested a liquid-cooled inverter converting 2,400-volt DC to three-phase AC with silicon carbide-based switches and 1.7-kW MOSFET power modules. [9]

- By May 2018, consulting firm Roland Berger counted almost 100 electric aircraft in development. This was up from 70 the previous year and included 60% from startups, 32% from aerospace incumbents, half of them major OEMs and 8% from academic, government organizations and non-aerospace companies, mainly from Europe (45%) and the U.S. (40%). Mostly urban air taxis (50%) and general aviation aircraft (47%), a majority are battery-powered (73%), while some are hybrid-electric (31%), mostly larger airliners. Industry experts expect a 50+ seat hybrid-electric airliner to debut in commercial operation by 2032 for routes like London-Paris. [10]

- The EU funded the Hypstair [11] program with €6.55 million over three years till 2016 for a TRL of 4: a Pipistrel Panthera mockup received a serial hybrid-electric powertrain, ground testing a 200-kW motor driven by batteries only, by a 100-kW generator-only and by both combined. It is followed by Mahepa [12] project from 2017, EU-funded over four years with €9 million under the Horizon 2020 research program to reduce aviation carbon emissions by 70% in 2050, till TRL 6 before entering product development. The Panthera drivetrain will be divided in modules: electric motor thrust generator and internal combustion power generator in the nose, human-machine interface and computing, fuel and batteries in the wing. Ground testing is planned for 2019 before flight tests in 2020.

- The dual-fuselage, four-seat, battery-powered Pipistrel Taurus G4 received a DLR hydrogen fuel cell powertrain to fly as the HY4 in September 2016, with hydrogen tanks and batteries in the fuselages, fuel cells and motor in the central nacelle. Partners are German motor and inverter developer Compact Dynamics, Ulm University, TU Delft, Politecnico di Milano and University of Maribor. Ground and flight tests should follow those of the Panthera a couple of months later. Along their ground handling, scaling to 19- and 70-seat airliners will be studied in two configurations: more of the same size modules for electric distributed propulsion, or larger sized modules extrapolating the flight-test results, powering twin propellers. Flights will test system behavior, measure performance and reliability, and evaluate failure modes. A failure rate of one per 10 million hours is targeted, as low as in airliners, with very reliable components or with redundancy. [13]

- Austrian company ScaleWing has developed a hybrid and redundant piston/electric engine, based on independent modules: a 1.15 L (70 cu in) four-stroke V-twin producing 80 and 120 hp (60 and 89 kW) when turbocharged, and electric motors, producing 170 to 350 hp (130 to 260 kW) combined. [14]

- VoltAero is developing the VoltAero Cassio 1, a hybrid testbed based on the Cessna 337 Skymaster, which it intends to fly in late February 2019. The clean-sheet, all-composite VoltAero Cassio 2 prototype should follow in 2020, before deliveries in late 2021 or early 2022. It will be powered by two 60 kW (80 hp) electric motors driving tractor propellers on the wing and a 170 kW (230 hp) piston engine and 150 kW (200 hp) motor driving a pusher propeller in the aft fuselage. The combination of fuel and batteries will give it a 1,200 km (650 nmi) range with nine people aboard. [15]

- On 31 October 2018, Diamond Aircraft flew the HEMEP, funded by Germany's economics ministry and the Austrian Research Promotion Agency, reaching 130 kn (240 km/h) and 3,000 ft (910 m) within 20 minutes. It is a modified DA40 with its single piston engine replaced by two Siemens 75 kW (101 hp) electric motors in the nose powered by a 110 kW (150 hp) Austro Engine AE 300 diesel or two 12 kWh (43 MJ) batteries, for a 5 h. endurance or 30 min. on batteries only. [16]

- By January 2019, U.S. startup Ampaire was replacing the Cessna 337 Skymaster (a push-pull aircraft) aft piston engine with an electric motor, to fly the prototype on Hawaiian Mokulele Airlines commuter routes operated with Cessna Caravans. Seven other airlines are interested by Caravan or Twin Otter conversions: Seattle's Kenmore Air, Tropic Air of Belize, Puerto Rico-based Vieques Air Link, Southern Airways Express of Memphis, Tennessee, Guernsey's Aurigny and Star Marianas Air, based in the Northern Mariana Islands, as well as Norway. [17]

- By March 2019, UTC was converting a 39-seat Bombardier Dash 8 Q100 into a hybrid-electric for demonstration flights from 2022 within its Project 804. The 2 MW (2,700 hp) design is similar to the Airbus E-Fan X program, but aims for certification and production for a subsequent commercial offer. One 2,150 hp (1,600 kW) PW121 turboprop will be replaced by a 1 MW (1,300 hp) gas turbine joined with an electric motor of the same rating, powered by off-the-shelf lithium-ion batteries for takeoff and climb. The turbine is used alone in cruise and drives the motor-generator to recharge the batteries in descent. The downsized engine operates at its optimum for 30% fuel savings over 200–250 nmi (370–460 km). Range is reduced from 1,000 to 600 nmi (1,900 to 1,100 km) due to the higher empty weight and 50% lower fuel capacity. [18]

The potential of electric and hybrid-electric propulsion remains limited for general aviation, according to Textron Aviation, as the specific energy of electricity storage is still 2% of aviation fuel. A hybrid configuration is needed for airliners: lithium-ion batteries including packaging and accessories generates 160 Wh/kg whereas aviation fuel generates 12,500 Wh/kg. As electric machines and converters are more efficient, their shaft power available is closer to 145 Wh/kg of battery while a gas turbine gives 6,545 Wh/kg of fuel: a 45:1 ratio. [19]

4 INITIAL PERFORMANCE ESTIMATION

4.1 WEIGHT MODEL [20]

Weight of the airplane is a major concern. We had to choose objectives to minimize weight as much as possible. Weight summary of the airplane is given below. A preliminary c.g. model was also incorporated into the Excel spreadsheet for initial analysis. The moments of inertia were calculated using a Solid Works model.

The weight of the wing was calculated by integrating its volume. We assumed a constant t/c and the airfoil remained constant throughout the wing. The wing weight was estimated as

$$W_{wing} = \rho_{foam} A_{airfoil} c^2 b \left(\frac{1+\lambda+\lambda^2}{3}\right)$$

where;
W wing = weight of the wing
ρ foam = density of foam
A airfoil = dimensionless area of the airfoil
b = span of the wing
c = mean chord length
λ = taper ratio of the wing

The c.g. location of the wing from the leading edge of the center of the wing is:

$$x_{cg,wing} = \left(\frac{c}{4}\right) + \tan\left(\Lambda_{c/4}\right)\frac{b}{8}\left(\frac{1+2\lambda+3\lambda^2}{1+\lambda+\lambda^2}\right)$$

Where;
Λc/4 = Quarter chord sweep

The weights of the tail and fuselage were calculated based on area and thickness of Depron foam used. The weights of the booms were calculated simply from their volume. The c.g. location was taken at the geometric center of these components.

Control and Power	Spread Sheet (grams)	Actual (grams)
900kv Brushless Outrunner Motor (2)	80	160
30A Fixed Wing Brushless Speed Controller (2)	12	21
Multistar 4000mAh 3S 20C Lipo Pack	200	200
Servo (3)	9	27
Flysky receiver	3	3
Control Linkages	2	4
Propeller (2)	2.5	5
Pushrod	2	6
Dc Motor + Turbine Propeller (2)	10	22
Motor Mount	3	6
Wing + Fuselage + Horizontal Tail + Vertical Tail	700	700
Total	**123.5**	**1148**

Table 1: Weight Summary

The weight of the battery, motor, ESC and all other electric parts was fixed. The weight of the wing, booms, fuselage and the tails could be varied. The total fixed weight of the components was around 500 gms; about half of the total aircraft weight.

The chosen design does not utilize landing gear as this would add weight and drag, which is contrary to the objectives outlined earlier in the report. The craft is expected to glide to a landing base.

4.2 PROPULSION MODEL

The aircraft used two SunnySky 2216 900kv brushless motors with 30A ESC 1045 size propeller. The manufacturer specification and output thrust and efficiency are given in **Appendix B.**

4.3 PERFORMANCE MODEL

The performance model combines calculations from the weight model and propulsion model. Wing area and aircraft speed are taken as input. During optimization process we fixed the assumed cord other variables such as the thickness to cord.

5 AIRFOIL SELECTION

The initial airfoil selection criterion is to choose existing airfoils that has maximum C_L of at least 1.2. To minimize drag at cruise, the airfoil should have minimum C_D at C_L from 0.5 to 0.7, and the C_L at zero angle of attack should be as high as possible.

The lift curves and drag polars of several existing airfoils are shown in the following figures. These plots are computed using XFLR5 viscous computation at Re=120000. It can be seen that NACA 4312 has the highest C_{Lmax} and stall angle of attack. Therefore, NACA 4312 is chosen as our initial airfoil.

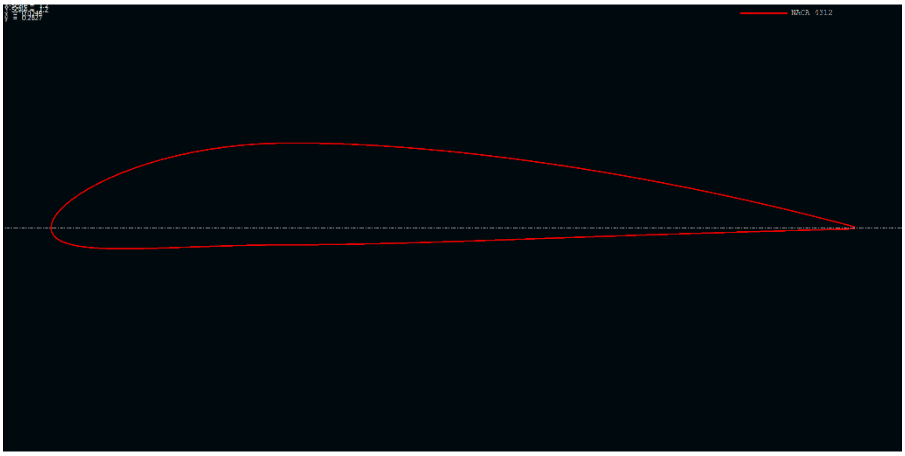


Figure 7: NACA 4312 Airfoil

The objectives for our airfoil were to have a thin airfoil to save weight, to reduce drag, and to have a relatively high CL_{max} for stall margin. An existing airfoil, NACA 4312, was taken as a starting point and modified to help move the turbulent separation point farther back on the trailing edge. Care was taken that the pressure recovery was smooth for a reasonable range of angles of attack.

5.1 DRAG POLAR

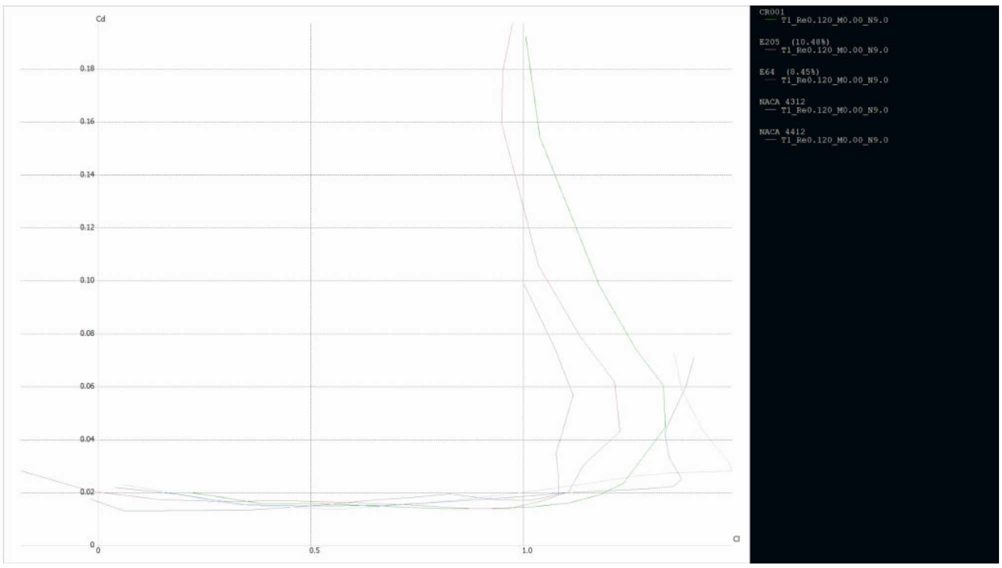


Figure 8: C_D vs. C_L

The "drag polar" specifies the drag coefficient C_D for a given lift coefficient C_L. This is often the most important part of the results and can be used to find the best climb or sink rate as well as the optimum glide angle ideally possible with an airfoil. NACA 4312 has the highest CL_{max} among the analysed airfoils.

5.2 LIFT POLAR

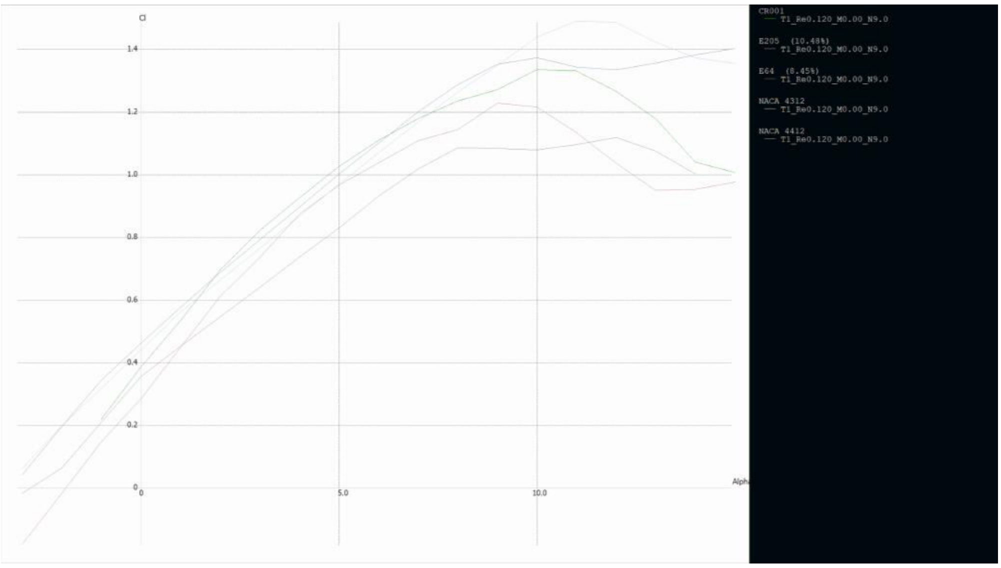


Figure 9: C_L vs. Alpha

The "lift polar" shows the lift coefficient C_L, plotted versus the angle of attack *alpha*. It plots the lift of the airfoil for a given angle of attack. NACA 4312 has the highest stall angle of attack.

5.3 MOMENT POLAR

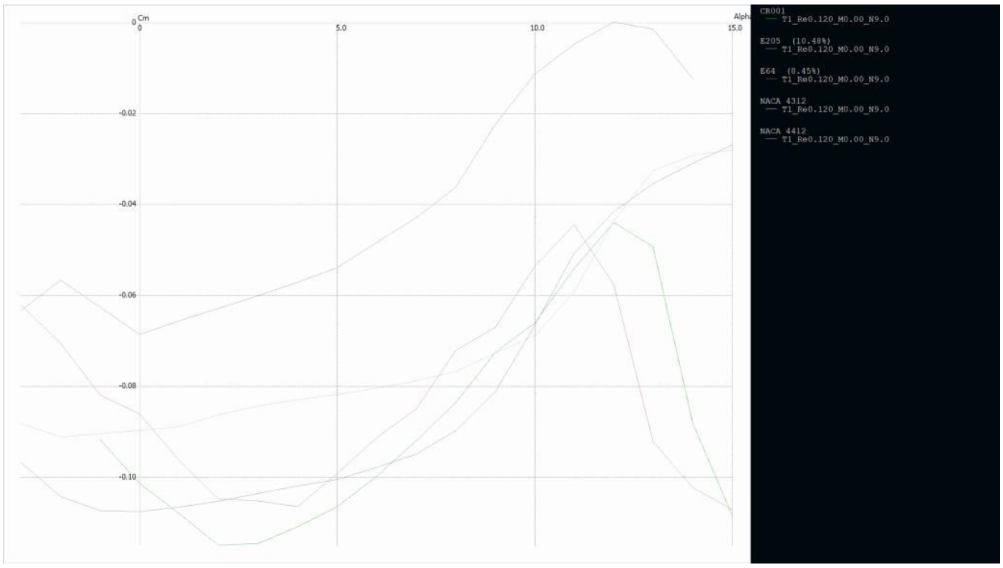


Figure 10: C_m vs. Alpha

The "moment polar" is similar to the "lift polar", but shows the moment coefficient C_m of the airfoil section instead of the lift coefficient versus the angle of attack.

5.4 TRANSITION POINTS

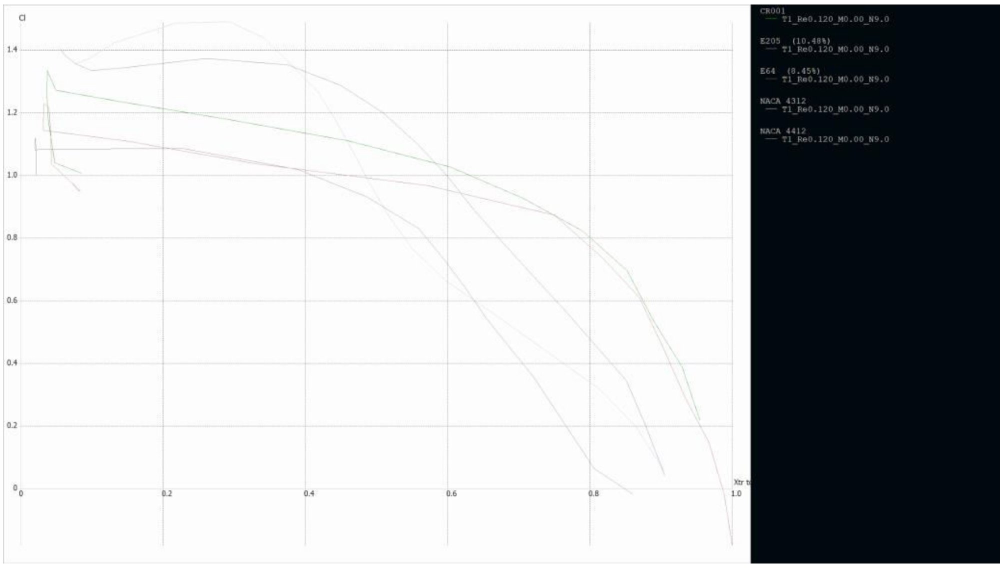


Figure 11: C_L vs. Xtr_{top}

C_L v/s Xtr_{top} plots the lift coefficient for a given transition point on the upper surface where the boundary layer changes from laminar to turbulent.

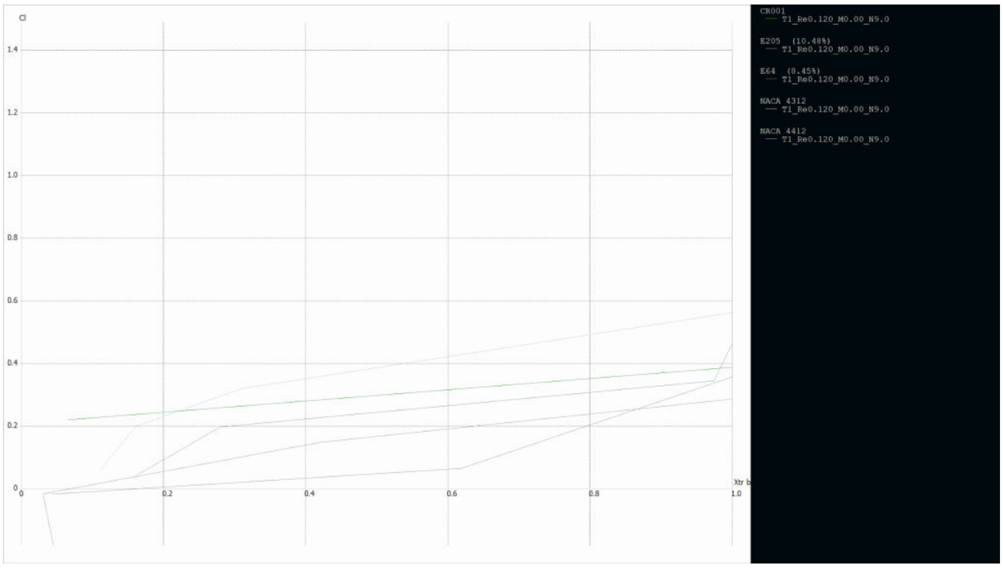


Figure 12: C_L vs. Xtr_{bot}

C_L v/s Xtr_{bot} plots the lift coefficient for a given transition point on the lower surface where the boundary layer changes from laminar to turbulent.

6 PERFORMANCE ESTIMATION

Utilizing the information from the design analysis phase and Newton's force equation as well as data from the SolidWorks 3D and XFLR5 software packages, the following performance specifications were estimated:

Plane Weight	900 g
Plane Airspeed	16.42 m/s
Maximum Lift Generated	57.04 N
Maximum Payload that can be lifted	4.96 Kg
Payload to Total Weight Fraction	0.85
Assembly Time	160 – 240 seconds

Table 2: Predicted Performance Specifications

6.1 EXPECTED FLIGHT PARAMETERS

The following are the expected flight characteristics based on research, the design features and the results of the calculations and testing phase:

I. Stable lateral and directional flight conditions

II. Slight instability in terms of pitch stability

   a. *Care must be taken to maintain speed above 12 m/s*

III. Plane should be self-correcting in most conditions

IV. Time required to complete course should be 1.22 s

7 SOLID MODEL

CAD modeling of the aircraft was done in OpenVSP in order to provide a solid base to validate concepts.

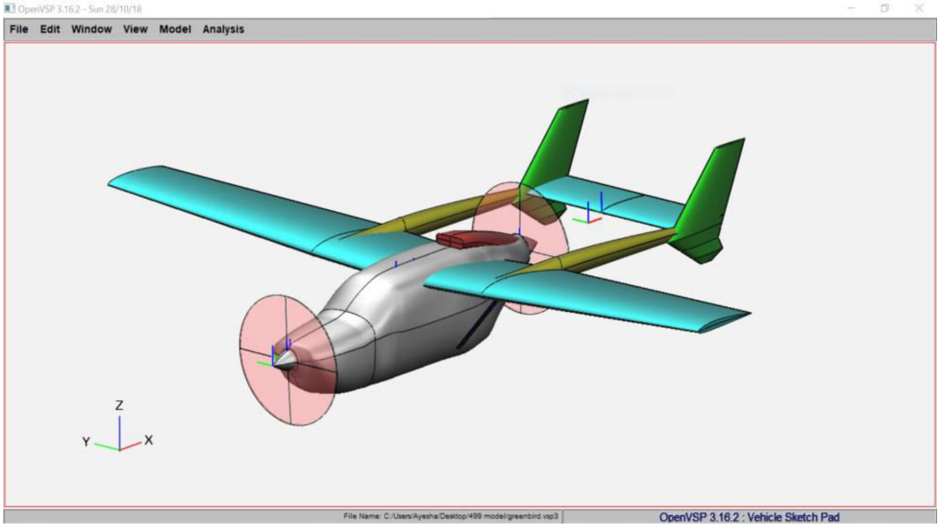


Figure 13 : Angled View

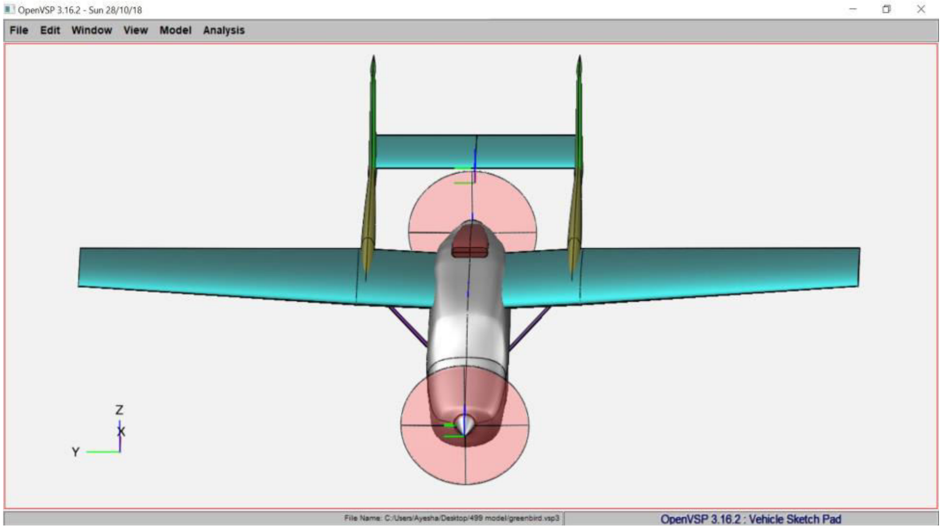


Figure 14 : Front View

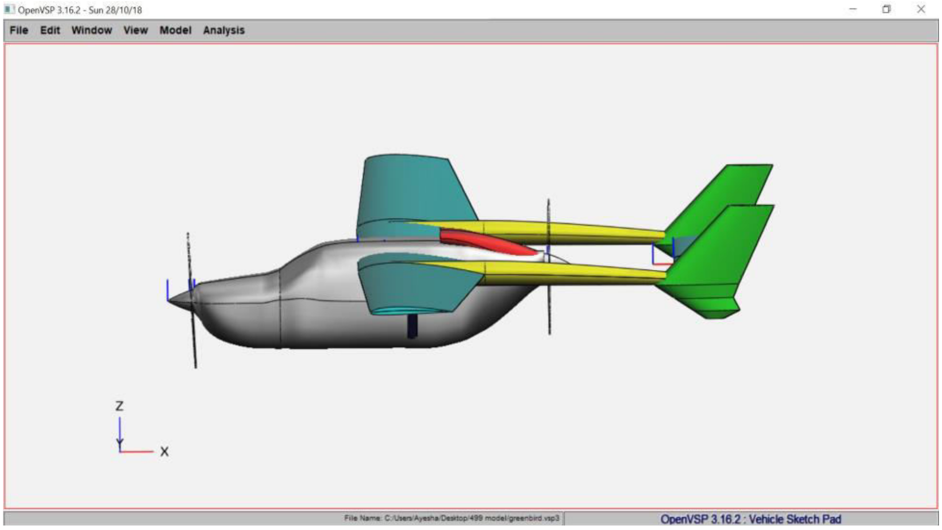


Figure 15 : Side View

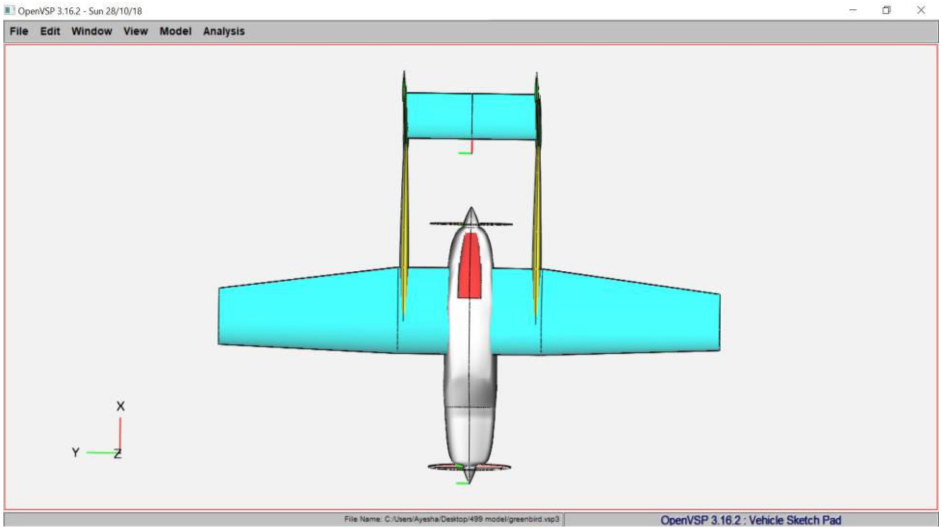


Figure 16: Top View

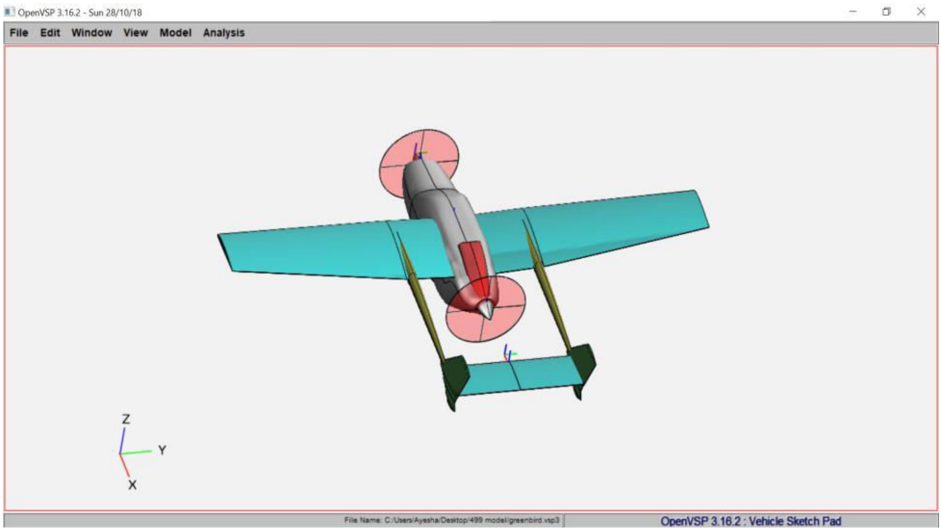


Figure 17 : Top View (Angled)

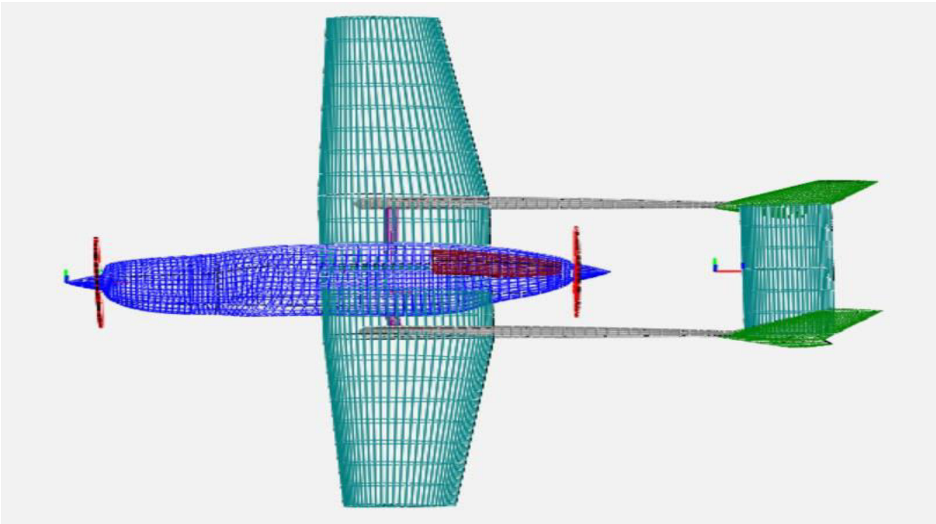


Figure 18 : Top View (Wire Model)

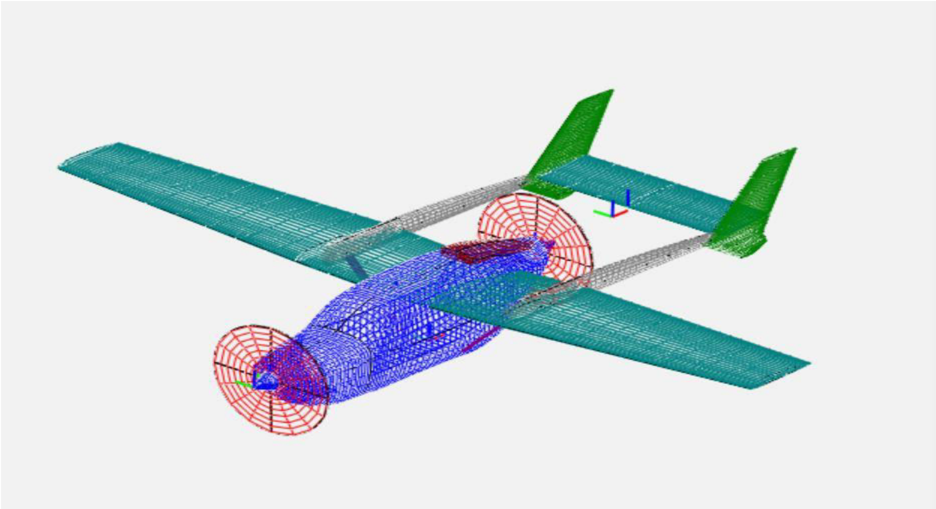


Figure 19 : Angled View (Wire Model)

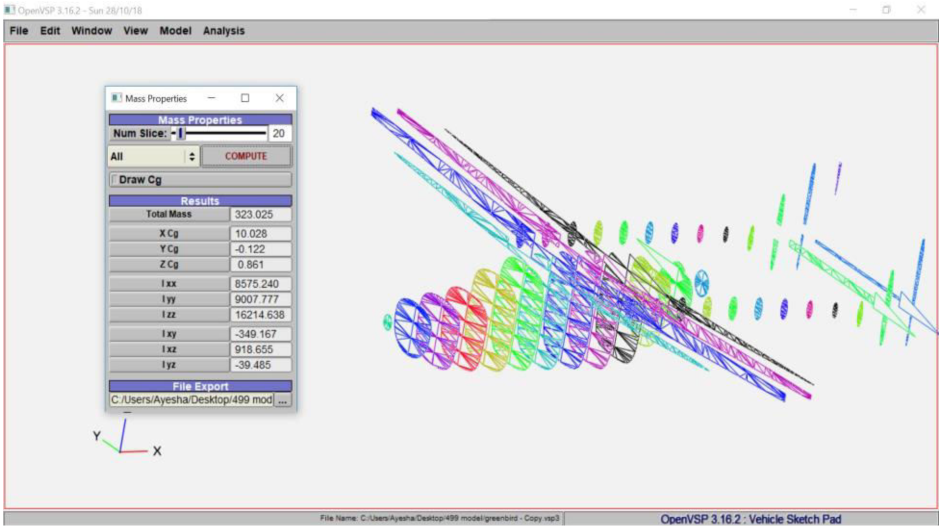


Figure 20 : Mass Properties

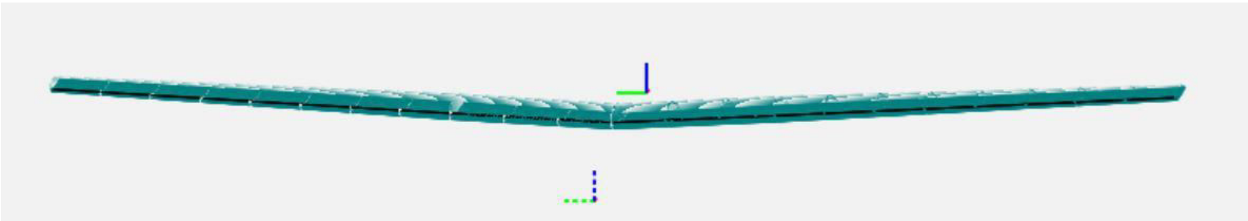


Figure 21 : Wing (Front View)

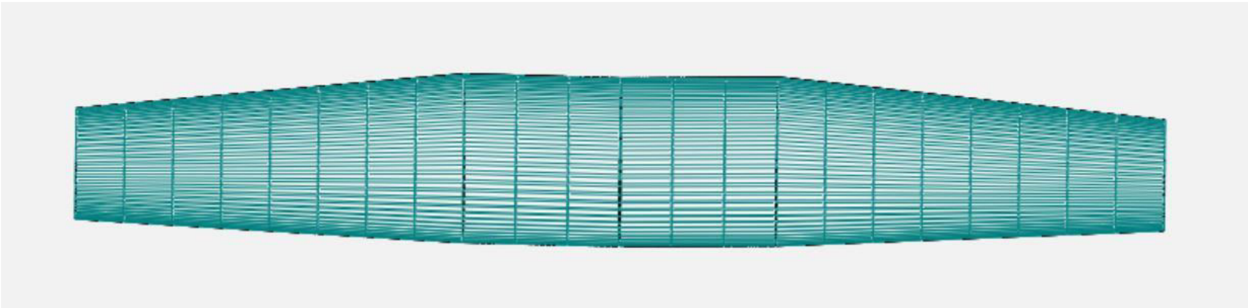


Figure 22 : Wing (Top View)

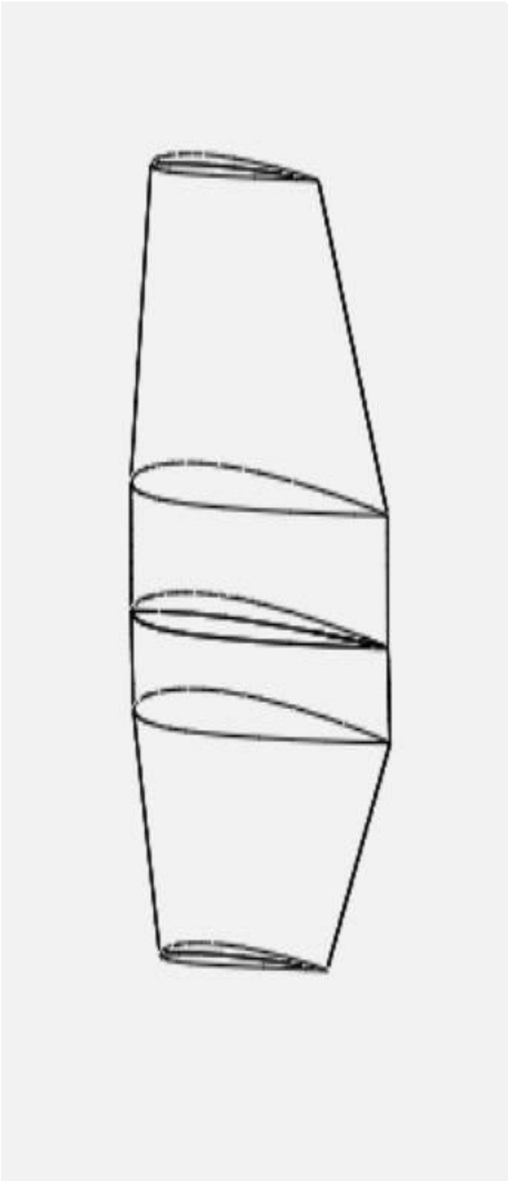


Figure 23: Wing Model **Figure 24: Wing Model (Wire)**

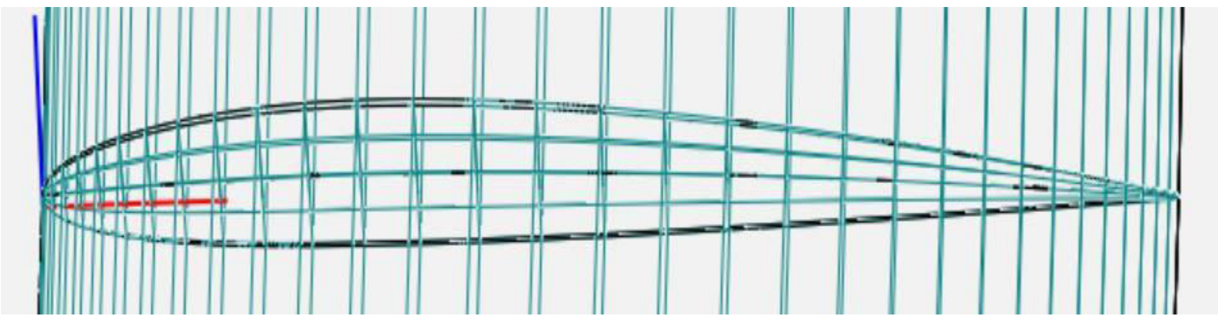


Figure 25: Airfoil (Lateral View)

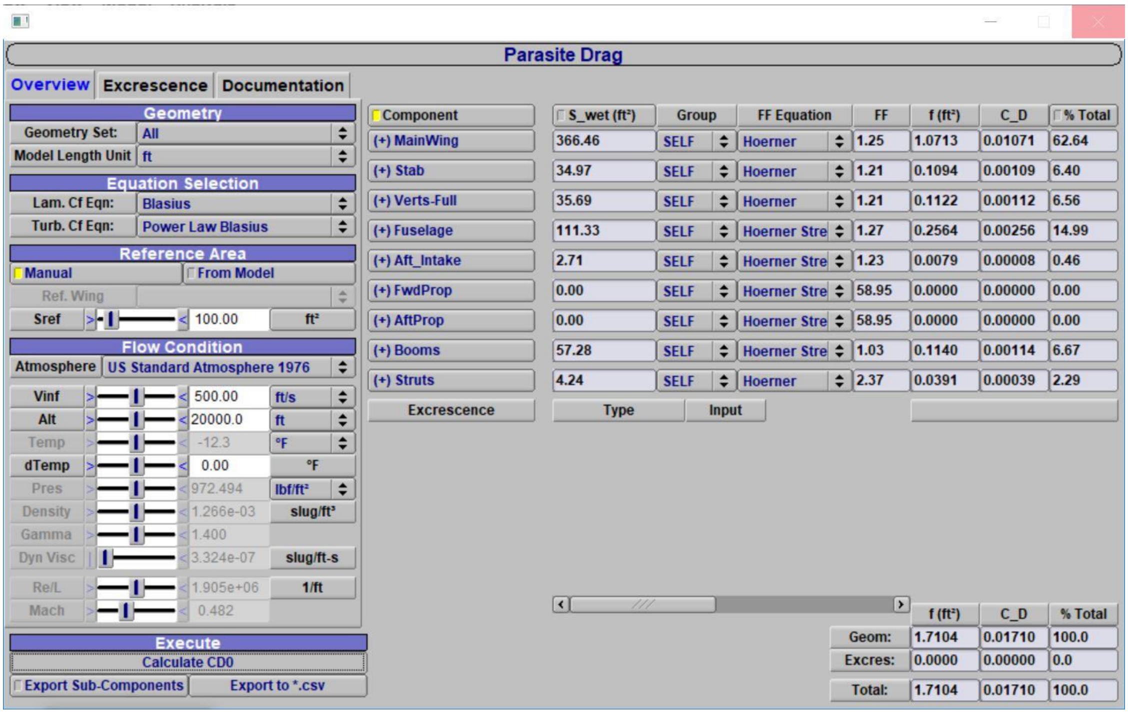


Table 3: Parasite Drag

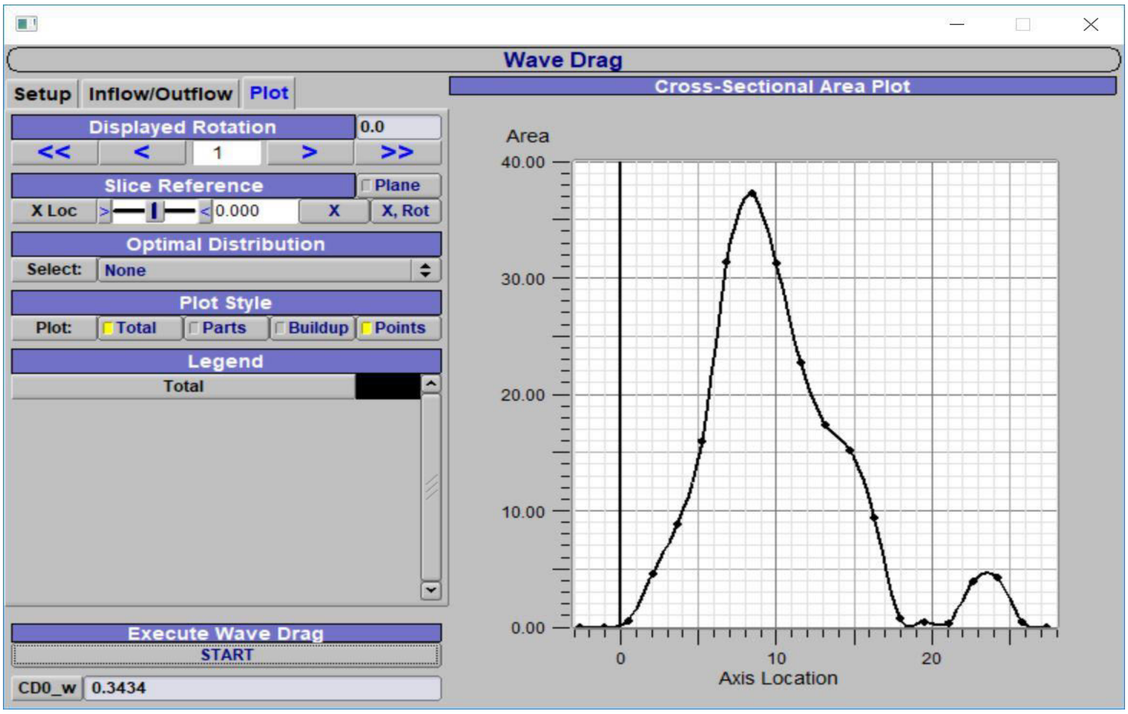


Table 4: Wave Drag

8 ANALYTICAL PHASE CONCLUSION

Upon completing the research phase of the project, it was decided that the best design route for maximizing lift would be utilizing a flying wing or delta wing design. To minimize weight and still maintain structural integrity, the RC airplane was constructed using depron foam and wood, with basswood being used in areas that required greater stiffness. Upon deciding on a design direction, vibration, deflection and bending stress tests were performed both analytically and experimentally to refine the design parameters. From these tests it was determined that the craft should be able to withstand the effects of the loads that will be imposed on the craft. Further analysis proved that the craft should be able to lift a 4.96 kg weight at the maximum whilst weighing approximately 854g. This yields a payload to total weight fraction of 0.85 which is fairly close to the 0.9 fraction set as a design objective.

9 MANUFACTURING AND FABRICATION

9.1 PROTOTYPING

To aid in fabrication decisions, a prototype of the design was created using corrugated cardboard and masking tape. This was done in order to get an idea of the possible issues that will be encountered in the process of creating the frame of the model. It also helped the team to gain an idea of what process would best be employed in order to fabricate each part. The Part Fabrication considerations are listed in **Table 6:**

PART	*FABRICATION PROCESS*
Wing	• Ribs - These were cut using the sharp cutter as precision is required. The ribs will be attached to the support spar and dowel spar using cyanoacrylate glue. • Support Spar - Cut with the cutter and attached using glue. This was made of foam board for extra stiffness. • Spar (Dowel) - Cut with the cutter and attached using glue gun. • Covering - The covering was vinyl and was done by hand using and knife for trimming. • Elevon - Cut with the cutter and attached to the wing using adhesive tape. • Servo Motors - Attached using 2 sided tape, and connected to the elevons using wire and an aluminum tube. • Magnets – Magnets will be glued to the end of the wings and used to attach the wings to the fuselage. • Tape was also used.
Fuselage	• Airfoil - These were cut using the sharp cutter as precision is required. They were glued into position on the mounting space using hot glue. • Mounting space - Can be cut with the cutter, but band saw will be just as effective and more time efficient. This will be made of basswood for additional stiffness. • Nose - The nose of the plane is a foam block that consists of 1.5 inch segments that are glued together. Each segment is cut using the cutter. • Covering - The covering is vinyl and was done by hand using heating iron and knife for trimming. • Rubber – Rubber is used to attach the fuselage to the wings.
Fuselage Case	• Sides - These were cut using the laser cutter as precision is required. • *Spars* - These needed little precision and as such were cut with a band saw. • Covering - The covering is vinyl and was done by hand using heating iron and knife for trimming.
Mounts	• Battery & Speed Controller - Attached using velcro. • Motor - Mounted in specially designed basswood mount. • Payload - Mount was constructed using aluminum bar. The bar was bent into shape and holes were tapped into the side of the case to insert dowels to hold the payload in position.

Table 5: Fabrication Decisions

9.2 CONSTRUCTION DETAILS

Three main ideas were taken into consideration whilst deciding what the design objectives were: maximizing lift, minimizing drag and minimizing airplane weight. Keeping these in mind, the following objectives were set:

Plane Weight	800g – 900g
Payload to Total Weight Fraction	2 -2.5Kg
Assembly Time	Less than 2 minutes
Target Airspeed	10-30 mph
Wing Area	560 – 600 squared inches
Wing Span	60 inches
Taper Ratio	0

Table 6: Initial Design Objectives

9.2.1 DRAWING AND CUTTING

After initial inspection was completed, the aircraft sketch was drawn using approximate measurement. Minimal tools were used to construct the craft. The plane required 4 sheets of Depron foam board and almost a full sheet of poster board. Each part of the airplane was cut according to the measurements.

Figure 26: Drawing and Cutting Phase

Added stress was exerted on the wing spar due to the fuselage carrying 2 motors. To alleviate this, an aluminum flat bar (thickness $1/16^{th}$ of an inch) was used and a heavier gauge pushrod was also used for the elevator and rudder. A music bar of thickness 0.055 inch was used. It can fly this as a 3 channel. A single power pod was mounted in the front and the battery was mounted under the wing for an ideal c.g. The same size motors are used for the airplane.

Figure 27: Front-end of Model

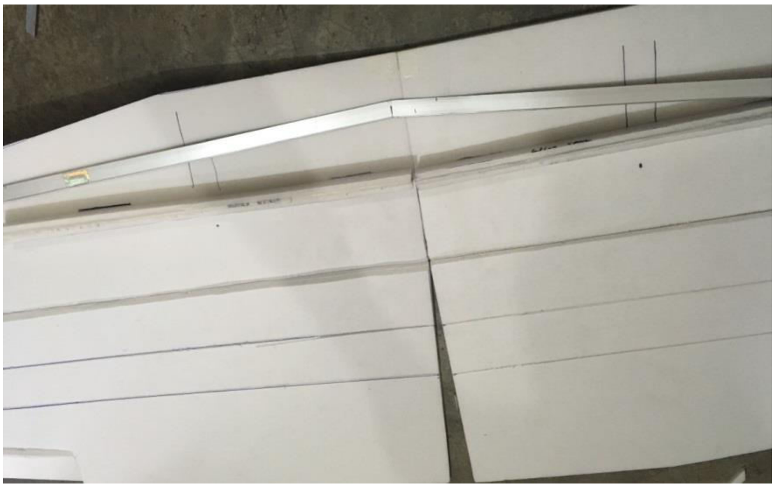


Figure 28: Aluminum Flat Bar under Wing

9.2.2 ELECTRIC CONNECTION

A soldering iron was used for this build. The two ESC leads were connected together in parallel from the battery. Only 4 connections will required to be soldered. The rear ESC will need an extension to the power leads. A power distribution board was used to add two ESC together. All connections were heat shrinked properly. The ESCs are now connected in parallel, so both are getting the same full voltage of the battery.

For storage of energy generated, a customized DC motor connected with wind turbine propellers was used. Output energy was stored in secondary battery that will be used for power up the auxiliary systems of the model.

10 WORKING PRINCIPLE

10.1 METHODOLOGY

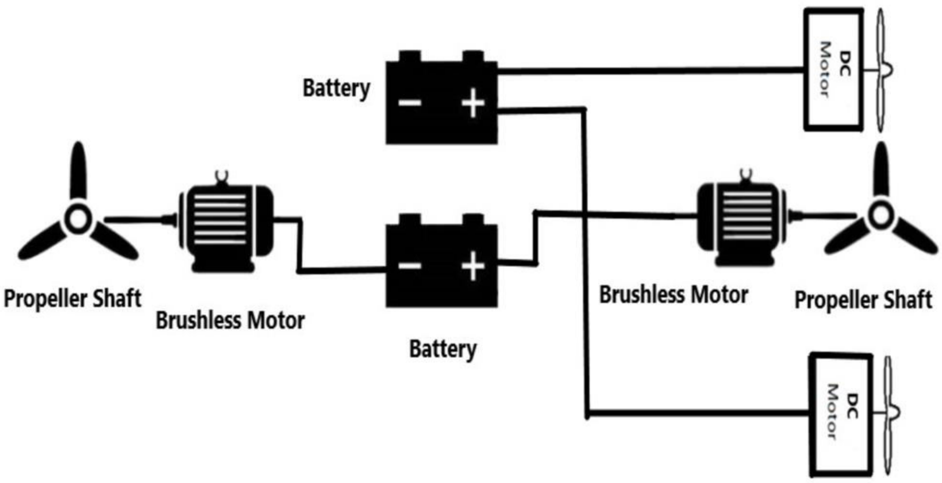


Figure 29: Methodology

- A battery is used to power two brushless motors used to run a configuration of forward-mounted (tractor) propellers and backward-mounted (puller) propellers.
    - The advantage this configuration provides is the ability to mount two propellers on the aircraft's centerline, thereby avoiding the increased drag that comes with twin wing-mounted engines.
- The turbines connected to the DC Motors are used to extract energy from the wind and convert it to electrical energy; which is used to charge the connected battery.

10.2 ENERGY GENERATED

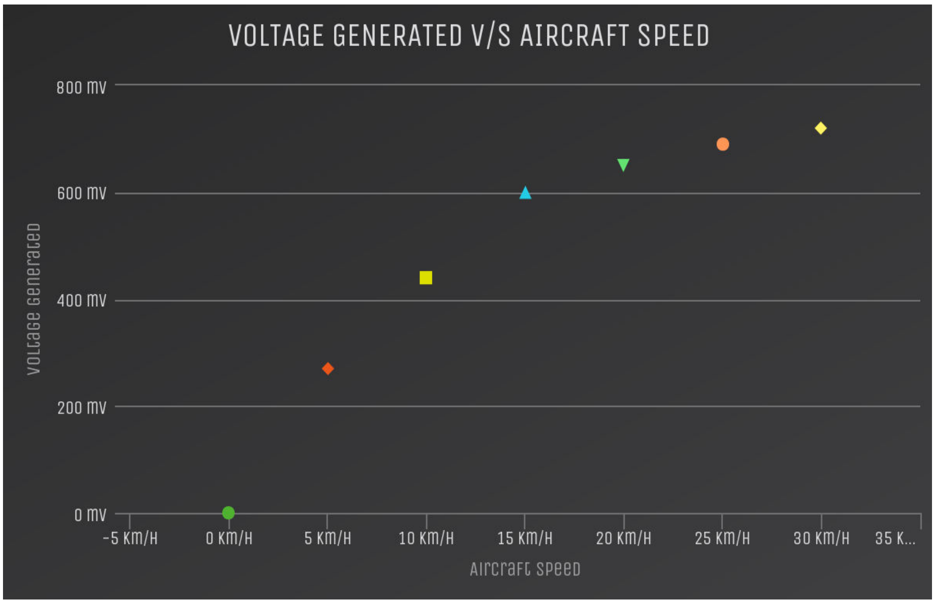


Figure 30 : Voltage Generated v/s Aircraft Speed

- A sensor was attached to measure the voltage generated at various speeds during flight.
  - The measured data was used to plot a graph.
  - This revealed a non-linear relationship between the variables.
- Approximate 720mV was generated at a top speed of roughly 30km/h.

11 FUTURISTIC AIRCRAFT MODEL

11.1 INTRODUCTION

This project was aimed at building a unique environment-friendly air transport system. The aircraft is to be quieter than any of those currently existing and is to have a lower carbon footprint.

We have focused on two possibilities - a commercial sized passenger aircraft which can carry around 500 passengers around continents and a personal aircraft capable of carrying 2-to-4 passengers. For the commercial sized aircraft, the focus was to have a considerably high speed so as to reduce the time taken to fly between continents. For the personal aircraft the main purpose was to alleviate congestion on the roads by carrying passengers intra- and inter-cities. For both types, we have focused on building a model that will be a proof-of-concept for the sustainable technologies that we have been keen on.

A lot of work has already happened on this issue of “green aircraft”. But most of them toss out the fuel propulsion systems for the currently available rechargeable batteries. While we do believe that an alternative to the fuel propulsion systems is a must-have, it was clear from the onset that, to have a sustainable air transport system, today’s batteries are just not efficient enough. As such we have researched several different alternatives. One alternative is to have flights flying completely using ions from the air as the propulsion method. With no fuel on board and minimum current requirement, this method has a lot of potentials. But of course, the major breakthrough will only be achieved when the efficiency of the energy storage system of today is dramatically improved upon. Thus, our research also expanded on how to build improved energy storage system along the obvious such as an improved aerodynamic design made with high efficiency and lightweight materials.

11.2 PROPULSION SYSTEM

An ionocraft is a fixed body plane that operates using ionic propulsion. It uses electrohydrodynamics (EHD) to provide lift or thrust in the air without requiring any combustion or moving parts. Current designs do not yet produce enough thrust for manned flight or heavy loads. [21]

The principle of ionic wind propulsion with corona-generated charged particles has been known from the earliest days of the discovery of electricity with references dating back to 1709 in a book titled Physico-Mechanical Experiments on Various Subjects by Francis Hauksbee. [21] In 2014, Ethan Daniel Krauss of US, invented the first solely ion propelled aircraft in history, that can both take off and fly with its power supply onboard.[22] Later, in late 2018, a set of MIT engineers has also researched on ionocraft and have come up with their own version of it. [23]

The ionocraft has electrodes that are attached to the plane body that ionizes the air as the plane flies and consequently generates a force to push the plane in the direction desired. The frame of the ionocraft is created using lightweight wood strips and wrapped up with aluminum foil. This frame acts as an electrode itself, i.e. the Collector. Thin conducting wires are placed on top of the frame. These act as the second electrode, i.e. the Emitter. There is an air gap between the Emitter and the Collector. A 3.7V Li-Po battery connected to a 400kV Voltage boost module is used as the onboard power source. The required voltages are supplied to the Thin Wire and to the frame. The thin wires are set at a very high positive voltage. This ionizes the air molecules near it. The frame is set at an equally high but negative voltage. This creates an electric field between the thin wire and the frame causing the created ions to move through this field. The movement of the produced ions and electrons creates an Ionic/Electric wind. This wind produces the thrust required for the ionocraft to move. Greater thrust is created eventually as the ions and the electrons collide with the neutral particles. **Figure 31** below shows the working principle of our ionocraft model.

The advantages are that it is a completely fossil fuel free flight, and, as was the purpose of this project, it does fly absolutely silently. However, at the current capacity, only very short and light flights are possible. Current designs do not yet produce enough thrust for manned flight or heavy loads. [21]

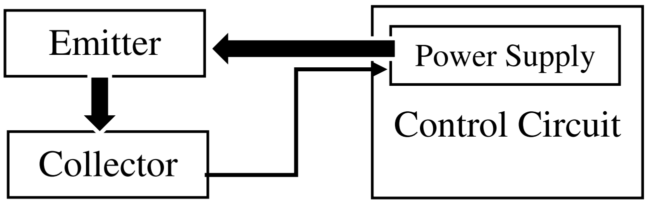


Figure 31: Block Diagram of Ionocraft

11.3 ENERGY STORAGE SYSTEM

Today's batteries have a lot of scope of improvements. Their low energy density along with their heavy weight makes them impractical to be used in a full-size flight. Emerging applications require batteries to have both high energy and high power which are not necessarily compatible. The typical inverse relationship between power and energy in batteries is often due to the slow ion diffusion in electrode materials. While the optimization of current battery technology may be sufficient to fully address this issue, researchers at the Stony Brook University and the Brookhaven National Laboratory have collaborated to find novel chemistry-focused strategies based on the new fundamental understanding of materials that may be applied to lead to the development of a new generation of batteries that store energy sufficiently and deliver it rapidly. [24] At the same time scientists in China are researching on high-energy density materials as a means to tackle the issue. High-energy density materials represent a significant class of advanced materials and have been the focus of energetic materials community. The main challenge in this field is to design and synthesize energetic compounds with the highest possible density and maximum possible chemical stability. They have developed compound that shows a great promise for potential applications as a high-energy density material. [25]

Yet another researcher at the Swedish University of KTH has studied on the potential of using carbon fibers for multifunctional Lithium ion batteries. Through the use of Carbon fibers, he aimed at tackling the weight issue of the today's batteries that limits the effectiveness of today's electric vehicles. One of the possible routes to reduce the weight on a system-level is introducing structural batteries, batteries that simultaneously store energy and hold a mechanical load. Placing these batteries in a load-bearing part of the structure reduces weight and increases effectiveness on a system level. Carbon fibers are especially suited for structural batteries because of the high performance as reinforcement material in a polymer composite, as well as the ability to insert lithium to function as negative electrodes in batteries. [26]

Another field that has attracted attention in the latest years is flexible batteries due to the emerging of flexible displays and wearable electronics. Carbon fibers can be a suitable material in flexible batteries due to the good conductivity, mechanical integrity and ability to form an integrated flexible film with cellulose nanofibrils (CNF) as the binder. The $LiFePO_4$ coated carbon fibers show promise as a structural electrode with moderate capacity, high coulombic efficiency, good rate performance and good adhesion between fibers and coating. The flexible electrodes with carbon fibers as current collectors perform well with a high capacity, good rate performance, low weight, and high flexibility. The electrodes withstand bending for 4000 times without any performance degradation. [26]

At the Imperial College in London a materials development project was launched that brought together nine European companies and institutes. Volvo Cars with financial support from the European Union, developed a composite blend of carbon fibers and polymer resin that can store and charge more energy faster than conventional batteries can. At the same time, the material is extremely strong and pliant, which means it can be shaped for use in building the car's body panels. According to their calculations, the car's weight could be cut by as much as 15 percent if steel body panels were replaced with the new material. [27] Similar material can also be used to make the fuselage.

11.4 RESEARCH ANALYSIS

All the models discussed here have their own potentials. The ionocraft is an extremely environment friendly model. But its low thrust production makes it impractical for commercial use at the moment. The work with energy storage systems needs further research. A smaller, lightweight, high energy density version of today's batteries will dramatically reduce weight. While a lot of these ideas are capable of dramatically changing the scenario of today's aviation industry by providing environment-friendly alternatives, they need major works to be done in order to turn them into reality. A considerable amount of investments needs to be made, both in terms of time and financial and other resources. Our location, Bangladesh, had both an advantage and disadvantage over our work. We did not have access to a lot of equipment and materials that were necessary for doing such research works; some could have been purchased from abroad, but that required both time and money, which were beyond this project's scope. There were parts and materials that could have been custom made but that required a much longer time than the scope of this project allowed us to have. This project is thus to be taken as a stepping stone towards an efficient and sustainable aviation industry. We believe that with a larger scope in terms of time and resources, the findings of this project will prove invaluable in gifting the world the air transport technology of the future.

11.5 PROTOTYPE

Figure 32 : Ionocraft Prototype

Working Principle & Methodology:

- A fixed body plane is built that operates using ionic propulsion.
- Electrodes are attached to the plane body that ionizes the air as the plane flies and consequently generates a force to push the plane in the direction desired:
  - The frame of the ioncraft is created using lightweight wood strips and wrapped up with aluminum foil. This frame acts as an electrode itself, i.e. the Collector.
  - Thin conducting wires are placed on top of the frame. These acts as the second electrode, i.e. the Emitter.
  - There is an air gap between the Emitter and the Collector.
  - A 3.7V Li-Po battery connected to a 400kV Voltage boost module is used as the onboard power source. I supply the required voltages to the Thin Wire and to the frame. The thin wires are set at a very high positive voltage. This ionizes the air molecules near it.
  - The frame is set at an equally high but negative voltage. This creates an electric field between the thin wire and the frame causing the created ions to move through this field.
  - The movement of the produced ions and electrons creates an Ionic/Electric wind. This wind produces the thrust required for the ioncraft to move. Greater thrust is created eventually as the ions and the electrons collide with the neutral particles.
- Advantages:

  \- Fossil-fuel free flight; Flies silently
- Disadvantages:

  \- At current capacity, only very short and light flights are possible

12 WORKING SHEETS

12.1 WORK BREAKDOWN STRUCTURE

After gathering the project information and defining the project requirements, the project management began. We used a chart to allocate the tasks and set tentative deadlines. All associated tasks are addressed in the chart whose structure changed over the course of the project until completion. The chart shows the activities in sequential order according to completion dates and the order of linearity in project organization. Although a critical path method was suggested in the first report, the project team decided that this was not necessary because the chart was sufficient to monitor whether the project was on schedule and also to ensure that all tasks were completed and executed within the given time frame.

MODEL	*TASK*	*TENTATIVE DEADLINE*
Prototype 1	Simulate	Mid-Jan 2019
	Build	Jan 2019
	Flight Tests	Feb 2019
Prototype 2	Design	Mid-Feb 2019
	Simulate	Ma 2019
	Build	Mar 2019
	Flight Tests	Mid-Mar 2019
Next Generation all-electric Aircraft	Preliminary Research	Jan 2019
	Preliminary Design	Feb 2019
	Detailed Research	Mar 2019

Table 7: Timeline

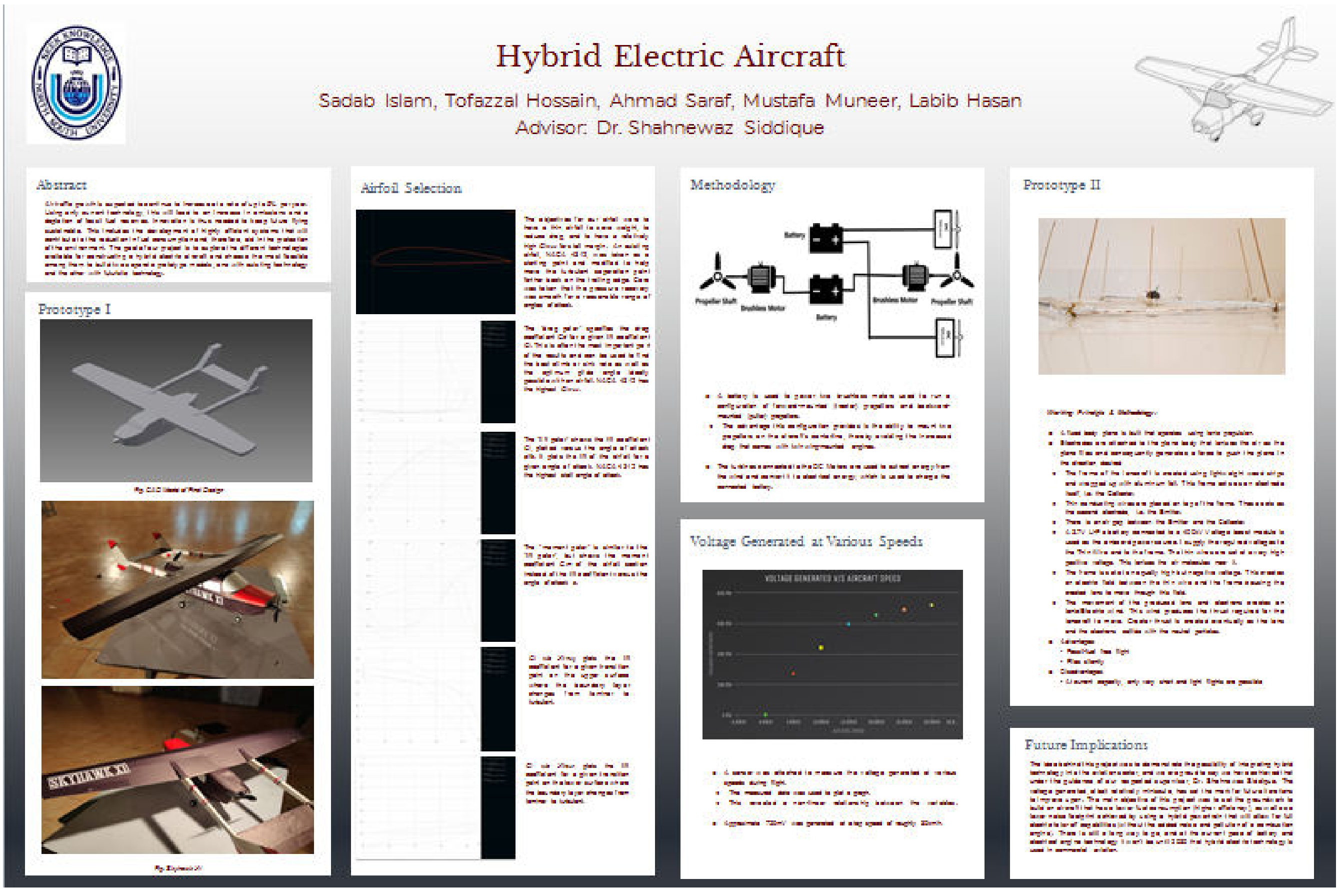
12.2 FINANCIAL PLAN AND COSTS

Product Name	Quantity Number	Description	Taka
Brushless Motor	2	Sunnysky 900Kv	4,000.00
Servo motor	3	servo 9g	600.00
Lipo Battery	1	Multistar 4000 mah 3cell	4,000.00
Propeller	2	Motor Requirment (pushar+Puller)	1,000.00
Control Horns	8	Servo horn+servo rod	400.00
Landing gear	1	general/custom made	1,000.00
Aluminiam Bar	1	Wing load	300.00
Battery Charger	1	imax B6	2,700.00
Depron Foam	7		1,050.00
Cutter Blade	10		500.00
Servo Extension Wire	4		400.00
Glue	12		200.00
Dc Motor + Propeller	2		500.00
Sticker			1,200.00
RC Remote	1	Transmitter+Receiever	5,000.00
Servo Stopper			200.00
Motor Mount+Push Rod	2		400.00
Tape + Y Cable	2		200.00
Accessories			1,000.00
Transport			1,000.00
		Total=	25,650.00

Table 8: Cost Breakdown

13 CONCLUSION

The idea behind this project was to demonstrate the possibility of integrating hybrid technology into the aviation sector, and we are proud to say we have achieved that under the guidance of our respected supervisor, Dr. Shahnewaz Siddique. The voltage generated, albeit relatively miniscule, has set the mark for future iterations to improve upon. The main objective of this project was to set the groundwork to build an aircraft that has a lower fuel consumption (higher efficiency), as well as a lower noise footprint achieved by using a hybrid powertrain that will allow for full electric take-off capabilities (without the added noise and pollution of a combustion engine). There is still a long way to go, and at the current pace of battery and electrical engine technology it won't be until 2030 that hybrid electric technology is used in commercial aviation.



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SUNNYSKY V2216-12

Motor:V2216-12 KV:800

Technical Datas	
KV	800
Configu-ration	12N14P
Stator Diameter	22mm
STator Length	16m
Shaft Diameter	3mm
Motor Dimension(Dia.*Len)	Φ27.8×34mm
Weight(g)	75
Idle Current(10)@10v(A)	0.3
No.of Cells(Lipo)	2-4S
Max Continuous current(A)180S	17A
Max Continuous Power(W)180S	180W
Max. efficiency current	(5-15A)>80%
internal resistance	175mΩ

Recommended Prop(inch)			
Standard	3s-1045/1150	Max thrust	3S-1150
	4S-8040/8050		4S-9047/9050

Tested with SunnySky motor 20A ESC

Prop	Volts (V)	Amps (A)	Watts (W)	Thrust (g)	Thrust (oz)	Efficiency (g/W)	Efficiency (oz/W)
1047	7.4	5.8	42.92	510	17.99	11.88	0.42
	10	9.2	92	800	28.22	8.70	0.31
	11.1	10.5	116.55	960	33.86	8.24	0.29
11X7	7.4	5.8	42.92	510	17.99	11.88	0.42
	10	9.5	95	850	29.98	8.95	0.32
	11.1	10.9	120.99	1020	35.98	8.43	0.30
12X6	7.4	7.7	56.98	680	23.99	11.93	0.42
	10	12.1	121	1020	35.98	8.43	0.30
	11.1	13.8	153.18	1130	39.86	7.38	0.26

DEPRON FOAM

Depron is a brand name for Extruded Polystyrene (XPS) closed cell foam in sheet form. It is a fantastic medium for building model aircraft, and also a popular medium for architectural model building, as well as model boats and prototype design. XPS foam is stronger than traditional EPS Thermocol and can be further strengthened with carbon fiber or wood strips.

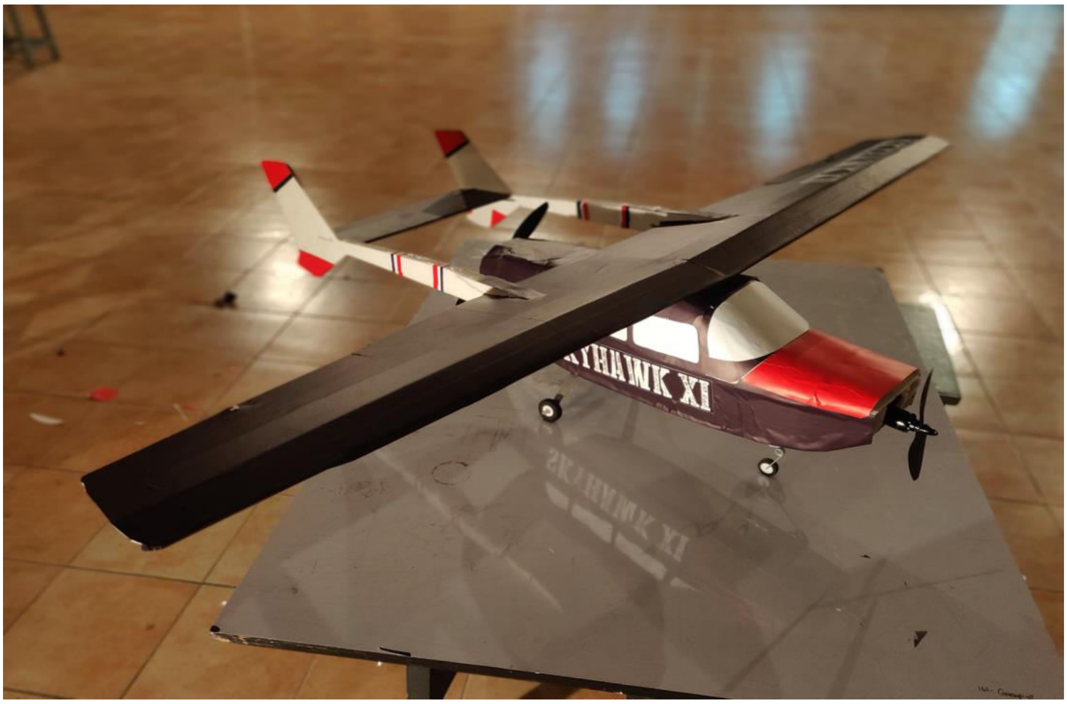
- Strength to weight ratio and rigidity is perfect for RC airplanes
- Easy to cut with precision by knife
- Easily sandable
- Sheets are flat and have a smooth finish.

Specifications:

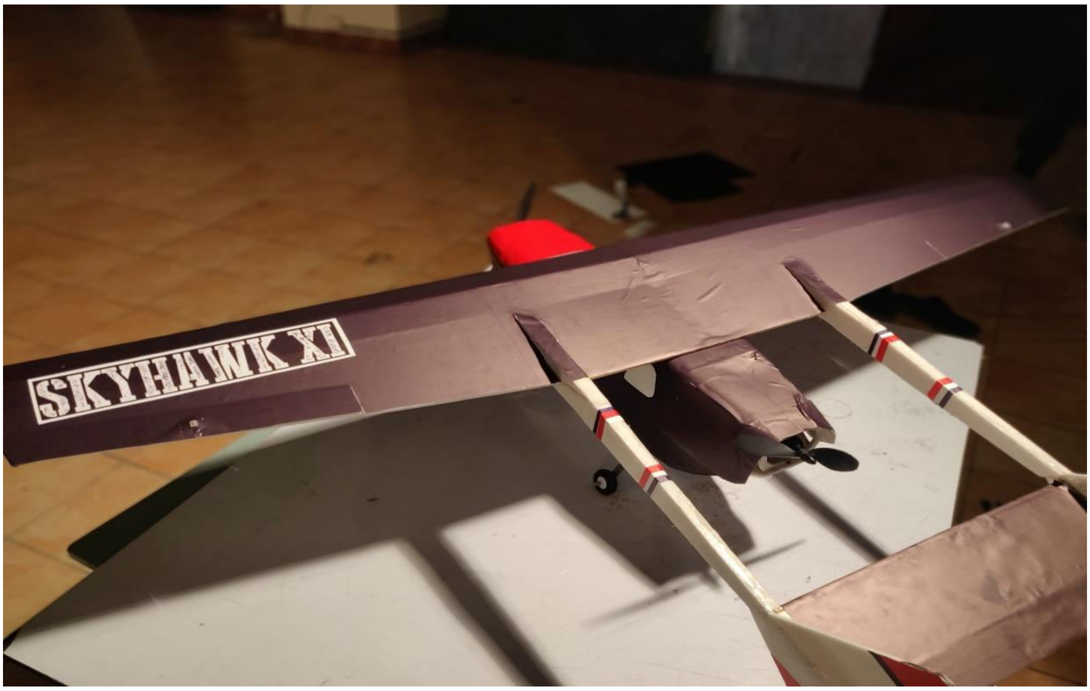
- Sheet thickness is 5MM.
- Color: white.
- Size: 800mmx500mm

FLIGHT VIDEO:

https://youtu.be/UuBmR9cLxrY



Angled View (Front)



Angled View (Back)

During Flight