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IMPROVED DESIGN AND MANUFACTURE OF SMALL REMOTE-CONTROLLED AIRCRAFT FOR FOOD DELIVERY

CAPSTONE PROJECT

B.Sc. Mechanical Engineering

Melinawo Korku Vowotor

2020

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Mechanical Engineering.

Melinawo Vowotor

2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

……………………………………………………………………………………………

Candidate's Name:

Melinawo Korku Vowotor

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Date:

29th May, 2020

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I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Abstract

Transportation and delivery have become an essential part of our everyday lives. It is constantly evolving as people try to develop new ways to improve a mode of transportation or make delivery in lesser time than expected, all in the safest way possible. The lack of an effective delivery/transportation system and low manufacturability of such systems in Ghana and most parts of West Africa has seen little to no efforts being made to curb the said issue. Unmanned aerial vehicles such as the typical quadcopter drones are gradually being employed for emergency pharmaceutical and paramedic uses in developed countries. Efforts to replicate this use of technology in developing countries has seen companies like Zipline set up outstanding drone delivery services to health facilities in rural areas that would be otherwise difficult to navigate and journey to by land. In this project, an unmanned aerial vehicle will be designed and manufactured in an attempt to create new delivery avenues for business owners.

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Abbreviations

AoA – Angle of attack

CG – Center of gravity

Re – Reynold's number

AC – Aerodynamic center

C_d – Coefficient of drag

C_l – Coefficient of lift

DBF – Design, Build, Fly

CAD – Computer Aided Design

RC – Remote Controlled

AR – Aspect ratio

STP – Standard Temperature and Pressure

Chapter 1: Introduction

Over the years there has always been a constant search for more efficient aircraft designs and manufacturing processes to improve the safety, comfort, and productivity of modern aircraft in the current economy. This has led to countless engagements in improvements of the current design of aircraft in different aspects such as the fuselage, wingspan, noses, etc. The improvement in one of these design areas can go a long way to creating more cost-efficient airplanes during the manufacturing process as it improves the material selection and other determining factors [3].

1.1 Background

The community on Ashesi University's campus in Berekuso (a small village about a kilometer away from Kwabenya in Accra) in the Eastern Region of Ghana is made up of the students, teaching and non-teaching staff, security, hostel, health, and cafeteria personnel. The campus is continually growing with a vibrant environment buzzing with activity at all hours of the day. All these members of the community interact and communicate everyday moving items from one point to another either by walking or by car. One rapid increase is the demand for these items to be delivered. A growing concern during this process is the heat from the sun during the day as it makes walking somewhat difficult. This inconvenience reduces productivity amongst delivery workers as there is the possibility that a faster method of delivery of these items could effectively increase revenue for businesses.

1.2 Proposed Solution

One pending solution is a device that can easily deliver these items to people to save time and energy. Unmanned Aerial Vehicles could thus prove useful in this regard. The American Institute of Aeronautics and Astronautics holds a Design-Build-Fly Competition for university students annually and this provides an opportunity to create an aircraft that meets certain design and user requirements [5].

Figure 1.1 Typical RC winged aircraft made mainly of balsa wood

The overall goal is to design, build, and fly an airplane that will result in the highest possible score on a prescribed cost function. The cost function includes vast performance measures including cargo weight, speed, take-off distance, stability [1].

My project would focus on adapting an existing design using engineering analysis and optimizing the payload/cargo weight which should allow easier delivery of lightweight goods in and around the Ashesi campus.

It should implement knowledge from aircraft design [3], mechanics of materials, and fluid mechanics. This also means the electrical and control system components that make it remote-controlled would not be greatly focused on in this project.

1.3 Prototyping and Testing

My capstone seeks to address one of these design areas and apply it to existing aircraft design. The prototype would be an aircraft that must validate the hypothesis regarding the weight and effective flight time of the aircraft while it carries items from one point on the Ashesi campus to another. Testing would also encompass an area on the Ashesi campus with strong wind conditions to test and validate an improved aerodynamic design.

Chapter 2: Related Work

2.1 John Hopkins University DBF

The DBF competition allows many engineering students to participate in the aircraft design process using various means at their disposal [5]. As such, the team of students from the John Hopkins University entered the 2016-17 competition and designed an aircraft that was meant to meet certain requirements to be awarded points and progress in the competition. The team designed, built and tested a winged RC aircraft that was meant to achieve three mission requirements: the aircraft fitting into a launch tube and transition into a flight state when launched out of the tube, the aircraft flying within the required course and it must be able to carry the weight of three hockey pucks [6].

Figure 2.1 RC aircraft built by the John Hopkins team

2.2 Raymer's Aircraft Design

Dr. Daniel Raymer of the American Institute of Aeronautics and Astronautics (AIAA) releases books on the conceptual approaches to aircraft design and the manufacturing limitations that designers often face when making choices. These usually range from propulsion choices such as electric propulsion (new emerging technologies), preliminary sizing, aerodynamics, structures, stability and control, configuration layout, performance, cost analysis, etc. He also gives some insight into designing the uncommon and exotic aircrafts such as helicopters, hypersonic aircraft, airships, and so on. All this is coupled with the perspective of designing the aircraft as any designer and not one specific expert in a particular field.

2.3 Aeronautical Engineer's Data Book

The data book written on aeronautical design gives a concise approach to understanding the various concepts associated with aircraft design. The chapter on propulsion is where Matthews breaks down the various aspects that give aircrafts the power they need to fly. He explains propeller systems and their characteristics as well as sheds light on the gas turbine engine and how it contributes to the propulsion of aircraft systems. He further explains aero terminology and how it relates to propulsion systems. Matthews dedicates a whole section to the dynamics of propellers configurations and explains how the flow over an airfoil is assumed to be two-dimensional and further explains the equations that govern the efficiency of a propeller blade [9]. This essentially ties into performance characteristics of an aircraft in flight and Matthews illustrates how some of the quantities under observation affect power, torque, thrust, etc.

Chapter 3: Requirements

3.1 Requirements of The Plane

As discussed earlier this project will focus on the design characteristics that the AIAA considers when students design, build, and test their planes for the Design-Build-Fly (DBF) competition. The scope of the project would be to optimize the payload for a different type of cargo as opposed to the regular DBF cargo. Since the project is adapting an existing design, most of the design decisions unrelated to cargo, cargo weight or fuselage would be selected from the existing design as they do not greatly affect the cost function or aerodynamics of the plane. Thus, the decision matrices would not involve parts of the plane that do not relate to the aforementioned characteristics.

Some project requirements and technical requirements in Table 3. 1 and Table 3. 2 have been outlined and they cover the entire project scope.

3.1.1 First Level: Project Requirements

Table 3. 1 Requirements of the project that meet the needs of all stakeholders.

Req. Type	Project Level Requirement	Stakeholder Addressed	Notes/Rationale
Proj_Req_1: System Function	The aircraft shall provide an alternative delivery service for food vendors as opposed to regular human intervention.	Ashesi Community	
Proj_Req_2: System Durability	The system shall operational within the confines of the Ashesi campus and its immediate environs (off campus hostels).	Ashesi Community, Off-campus food vendors, Ashesi Health Center	
Proj_Req_3: Power Source	The system shall operate using electronic remote-control components.	Ashesi Community, Off-campus food vendors	Users should be conversant with flying and

			controlling the aircraft
Proj_Req_4: Technology Transfer	The system's technology shall be transferrable in other campuses in Ghana.	Ashesi Community, Food vendors in other Ghanaian universities	
Proj_Req_5: Operational Reliability	The system shall operate during times when wind conditions are favourable.	Ashesi Community	Wind conditions must always be checked and users should be aware.
Proj_Req_6: System Durability	The aircraft and its content shall not exceed a maximum weight.	Ashesi Community, Off-campus food vendors	Lesser weight means possibly more payload

3.1.2 Second Level: Technical Requirements

Table 3. 2 Requirements of the project that meet the technical needs of the designer.

Req. Type	Parent Requirement	System Level Requirement	Stakeholder Addressed	Notes/Rationale
Sys_Req_1: Aircraft Payload	**Proj_Req_2** **Proj_Req_3**	The aircraft should be able to carry up to 2kg of cargo (Styrofoam food pack)	Ashesi Community, Ashesi Food vendors	This value is very quintessential to the design of the aircraft.
Sys_Req_2: Wingtip Test	**Proj_Req_2** **Proj_Req_3**	The entire aircraft (unloaded) must withstand a wingtip test	Project Lead	This enforces stability requirements.
Sys_Req_3: Fuselage Dimensions	**Proj_Req_2** **Proj_Req_3** **Proj_Req_5**	The fuselage should have a length to diameter ratio of 4:1	Ashesi Community, Ashesi Food vendors	
Sys_Req_4: Aircraft Weight	**Proj_Req_3** **Proj_Req_5** **Proj_Req_6**	The overall weight of the aircraft (unloaded) must not exceed 2kg	Ashesi Community, Ashesi Food vendors	Factor of safety should validate this requirement.

Sys_Req_5: Aircraft Flight Course	**Proj_Req_1** **Proj_Req_2** **Proj_Req_3** **Proj_Req_4** **Proj_Req_5**	The aircraft must complete 3 laps of the outlined course during testing	Ashesi Community, Food vendors in other Ghanaian universities	This requirement is very imperative and could be overlooked.
Sys_Req_6: Fuselage/Payload Volume	**Proj_Req_2** **Proj_Req_3**	The aircraft fuselage shall not exceed 22,000 cubic centimetres	Ashesi Community, Food vendors in other Ghanaian universities	

3.2 Concept of Operations

Below is a concept of operations that define what the aircraft is meant to do as a finished product and what functions it is meant to achieve underneath the scope of the project. It describes the simple steps any user would go through when operating the drone. It outlines the general behavior of the service from start to finish.

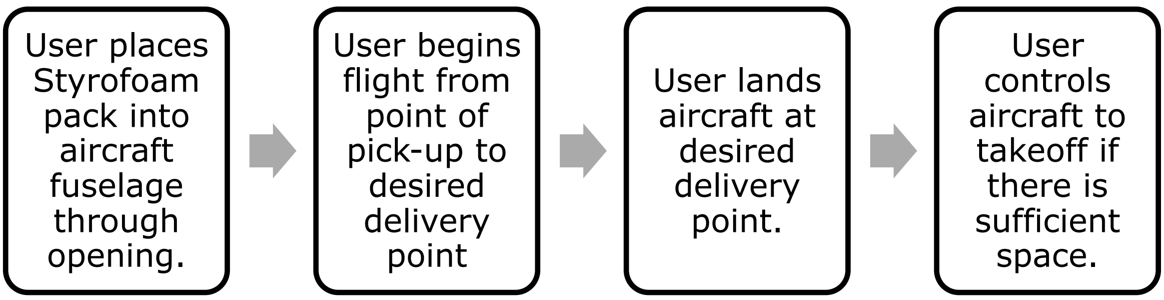


Figure 3.1 Concept of Operations for RC winged aircraft on campus.

For testing purposes, the plane would have to fly within a 200-kilometer radius to be able to achieve the minimum requirements for flight conditions. An outlined course for flight testing was created by the John Hopkins [6] team in which the plane would fly through a straight line for 1000 feet, make a 180-degree turn, fly for another 500 feet, make a 360 degree turn and then come back to the starting position. The flight path is shown below.

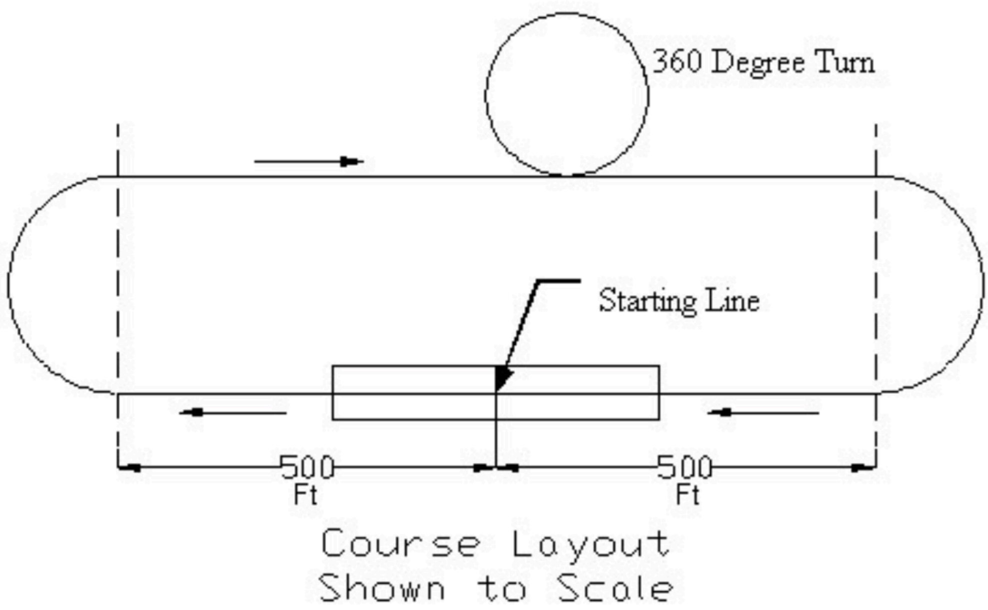


Figure 3.2 Outlined course for flight testing of the proposed plane

Chapter 4: Design/Methodology

4.1 Material Selection

In the first phase of the project, due to the unavailability of the preferred materials, the prototype was set to be built from improvisation using materials available at the time. Hence the first model was made from plywood and glue. This was meant to capture what the finished drone would look like if the desired materials had arrived. Figure 4.1 shows the model built from plywood. The plywood constituted two sets of sheets 1/4 inch and 1/8 inch respectively. These sheets were cut into shape and were assembled to make the first prototype.

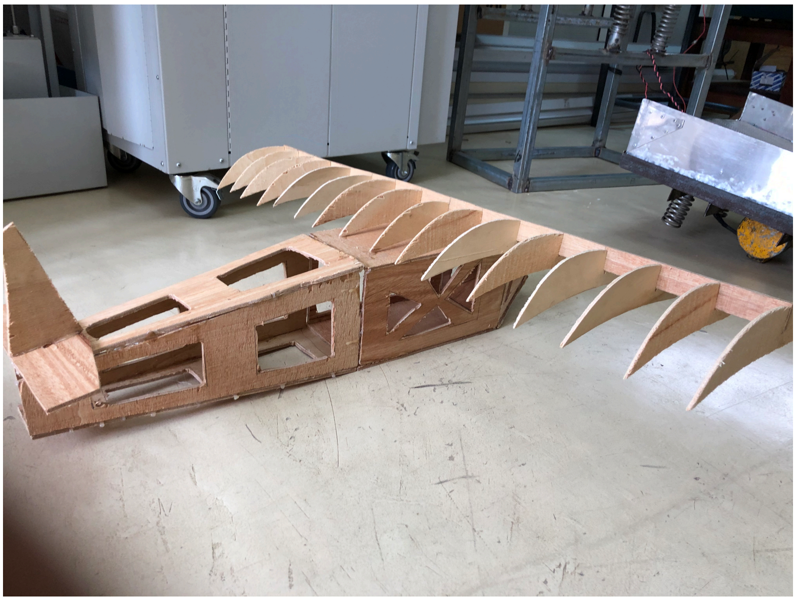


Figure 4.1 The model of the airplane built from plywood (Oak) and glue

In order to properly establish the best materials to use to construct the working prototype, a Pugh matrix was employed that saw four main materials compared: Balsa, Plywood, Foam, and Carbon Fiber. These materials were judged according to four main criteria: weight, strength, cost, and manufacturability. Table 4. 1 shows the results of the matrix. Balsa was chosen as the primary material for use in manufacturing the major parts of the aircraft because of its lightweight and aerodynamic characteristics.

Table 4. 1 Pugh matrix of the materials selected to build the final prototype.

Criteria	**Criteria Weight**	**Balsa**	**Plywood**	**Foam**	**Carbon Fiber**
Weight	0.4	1	-1	0	-1
Strength	0.3	-1	1	0	1
Cost	0.2	1	1	0	-1
Manufacturability	0.2	0.7	0.3	-1	0.9
Total	1	0.4	0.2	-0.2	-0.12

4.2 Preliminary Design

4.2.1 Aerodynamic Characteristics

In designing the wing as an improved version of the one built by the DBF team, many factors were considered in the analysis. These consisted of taper, dihedral/anhedral, airfoil, and aspect ratio.

The aspect ratio of a plane is an imperative part of its design in that maximizing the aspect ratio would effectively maximize the wing's lift capability [3]. Consequently, it is important to consider where to include a taper or not as the amount of stability it offers the aircraft can be determined. Thus, a dihedral or anhedral angle should greatly affect the stability of the plane. This allows us to economize on stability, weight, and expense. A dihedral effectively creates a self-righting behavior when the roll stability of the plane is minimal due to poor inputs such as turbulence, launches, piloting, etc. It is responsible for working on side slip from the pilot's input of yaw [6]. Implementing this dihedral would account for the wind conditions on the hill at Ashesi which will likely cause some flight instabilities. Lastly, the choice of an airfoil is important because of the required velocity range I would be dealing with on the Ashesi campus.

4.2.2 Airfoil Selection

The choice of airfoil was made by considering the general physical traits that would be desired in a wing: high lift and low drag. It is important to note that the thickness of the airfoil that will serve as the ribs of the wing affect lift and stability [3]. I chose rib thicknesses of 5mm and 10 mm due to the availability of materials and their advantages and disadvantages: thinner airfoils are more streamlined and can cut through the air easily but are less stable, while thicker airfoils generate more lift when carrying a larger payload [6]. The DBF team after some design iterations concluded at using the NACA 4412 airfoil to design their wing. Here is why I chose the same airfoil.

In the Ashesi environs, there are shifts in wind velocity at certain times of the day. Using an anemometer, I recorded values between 8m/s and 30m/s and an average of 12m/s from times between 6:30 AM and 12 PM and 5 PM and 11 PM. These values were recorded at different vantage points on campus. The Reynold's number can be a good indication of turbulent or laminar flow of a fluid due to the inertial and viscous forces over the object [9]. It is determined by the equation:

$$Re = \frac{\rho V L}{\mu}$$

where ρ is the density of the fluid, V is the velocity of the fluid relative to the aircraft (Aircraft velocity – (– Wind velocity)), L is the characteristic length of the object (in this case we would be using the chord length of the airfoil chosen), and μ is the dynamic viscosity of air. Using conditions at STP we obtain a *Re* of:

$$Re = \frac{(1.164\ kg/m^3) \times (23\ m/s) \times (0.200\ m)}{(1.872 \times 10^{-5}\ kg/ms)} = 286025.64 \cong 200{,}000$$

Using this *Re* we can refer from the Airfoil Tools databases [7], [8] on the coefficient of lift and coefficient of drag at different angles of attack. In this case, we would compare the NACA 4412 and SD 7037 airfoils at an AoA of 8°. From these plots, we can obtain the optimum lift-to-drag ratios for an airfoil right before it stalls. Figure 4.2. 1 and Figure 4.2. 2 show the results of these tests.

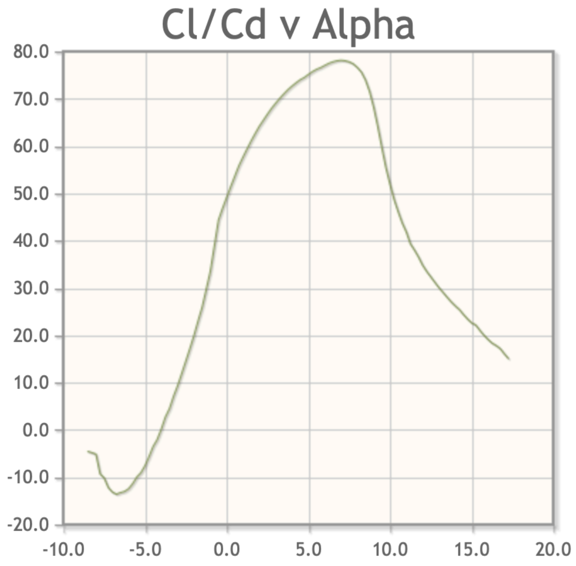


Figure 4.2. 1 C_l/C_d vs. Alpha for NACA 4412

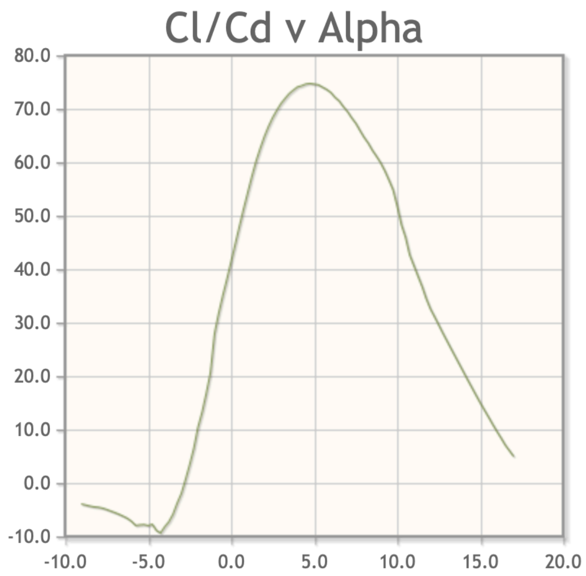


Figure 4.2. 2 C_l/C_d vs. Alpha for SD 7037

It can be seen that NACA 4412 has a spike around 7° while SD 7037 spikes around 5°. NACA 4412 will be chosen because it can produce a better lift-to-drag ratio at a higher AoA considering the purpose for which it is being used. It is important to also note that the large camber of the NACA 4412 will allow for more weight reduction slots to be created without affecting the flow around the wing [6].

4.2.3 Wing Span and Wing Loading

For an RC plane, it would be best to maximize the wing loading of the aircraft as it generates more lift during flight. Similarly, like gliders, slow-moving planes like RC planes will need a higher aspect ratio in order to fly longer [2]. For the wing design, the Lift equation and aspect ratio in the existing design allowed for the determination of the optimum wingspan [9]. Taking values of the flight velocity v to be $22\ ms^{-1}$(average flight velocity of the existing design), air density r at STP to be $1.164\ kgm^{-3}$, lift coefficient C_l to be 1.25 and aspect ratio AR to be 10 (large aspect ratio for a slow-moving plane to generate more lift), we assume a payload fraction of 0.5 (typical payload fraction of cargo planes such as the Boeing 74T) [2] and payload (estimated mass of a packed food containing say rice and a piece of chicken) of about $0.95\ kg$ and that yields a lift value of approximately $1.9\ kg$. For rectangular wing planform area A and wingspan b the Lift and Aspect Ratio equations are given as:

$$Lift = Cl \cdot \frac{rv^2}{2} \cdot A$$

$$AR = \frac{b^2}{A}$$

Solving for A and substituting it into the Lift equation and making that expression the subject gives us:

$$\frac{b^2}{AR} = \frac{2L}{Cl \cdot r \cdot v^2}$$

Plugging in the values and solving for b yields a wingspan of $1333.87\ mm$ approximated to $1400\ mm$.

4.2.4 Taper Ratio and Dihedral

There are several taper types and each one inherently reduces drag. The difficultly with some of these is the ease of manufacturability and maintaining structural integrity. I chose not to taper the wings in my design because rectangular wings are wing root stallers. It means the stall begins at the wing root, reaching the control surfaces (ailerons and flaps) last, and making the wing uncontrollable [2]. A rectangular wing is also easy to design and build. This means that it can be designed to have one single airfoil profile from root to tip (no aerodynamic twist) and evenly thick.

In the inclusion of a dihedral, I considered the benefits of creating one to help stability and lift. Section 4.3 further explains this.

4.2.5 Control Surfaces

In an attempt to improve the flight capabilities of the plane, I added control surfaces to the wing namely ailerons. In conjunction with the control surface research done by the National Advisory Committee for Aeronautics [4], I chose the Clark Y model for plain ailerons because it is generally used and has been tested to generate sufficient lift during takeoff and landing. For span b of $1333.87\ mm$ and a chord length c of $200\ mm$ the model is given by the equation:

$$0.25c \times 0.4\frac{b}{2}$$

This ultimately gives an aileron dimension of 50×266.7 and the planform for half of the wing would look like the diagram in Figure 4.2. 3.

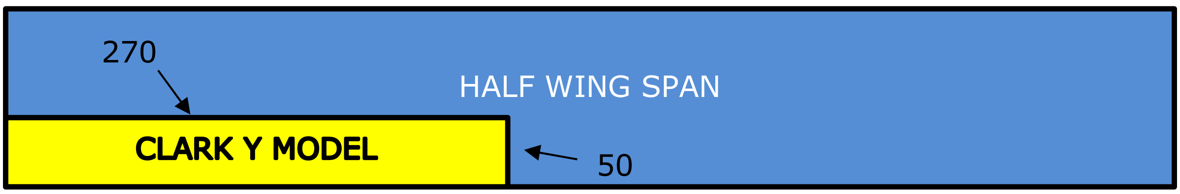


Figure 4.2. 3 New wing design for Clark Y model for plain ailerons

In the overall improvement of the design of the wing, some characteristics were compared side by side in order to summarize the changes made. Table 4.2. 1 shows the comparison.

Table 4.2. 1 Comparison of the old design to new design showing improvements made on the wing.

Characteristic	Existing Design	Proposed Design
Airfoil	NACA 4412	NACA 4412
Wingspan	1300 mm	1400 mm
Aspect Ratio	10.4	10
Tip Shape	Square	Square
Dihedral Angle	6.34 degrees	5 degrees
Taper Ratio	1.6	0
Control Surface	None	Clark Y Aileron model

4.2.6 Fuselage and Empennage

In designing the fuselage, the main factors considered are strength, weight, and aerodynamics. To build a fuselage out of a heavy material would not be advisable because it is the largest part of the plane and it would be too heavy to fly [1]. Thus, a combination of strong and lightweight materials which are aerodynamically capable of reducing drag will be selected. The design of the fuselage will also determine how much drag can be reduced. Figure 4.3. 1, Figure 4.3. 3, and Figure 4.3. 4 show the sketches of the proposed design.

4.2.6 Propulsion and Avionics

For successful heavier-than-air flight, the plane needs a propulsion train. For a small, slow-moving RC plane the propulsion system needed would be slightly different from ones used in life-sized planes. However, there are some similarities in which the propulsion system I chose reflects the type used in piston-driven propeller engines. I would not be considering propulsive efficiency or specific impulse of an engine. For such systems, Matthews [9] shows that the performance characteristics are determined by some propeller coefficients utilizing torque, power available, air density, etc.

I would consider the efficiency of a brushless DC motor that causes a carbon fiber propeller to produce thrust. A power distribution board, powered by a Lithium-powered battery, will be used to drive the electronic speed controller that also drives the motor and the propeller. The propeller selected was due to ease of use and manufacturability within the propulsion train as well as maximizing the cruise speed [6]. The battery selected was due to weight distribution in the fuselage and the estimated flight time of the plane. The motor selected was based on the power requirements of the aircraft in that the overall weight of the aircraft and stall speed. To get an idea of how much thrust can be produced from the propeller chosen, the equation put forward by Gabriel Staples [10] was entered into Microsoft Excel and a plot of a range of aircraft airspeeds and thrust was generated. The equation is as follows:

$$F = 1.225\frac{\pi \cdot (0.0254 \cdot d)^2}{4}\left[\left(RPM_{prop} \cdot 0.0254 \cdot pitch \cdot \frac{1min}{60sec}\right)^2 - \left(RPM_{prop} \cdot 0.0254 \cdot pitch \cdot \frac{1min}{60sec}\right)V_O\right]\left(\frac{d}{3.29546 \cdot pitch}\right)^{1.5}$$

where d is the diameter of the propeller in $14\ inches$, V_O is the aircraft airspeed in m/s, *pitch* is the pitch diameter of the propeller in $7\ inches$, and RPM_{prop} is the revolutions per minute produced by the motor selected at $10000\ rpm$. Figure 4.2. 4 shows the plot of the results when computed in Microsoft Excel.

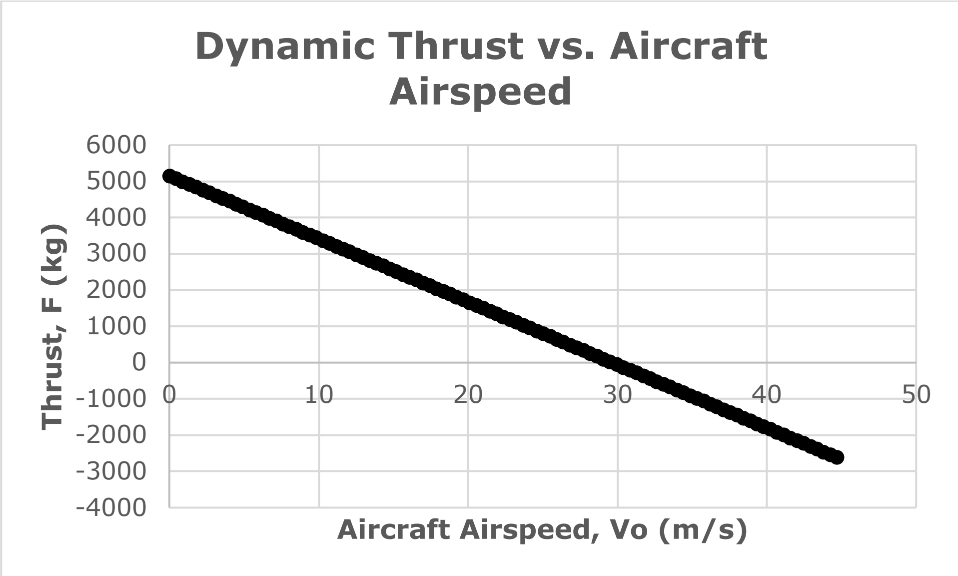


Figure 4.2. 4 Plot of dynamic thrust vs. aircraft speed for chosen propeller.

To establish the remote-control aspect of the propulsion, the Ardupilot controller module, and the FlySky RC transmitter and receiver will be implemented. The inputs from the RC transmitter are read by the receiver and fed to the flight controller. The flight controller will then drive the motor and the 9g micro servos powering the control surfaces. In order to track the flight of the aircraft, the flight controller would have to make the necessary computations to feed data to the ESC. The ESC can vary the motor direction and speed by varying the frequency, power, and 3-phase AC supplied. The use of an inertial measurement unit would be beneficial in this case because the integrated gyroscope and accelerometer allow for proper instrumentation of the aircraft during flight.

These will be monitored using software such as QGround Control or ArduPilot. These can allow us to obtain information like: flight map display showing vehicle position, waypoints and vehicle instruments, and mission planning. However, due to unforeseen circumstances, the propulsion train will not be implemented. Table 4.2. 2 shows the propulsion system chosen.

Table 4.2. 2 Propulsion system chosen for the desired flight.

Component	Existing Design	Proposed Design
Motor	2212-16 750 kV T-Motor	A2212 1400kV/2200 Brushless DC Motor
Propeller	APC 11x8.5 inch propeller	14-inch carbon fiber propeller
Battery	12-Cell Elite 1500 mAh NiMH battery pack	Hobby Hub 11.1v 1500mAh 40C LiPo Battery
Servos	None	Miuzei SG90 9g servos
Electronic Speed Controller	Turnigy Trust 45A ESC	Hobbywing Skywalker 30A ESC Speed Controller

4.3 Detailed Design

4.3.1 Fuselage

The fuselage was designed to achieve two major criteria: payload and structural soundness. The existing design saw the fuselage made from balsa sheet bulkheads held by basswood formers (see Figure 2). It is hollow for lightweight purposes and has balsa longerons and stringers that improve the overall structural integrity. My design is similar in that the fuselage is hollow but is made up of 3 sets of 4 balsa sheets laser-cut, drafted, and held together by epoxy to make up the shape shown in Figure 4.3. 1. The existing design saw the central fuselage section create a set of basswood formers placed at the wing's leading and trailing edge that houses the hockey pucks keeps them in place [6]. My design seeks to hold a Styrofoam food pack in place such that it does not slide from end to end destroying the food or the pack during flight. This is done by placing four carbon fiber rods on the bottom floor of the central fuselage section forming a rectangle. As the food pack is placed inside the fuselage the carbon fiber rods hold it in place but are not too tight to not be able to fit the pack within that space. Figure 4.3. 5 shows a much more detailed design of the central section.

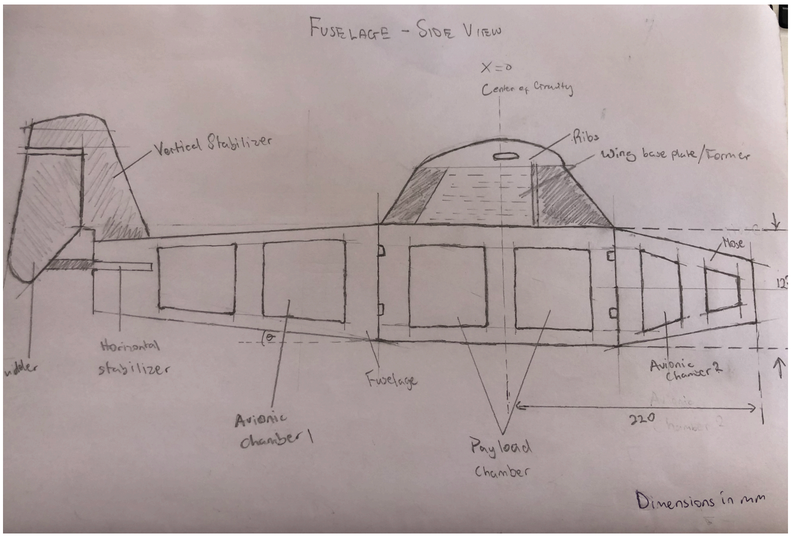
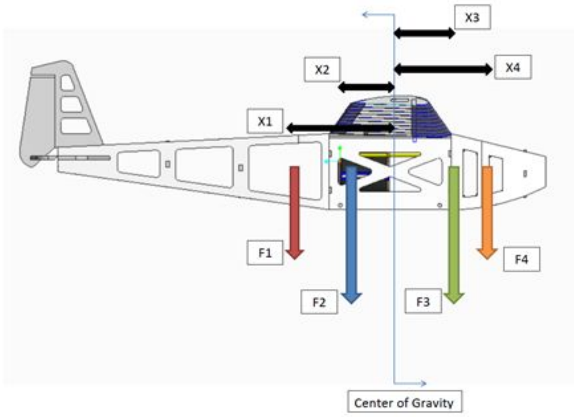


Figure 4.3. 1 Sketch of fuselage side view. Dimensions in mm.

For the entire aircraft to be stable during flight, the center of gravity of the plane must be determined. The DBF team employed the use of a moment diagram which is shown in Figure 4.3. 2 to calculate the CG of the existing aircraft [6]. I used this method as well as inputting values of masses and distances from the aerodynamic center in MATLAB to be able to determine the CG for my aircraft. The desired CG was estimated to be at ¼ of the length of the chord from the leading edge of the wing (essentially where the AC is acting). The equation for determining the CG is given by:

$$CG = \frac{Total\ moment}{Total\ weight}$$



Label	Force
F1	Receiver Battery
F2	Empty Weight
F3	Battery
F4	Receiver/ESC

Figure 4.3. 2 Moment diagram and legend for calculating CG for the DBF aircraft.

The masses, weights, distances from the AC and the moments are shown in Table 4.3. 1

Table 4.3. 1 Table showing parameters used to calculate CG

Item	Weight (mN)	Distance (mm)	Moment (mN·m)
Propeller	255.06	287	73202.22
BLDC Motor	1128.15	247	278653.05
Battery + ESC	3924	9.8	38455.2
Food Pack	9319.5	-10	-93195

The calculation yielded the center of gravity to be 20 mm from the AC.

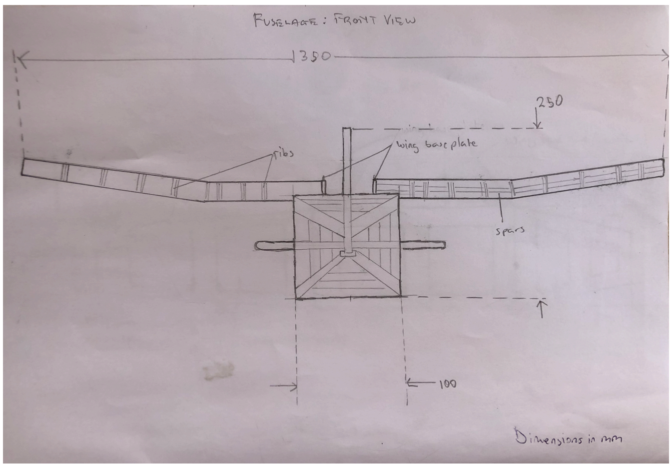


Figure 4.3. 3 Sketch of fuselage front view. Dimensions in mm.

The empennage plays a critical role in the stability of the aircraft. That is why control surfaces such as the rudder and elevator are implemented to cause certain aerodynamic movements during flight [3]. The pitch diameter of the propeller is very important for empennage design in that it determines the propeller wake region when the fluid flows past it. Hence, the horizontal stabilizer must not fall within the wake region else it will affect the overall stability of the aircraft. Also, to counterbalance the yaw moment produced, the vertical stabilizer must be cambered. Figure 4.3. 3 and Figure 4.3. 4 loosely illustrate the aforementioned characteristics.

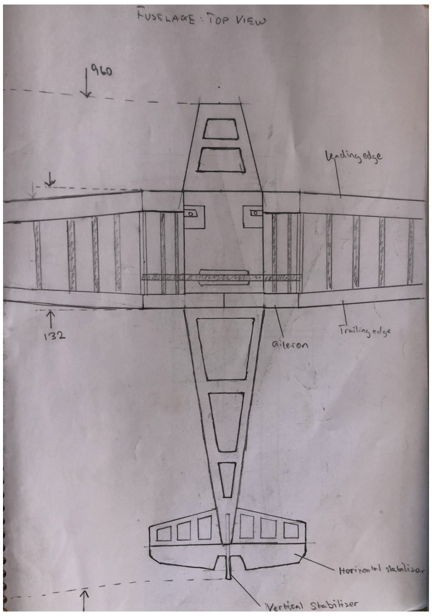


Figure 4.3. 4 Sketch of fuselage top view. Dimensions in mm.

A 3D CAD model of the proposed fuselage design was done in Solidworks and has been illustrated in Figure 4.3. 5 and Figure 4.3. 6. These show the use of how the carbon fiber rods are attached to create a temporary house for the food pack during flight.

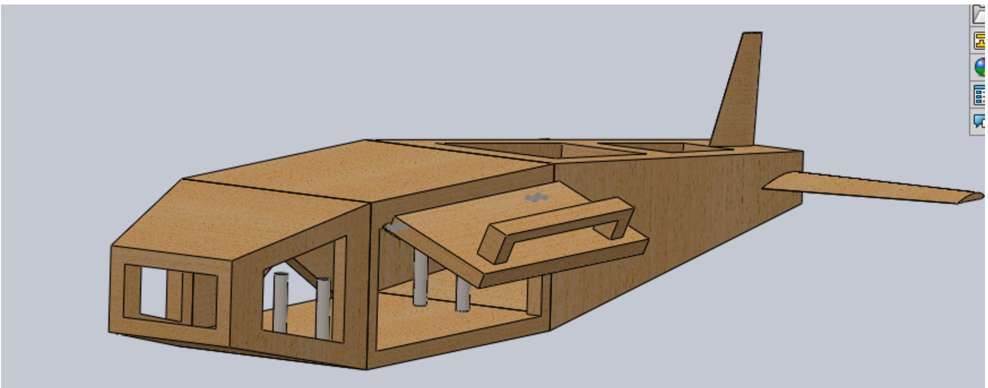


Figure 4.3. 5 3D model of fuselage showing all parts assembled.

A further exploded view of the parts used in the assembly shown in Figure 4.3. 6 have been broken down into their respected parts for more clarity below.

Table 4.3. 2 Parts used in fuselage assembly and their details.

	Part	**Material**	**Quantity**
1	Fuselage – nose section	Balsa	1
2	Fuselage – central section	Balsa	1
3	Fuselage – tail section	Balsa	1
4	Pack holder	Carbon fiber	4
5	Hinge	Brass	2
6	Door – central section	Balsa	1
7	Horizontal stabilizer	Balsa	2
8	Vertical stabilizer	Balsa	1

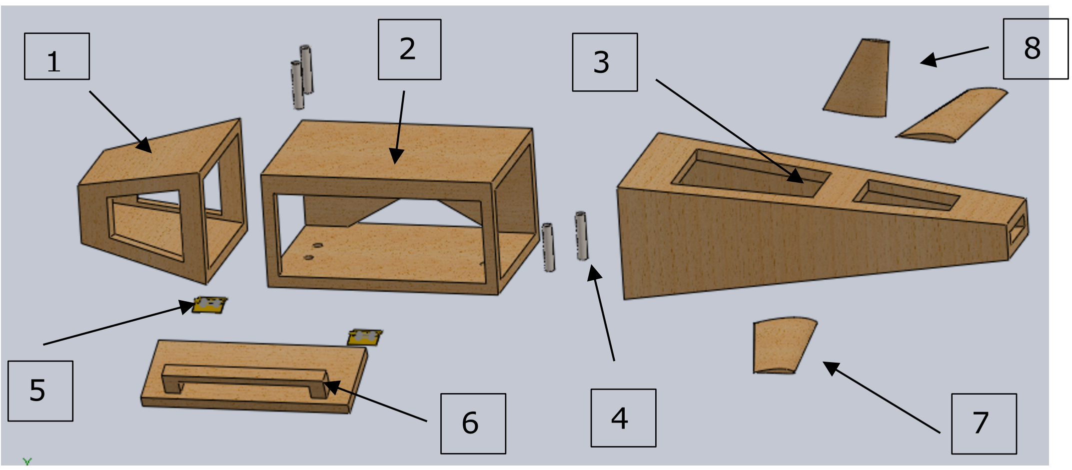


Figure 4.3. 6 Exploded 3D view of fuselage model showing all parts and carbon fiber rods.

4.3.2 Wing

The wing was designed with the intent of being as lightweight as possible without having to lose much stability in flight. It is made up of balsa ribs, carbon fiber spars, and balsa spars at the leading edge. The ribs which have some weight reduction pockets will be laser cut from the selected airfoil shape and together with the spars will act as the skeleton. This is illustrated in Figure 4.3. 1. The leading edge surface will be made out of balsa soaked in ammonia and wrapped around the leading edge of the ribs. Fibafilm will be employed to make up the rest of the surface of the wing to make it solid and will be attached using a hot air gun. A small section of the trailing edge of the wing as discussed in Section 4.2.5 will make up the ailerons of the wings. Figure 4.3. 8 illustrates how the 9g servo motor will control the movement of the ailerons during take-off, landing, and flight.

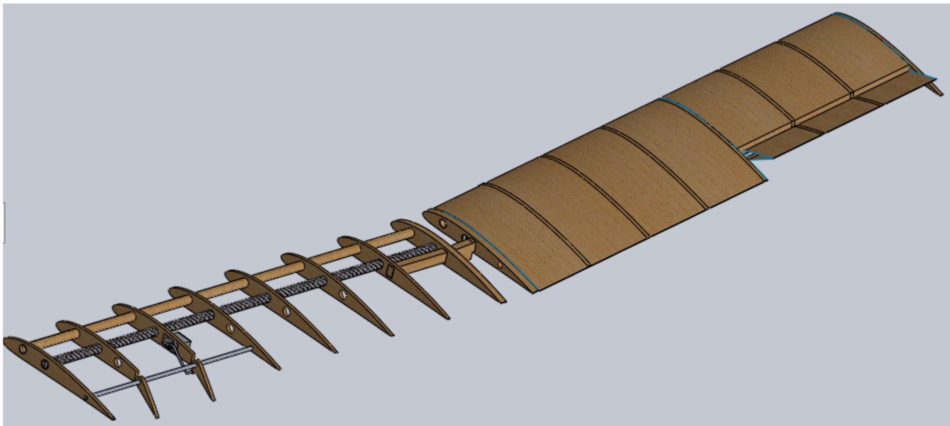


Figure 4.3. 7 3D model of the wing showing dihedral, control surfaces, and skeletal portion as well as full covered wing

The wing will be further strengthened using strips of plywood at the edges and thick sheets of plywood will be attached to the top of the central fuselage section and will form the base on which the dihedral will sit on.

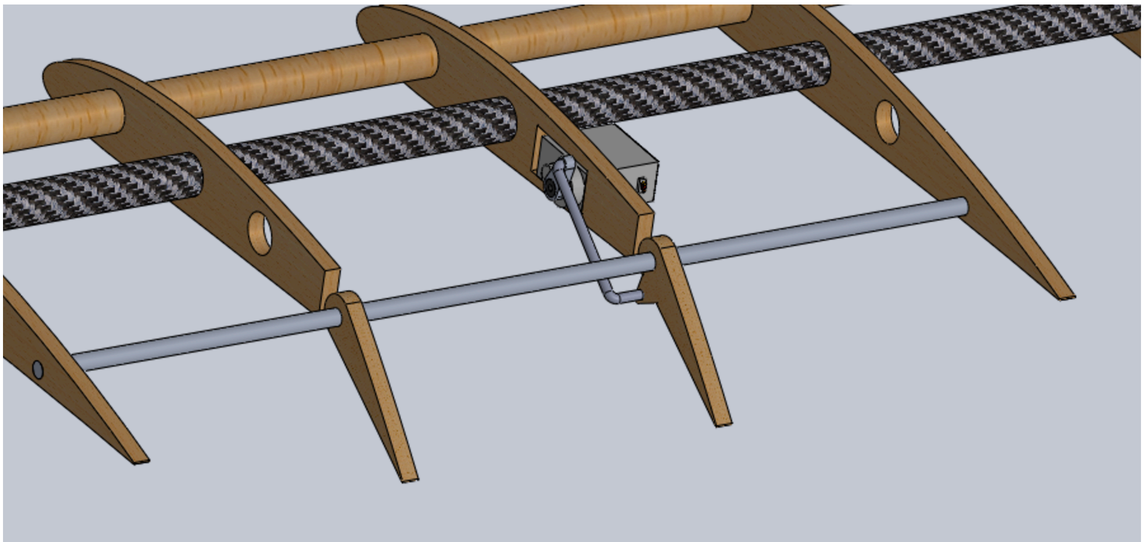


Figure 4.3. 8 Servo motor assembly on the wing to control ailerons during flight.

4.3.1 Entire Aircraft

When the entire aircraft is assembled it will look like the structure in Figure 4.3. 9. This structure will be tested to validate the improvements made in the preliminary design.

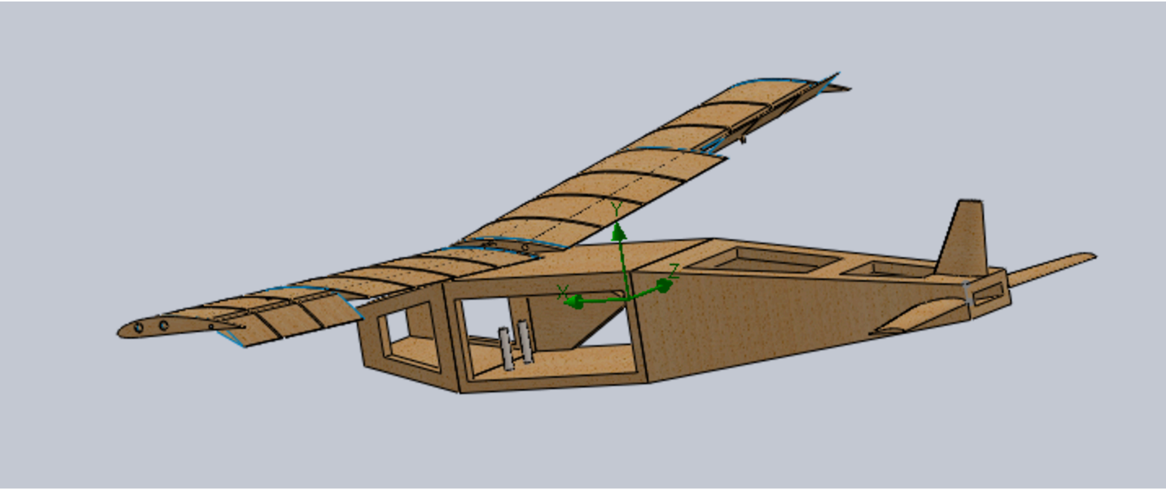


Figure 4.3. 9 Proposed entire aircraft assembly.

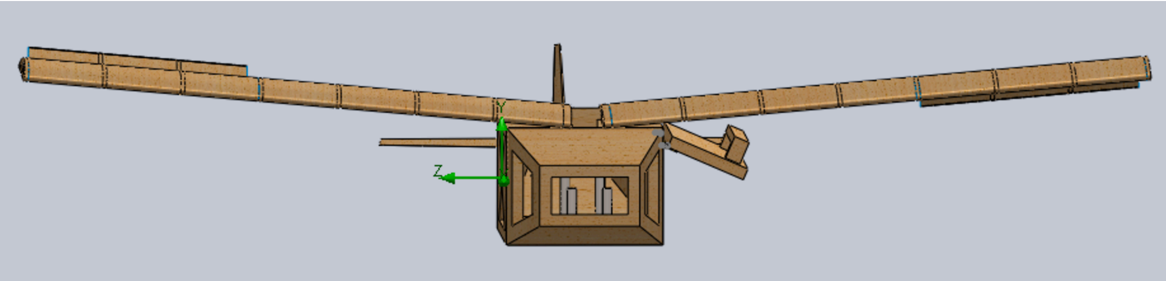


Figure 4.3. 10 Front view of entire aircraft assembly with dihedral attachment.

Chapter 5: Testing and Results

5.1 Static Analysis

A static analysis study was done using Solidworks on the fuselage assembly and the wing assembly. This was meant to determine the maximum stresses the structures can withstand under certain forces. Afterwards, a factor of safety plot was generated for both assemblies.

5.1.1 Fuselage

In the static analysis of the fuselage structure, fixtures were placed at the bottom of the central fuselage section and the frontal part of the empennage section while all the forces considered to act on the fuselage structure including, the avionics, the Styrofoam food pack and the wing were subjected (values between $1N$ and $3N$) according to their respective locations. Subsequently, a factor of safety plot was generated to understand the level of safety with which the fuselage was designed and it is shown in Figure 5.1. 1

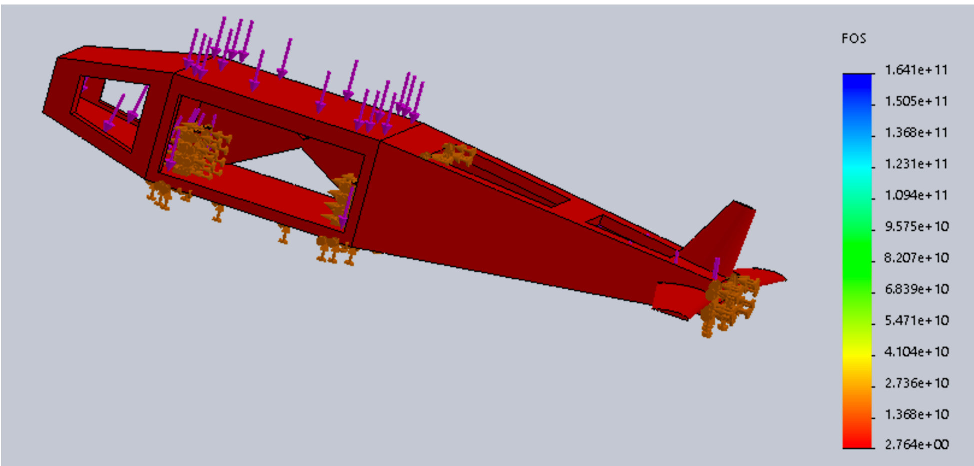


Figure 5.1. 1 Factor of safety plot of maximum von Mises stress on fuselage assembly.

It can be seen that, as expected, the fuselage assembly made will fail at stresses of about $4000\ Nm^2$. However, this is an indication of the fact that the weights that the fuselage structure will experience will not cause it to fail as they are way below this value. Also, the factor of safety plot shows a minimum factor of safety of about 2.7. This is an indication that the fuselage structure is safe to manufacture and be used for the required purposes.

5.1.2 Wing

The static analysis was also done on the wing assembly but done on just half of the wing since both wings are attached to the dihedral and attached to the top of the central fuselage section. This assembly in this study was the skeletal version of the wing consisting of spars and ribs to properly its structural integrity. Fixtures were created underneath the thickest rib which was meant to be attached to the dihedral and at ends of the spars to ensure they were fixed in such a position. Forces of $20N$ in total were subjected to the bottom of the ribs and the study was done. Figure 5.1. 2 and Figure 5.1. 3 show the results of the von Mises stress distribution and the factor of safety plot respectively.

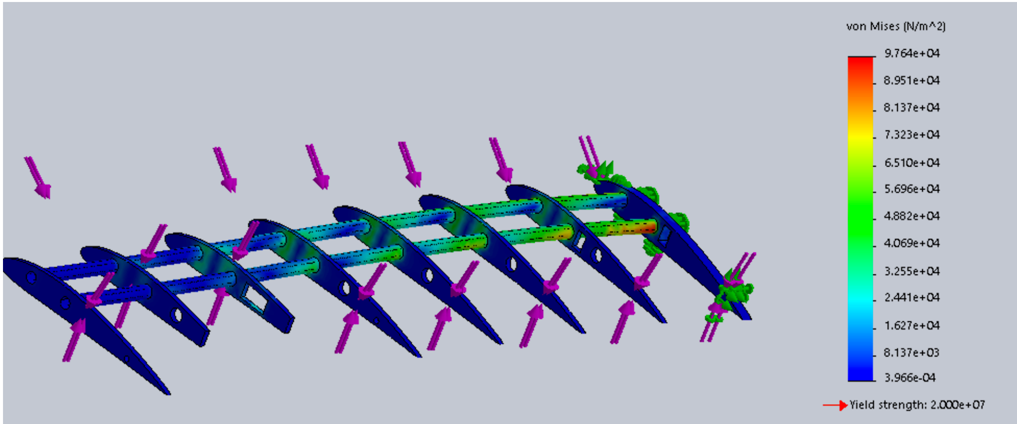


Figure 5.1. 2 Static analysis of skeletal wing with von Mises stress distribution.

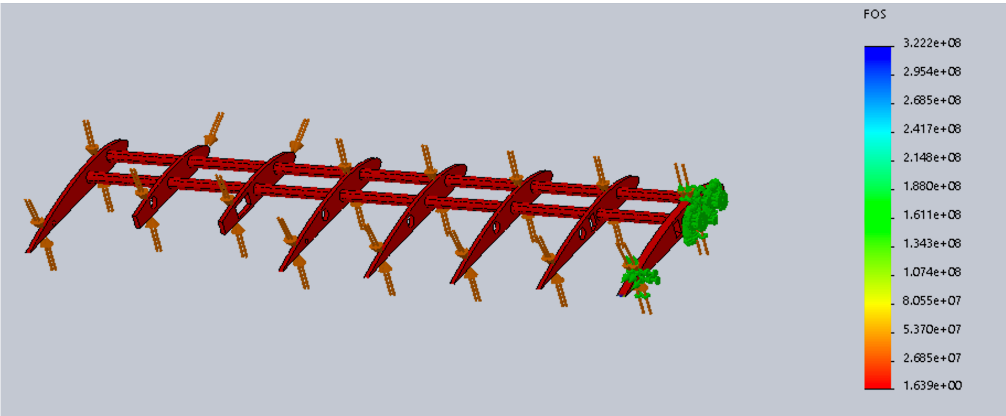


Figure 5.1. 3 Factor of safety plot of maximum von Mises stress on skeletal wing structure.

From the results in Figure 5.1. 2 it can be seen that the wing will most likely fail at the section where the thickest rib is connected to the main spar. This is an indication that the main spar must be made from a material that can withstand such stresses. Also, the factor of safety plot shows a minimum factor of safety of 1.69. Another indication of the possibility to implement such a wing structure in the new aircraft.

5.2 Flow Simulation

In order to understand how the aircraft performs in-flight/atmosphere, it is important to subject it to somewhat of a fluid flow test. A Solidworks Flow Simulation was carried out on the entire aircraft structure and plots of the surfaces' interaction with fluid flow in the air as well as the flow trajectories were generated. As the aircraft moves through the air it is assumed that the flow it experiences whether laminar or turbulent will be in the normal X and normal Y directions as can be seen in Figure 4.3. 9. The flow simulation was carried out with the following assumptions:

1. The flow is external and does not include closed cavities.
2. The fluid flowing over the aircraft surfaces is air at STP.
3. The boundary conditions are adiabatic.
4. The effect of gravity is negligible.

Global goals were used to carry out the simulation and they included static pressure, normal forces in the X and Y-direction. The flow speed was estimated to be $30m/s$. Figure 5.1. 4 and Figure 5.1. 5 show the Surface plots and flow trajectories respectively.

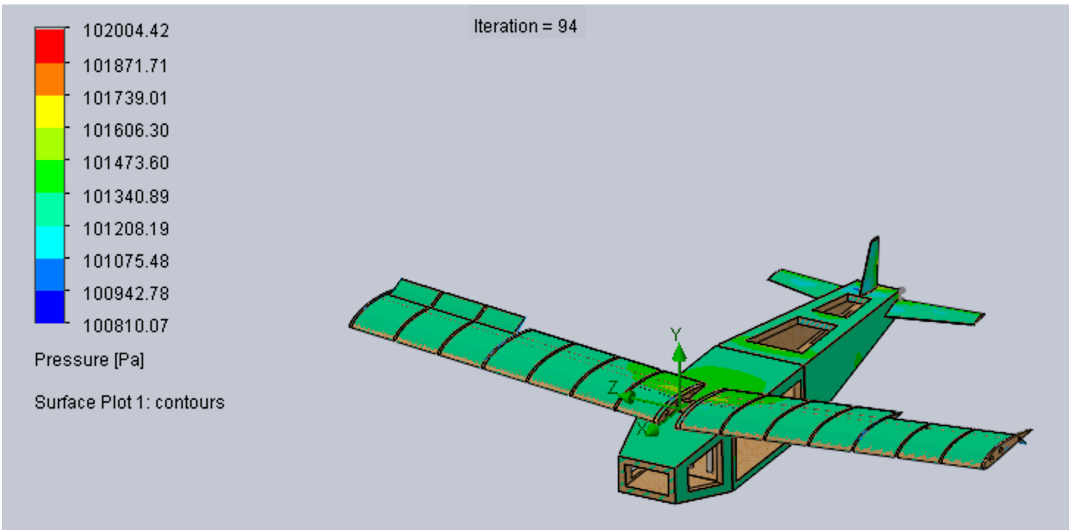


Figure 5.1. 4 Surface Plot of flow simulation on entire aircraft structure.

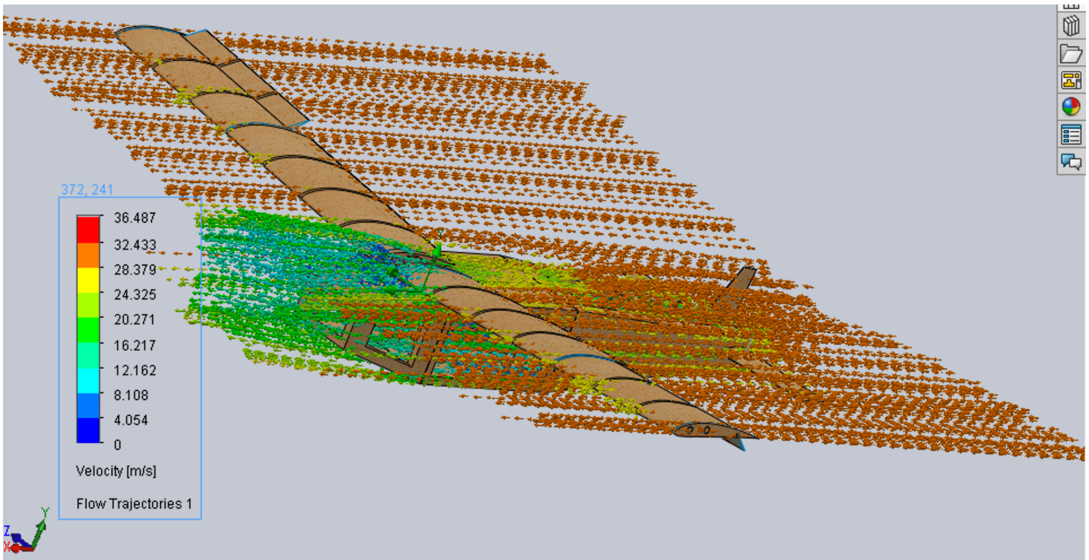


Figure 5.1. 5 Flow trajectories of fluid on entire aircraft structure.

It can be seen from Figure 5.1. 4 that the surfaces of the balsa structure can withstand pressure of up to about 100 MPa. This is an indication that the plane can fly in the conditions of the Ashesi environment. Also, in the flow trajectories, one interesting thing to note is the gradient of the flow across the surface of the wings. The lack of rapid change across the wings is an indication of the increased stability as compared with the existing design. The results from the flow simulation show the benefits the new wing poses encourages the development of this design.

Chapter 6: Future Works and Conclusion

6.1 Future works

6.1.1 Manufacturing

Moving forward it would be beneficial for testing purposes if some manufacturing of the entire aircraft was done. This would aid in effecting design alterations when results do not prove favourable. This also means that the creation of a physical prototype would better the design process as certain manufacturing processes would be considered while others would not.

6.1.2 Avionics

The avionics of the aircraft could be improved such that testing of a physical prototype would allow the user to determine if certain components meet the technical requirement specifications of the plane and the stakeholders involved. Perhaps a battery that lasts longer or a propeller with a larger pitch diameter would prove more useful.

6.1.3 Landing Gear

Moving forward it would be beneficial to implement landing gear like the one used in the existing design. No further analysis would be carried out for this component because it has proven to be effective for the payload it is carrying and would not be greatly affected by the new payload of the proposed design. Furthermore, it would be useful if the aircraft had a system that launched it into the air. This is because the energy required to take-off on its own is very large and could be preserved for different use.

6.1.4 Empennage Design

The empennage design of this aircraft saw it lack control surfaces namely the elevator and rudder. These devices could prove useful in increasing the stability of the aircraft during turning flight as the pilot may need to input some yaw or pitch. Also, the stability would be increased when the aircraft faces turbulent conditions and may need to fly without having to damage the cargo it is carrying.

6.2 Conclusion

From the analysis and results generated, it can be concluded that the new design of the aircraft will meet the requirements stated and will be able to fly without much hindrance. It is important to note that when designing careful consideration must be taken to improve the overall safety and stability of the aircraft. Aircraft systems are meant to be reliable, and drones even more so. A drone like the one designed and discussed can prove to be useful in many applications today, not just food delivery. Looking at the ongoing global crisis, it would be beneficial to all parties involved in making sure that everyone is safe and healthy by providing a means of transportation for equipment. Implementation of such a system could go a long way in helping the human race fight this battle.

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