Design and Fabrication of a Fuselage for a Remote-Controlled Electric-Powered Airborne Imagery Platform

by

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Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
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BACHELOR OF ENGINEERING (Hons)
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Approved by,

(Mr Rahmat Iskandar Shazi bin Shaarani)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(HASNUL RADZI BIN YAHAYA)

ABSTRACT

Remote controlled electric powered airplane is a popular sport around the world but still searching to gain its base in Malaysia. People playing remote controlled airplane is a rare sight in this country because it is not made available in shops. Basically, remote-controlled electric powered airplane consists of wings, fuselage, propeller, motor, transmitter, receiver, regulator, battery, servos and undercarriage. Focus of this project is to make a functional airplane in collaboration with Mechanical engineering and Electrical engineering department. Design and fabrication of fuselage is one of the subcomponents in completing the project. By design, phases of planning, concept design, technical drawings, and product drawings are followed and completed. By fabrication, phases of prototyping, final product build-up and testing are followed and completed. Virtual testing for structural analysis is produced to look at effect of certain impacts exerted on the fuselage while test-flight is done to determine the flying characteristics of the airplane. Based on these analyses, recommendations are given for a better project output. Finally, dissertation is produced to compile all the project works in a final report.

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CHAPTER 1
INTRODUCTION

1.1. Project Background

Remote controlled electric powered airplane is not a common sight in Malaysia. Lack of advertisement, lack of government support on aerospace technology and cost are some of the reasons why the sport of flying has not yet been popularized in this country. Airplane is one of the aircraft technologies, other than helicopters and jets. Previously, fuel powered airplane was more acceptable because of the availability of the products in the market. Just for the past few years, electric powered airplane come into the picture as more manufacturers have been interested in producing electric powered airplane. The main attraction of electric powered airplane is the low cost and simplicity of components. The focus of this project is on developing a practical airplane that can perform basic functions as well as certain product intent.

This project is a collaboration between department of Mechanical Engineering and Electrical Engineering school. The final output of the project is a functional remote controlled electric powered airplane. The Mechanical Engineering students will focus on developing the wing and fuselage of the airplane while the Electrical Engineering student will be responsible to specify and check the electrical components needed for the project.

The whole must be able to show engineering calculation and analysis in doing the project. Supervisor had given the team clear statement that the airplane needs not to be able to fly but engineering involvement must be shown as if the airplane was planned to fly. It will be an added value to the team if the airplane can actually flies and the team will be much respected for that.

1.2. Problem Statement

Problem statement given as per title is **Design and Fabrication of a Fuselage for Remote-Controlled Electric-Powered Airborne Imagery Platform**. This project is to design and fabricate a remote controlled electric powered airborne imagery platform. By designing term, the project should be able to follow proper design stages from planning until engineering approach. By fabrication term, it should be able to follow proper fabrication stages from material selection until product testing. The tasks are further revise into the design and fabrication of the wing, fuselage, propeller, electric motor and vision system. The airplane will have additional component of camera which is rarely found in current airplane. The engineering factors and application play critical roles in confirming the final product. Proper engineering measurements are to be taken into account in succeeding the project with the usage of design tools.

The end result of the project is very significant for the usage of aerial monitoring in remote areas. The military concern on advance espionage can actually exploit the idea to perform basic remote inspection with the minimal effort. Nowadays, surveillance on traffic is very important to road user for them to choose the easiest path to the destination. The idea of embedding vision system onto the airplane is useful to perform the observation action. Other than that, inspection on restricted areas where unreachable by human is obtainable if the plane is made sufficiently small.

1.3. Objectives

The project is done to satisfy several objectives that will be the guidelines for the team members to follow. The objectives are listed as below:-

1. To work with cross-functional department personnel in producing the final product.
2. To learn basic design and fabrication processes involved in developing a remote controlled airplane.

3. To use engineering tools like software and laboratory equipments in completing the project.
4. To design and fabricate the fuselage of the airplane that later combined with other parts to make a complete airplane.
5. To analyze and test the airplane in term of flying capability.

1.4. Scope of Study

For individual task scope, the airplane build up are divided into smaller parts as stated earlier. Design, fabrication and confirmation of the fuselage section of the total airplane is the main focus for the project. The fuselage is anticipated to perform several design criteria. The fuselage must be able to integrate and allocate spaces to attach other components. This means that the fuselage must have installation area of wings and propeller at the exterior body. Spaces for vision system and electric motor are provided in the interior body. The fuselage must be able to carry the gravitational load due to the weight of other components and the body itself.

The fuselage acts as a linkage beam hence it must be able to sustain mechanical load such as stresses and frontal impact. In order for the airplane to fly at certain height and speed at maximum capacity, the fuselage must be able to absorb vibration produced by motor and wind effect. The integration of components is made as such for the plane to have its center of gravity near to the wing section. This will greatly influence the airplane's stability during flight. The fuselage must be design according to the aerodynamic theory and does not obstruct air flow to the wings.

In order to achieve the design, the material for the fuselage must be well selected. Material chosen for fabrication must be able to carry certain amount of load exerted by the components and the wing. Hence, it must have reasonable compressive strength for it not to break down during flight. Other aspect that should be looked into when selecting the material is the cost of material, ease of fabrication on the material, availability of the material and weight of the material. The material must be cheap, easy to shape, easily available in the market and has considerably low weight.

Other than that, collaboration with Electrical Engineering student is necessary to know how the components work together so that they can be well-placed in the fuselage.

CHAPTER 2

LITERATURE REVIEW & THEORY

2.1. Level Flight Loads

When all loads are in balance, level flight is maintained at constant airspeed and altitude. The forces acting in trimmed flight are shown in Figure 2.1 below.

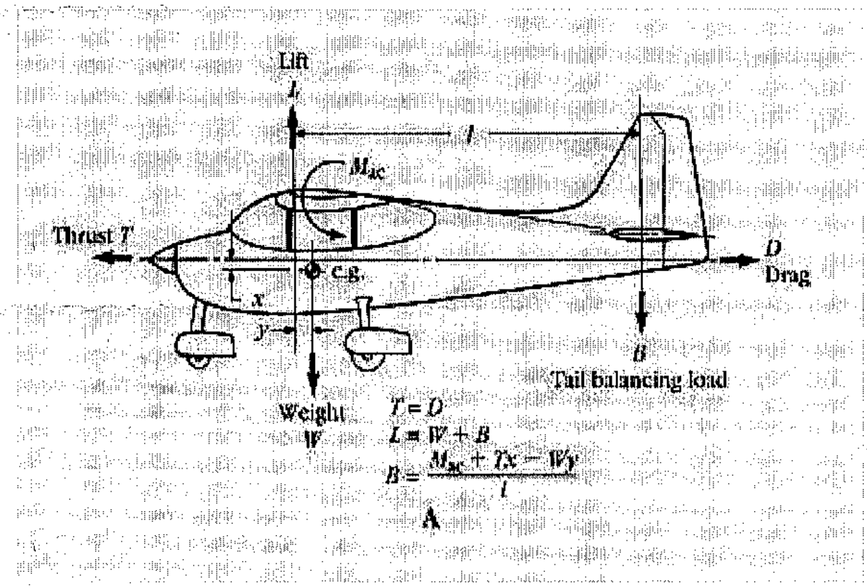


Figure 2.1: Level flight loads [1]

Most aviation texts refer to four forces of flight: thrust, drag, lift, and weight. However, there is a fifth force that interacts with the basic four, this is the horizontal tail balancing load represented by the symbol B of above figure. This value must be carried by the wings when the tail load is down, since both weight W and tail load B must be balanced by wing lift L if the airplane is to maintain level flight at constant altitude. Obviously, the lower tail load the lower the total wing lift required; and less wing lift means less wing drag, which results in more cruising speed. As a result, the search for reduced horizontal tail loads has produced lifting aft surfaces, the canard configuration, and three surface aircraft. [1]

2.2. Center of Gravity

The center of gravity (COG) is the point about which the weight of an aircraft is equally distributed. If you were to suspend the aircraft from this point, it would be perfectly balanced. The location of the COG is crucial for such purposes as aircraft stability, control surface design, and landing gear design. In general, the COG is computed by the following method. [8]

1. Select a baseline point from which all dimensions are measured, or a datum. It is typical to use the airplane nose and measure all distances aft of this location.
2. Estimate the weights of the major components (engines, fuselage structure, tail assembly, landing gear, wing structure, control surfaces, fuel load, pilots, passengers, payload, avionics, etc.) as accurately as possible. In the early stages of design, it is only able to make rough guesses, but the estimates become more accurate as specific systems and materials are selected.
3. Estimate the center of gravity of each component and measure its location aft of the datum point. Again, it is adequate to use rough approximations until the design becomes more settled.
4. Sum up all of the component weights to determine the total weight of the airplane.
5. Compute the COG of the entire aircraft using weight ratios (i.e. weight of the component over the total weight) and summing up the moments created by each component about the datum point.

The center of gravity about the O-Z axis can be calculated using equations below. [2]

$$W\bar{x} = (W_1x_1) + (W_2x_2) + (W_3x_3) + (W_4x_4)$$

$$\bar{x} = \left(\frac{W_1}{W}\right)x_1 + \left(\frac{W_2}{W}\right)x_2 + \left(\frac{W_3}{W}\right)x_3 + \left(\frac{W_4}{W}\right)x_4 \quad \text{......Eq 2.1}$$

The ratio (Wn/W) is a measure of the percentage weight of part n. so that in the calculation of the COG position of the airplane, it is more convenience to use percentage weights. Similarly, the position of center of gravity about the O-X axis can be calculated using below equation.

$$\bar{z} = \left[\frac{W_1}{W}\right]z_1 + \left[\frac{W_2}{W}\right]z_2 + \left[\frac{W_3}{W}\right]z_3 + \left[\frac{W_4}{W}\right]z_4 \text{ ....Eq 2.2}$$

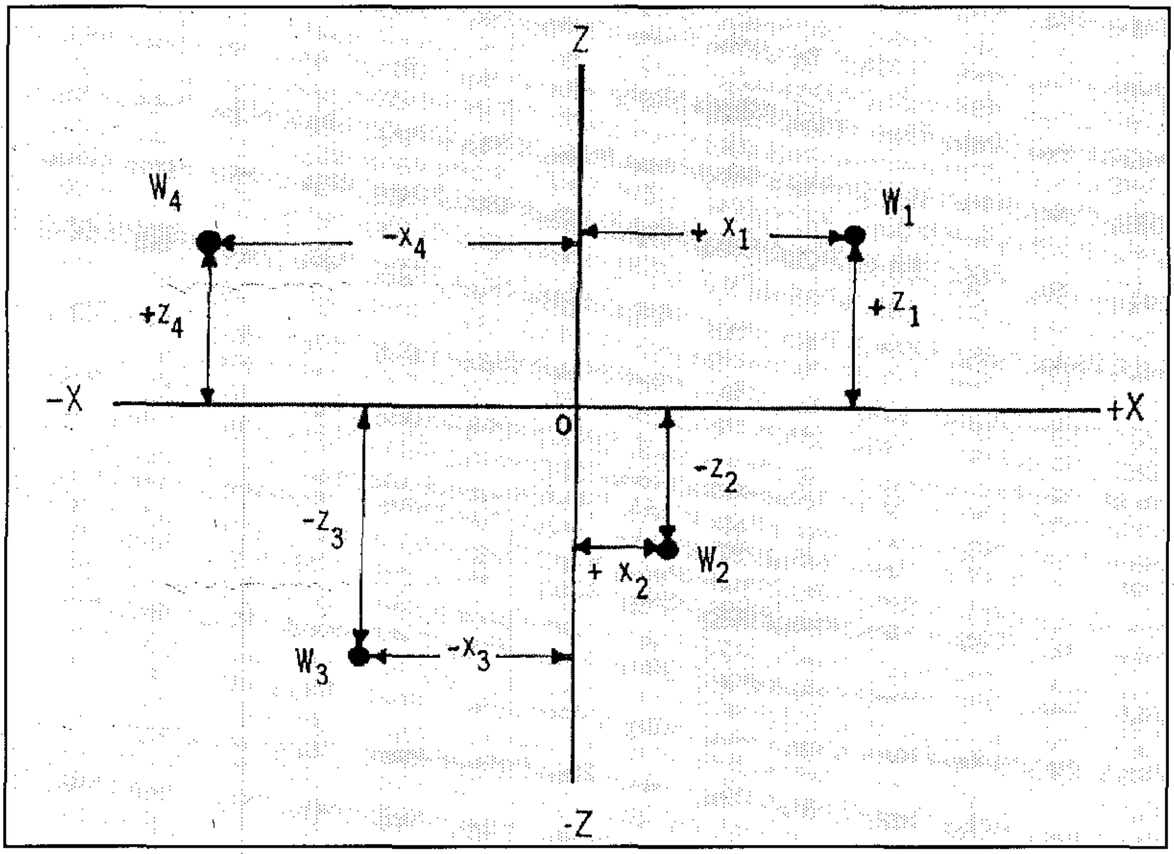


Figure 2.2: Center of gravity system coordinates [2]

A desirable COG range for powered aircraft extends from about 15% to 28% of the average wing chord, or more correctly referred to as the mean aerodynamic chord, or MAC. Sailplane designers prefer the center of gravity further aft to keep the horizontal tail relatively unloaded, and so reduce tail area and drag. Such a COG location is usually accompanied by neutral or slightly positive longitudinal stability and very low sticks forces, which are not acceptable for private aircraft operation. [1]

2.3. Fuselage Design

The larger the vertical and horizontal tail surfaces, the greater the aft fuselage loading and structural weight. Figure 2.3 below greatly simplified presentation of this tail loading condition, but it helps to show how aft fuselage loads are generated. When the horizontal tail is loaded symmetrically as shown, that is, with the same amount of load on each side, the fuselage tends to bend down and the further this load travels forward from the tail, the greater the bending moment because the arm distance to the tail load increases (moment = arm x load).

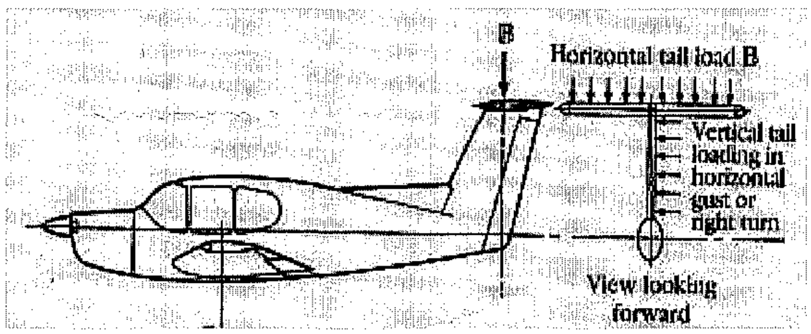


Figure 2.3: Tail loading condition

This bending must be resisted by the fuselage aft structure, and the further apart the supporting structural members or longerons can be placed, the lower the resisting load becomes. But as the fuselage is made deeper to reduce bending loads and so lighten the longerons, the skin area increases and becomes heavier. Some design study is usually advisable to review combination of skin, stringer, and longeron sizes for weight optimization.

In addition to vertical bending, the illustration also include vertical shear. Shear of this type is probably best understood as a load acting as though it could be applied at every point along the aft fuselage. That is, the horizontal tail load acts with the same (shearing action) load value all along the aft fuselage right up to the wing beam. For our purposes, the shear load is supposedly balanced out at that pint by countering shear forces acting downward ahead of the beam, as provided by the forward structure and equipments. Of course, more than just horizontal tail load is acting down, since the weight of the fuselage and tail surfaces also acts down for the condition shown and must be added to the horizontal tail load. The structural weights must be multiplied by the maneuvering load factor to obtain the actual design load, increasing both the bending moment and shear loads for this design condition.

In Figure 2.3, it contains a vertical loading that could result from a horizontal gust or maneuvering condition. Just as the horizontal tail down load caused aft fuselage bending and vertical shear, the vertical tail load shown would result in the application of horizontal bending and shear in addition to the vertical loading previously discussed.

The wing carries bending and shear loads into the fuselage where they must be taken out through strong connections and balanced by inertia forces. This is why a load carry-through beam or set of compression tube is carried across the fuselage. The wing attachment and fuselage carry-through structure must be designed for an unsymmetrical wing loading of 30% maximum flight load; full lift load applied on one side of the fuselage and 70% of that load on the other side. This condition, which tends to load and rack the fuselage in torsion at the wing attachment points, must be resisted by the fuselage carry-through beam and then transferred into the fuselage structure.[1]

2.4. Basic Design of Airplane

There are rules of thumb and basic parameters in designing remote controlled airplane. These basic parameters have been proven successful when applied for sports model. After a using these parameters, a crafter might gain some knowledge and later on design an airplane that suits his needs. These design parameters were originally collected by Romney Bukolt and published in "Marcs Sparks" in about 1975. Since that time, the validity of the parameters has been proven by the many different models which have been designed using this method.

Figure 2.4 below shows the parameters that should be followed during designing the airplane model. [9]

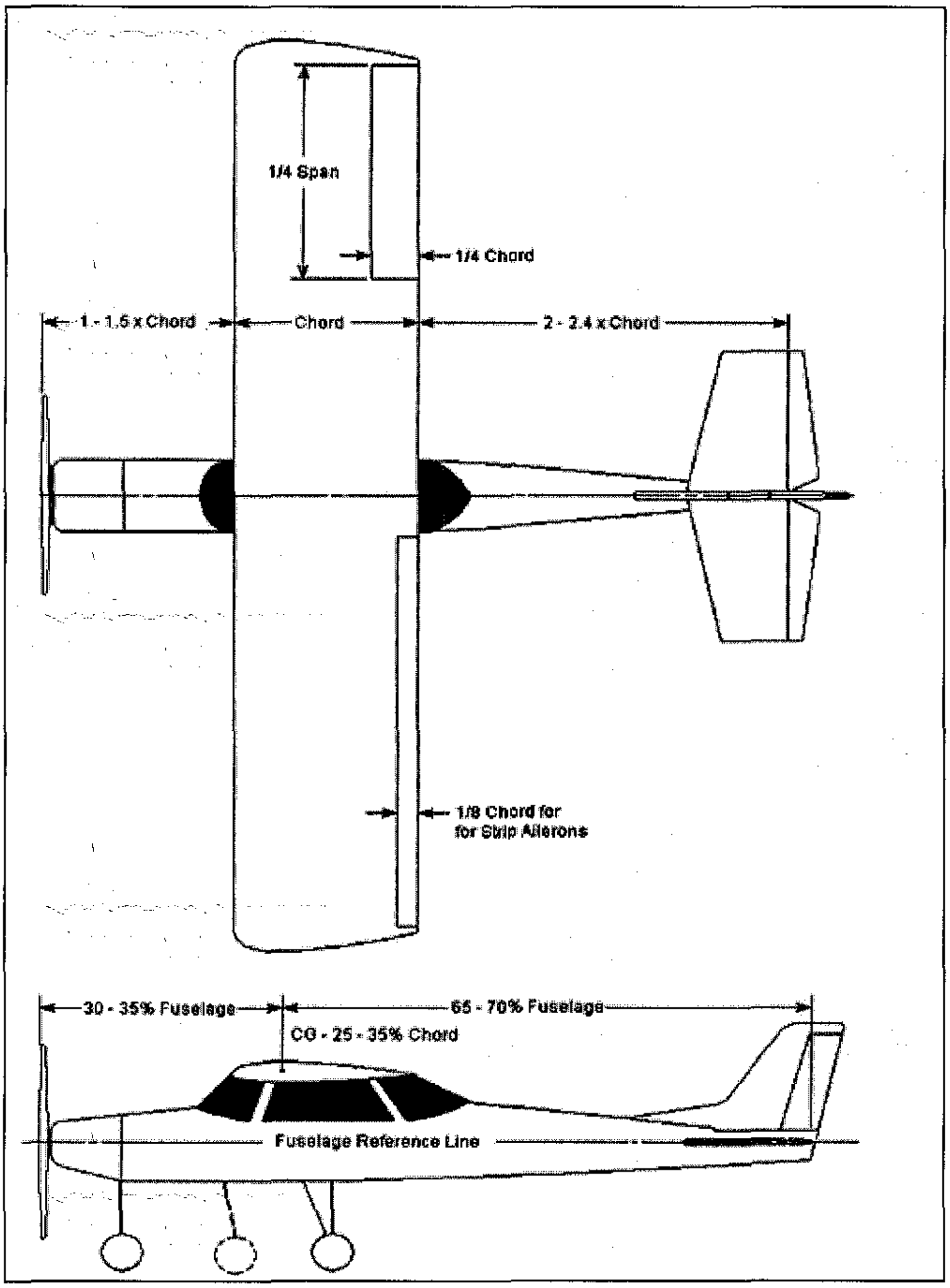


Figure 2.4: Basic airplane design parameters

CHAPTER 3
PROJECT METHODOLOGY

3.1 Project Procedures

The project consists of design and fabrication tasks. For the first semester, only the design works would be implemented. Fabrication done in the first semester was only to get the feel of making an airplane from scratch before crafting the actual intended airplane. The design works will follow normal design process from project planning until they reach prototyping. The design flow can be viewed as follows: -

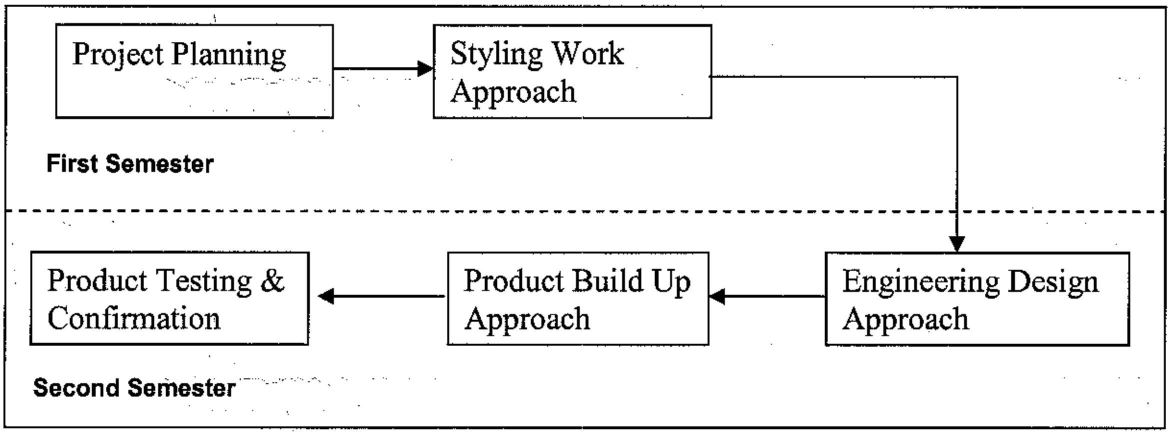


Figure 3.1: Project design work flow

3.1.1 Project Planning

In project planning, basic literature review was done first before proceeding with the project to determine the project feasibility. Most of the reviews are from book references and Internet research. Proper planning will have the product concept and planning schedule for project main reference. The schedule for the first and second semester can be viewed later in this chapter. Hence, the first semester project works can be viewed as follows.

3.1.2 General Discussion

At this stage, discussions were made between team member and supervisor in order to receive a clear statement on the team's scope of works and also individual's scope of works. Discussions were also done between team members in order to have general knowledge on other's part of work interest. From the discussion, relation between individual works and other's works can be determined.

3.1.3 Literature Review

Books literature and Internet browsing are the main resources for the completion of this project. Basic idea of airplane and fuselage design was achieved through literature review.

3.1.4 Design Sketches

From the literature review, simple sketches of functional airplane were produced to gain some in sight of the airplane design. From the sketches, one sketches is selected as design model where the final product will look alike the model.

Project planning can be divided into 2 semesters. In the first semester timeframe, most of the work done was on literature review and basic sketches and design of a functional airplane. Design approach was opted in the first semester but the information gathered was still not enough to continue with engineering design works. Project planning for the second semester started from engineering design approach until product testing and confirmation.

3.1.5 Styling Work Approach

During the styling timeframe, several concepts of full airplane sketches are to be proposed. At least, 3 proposals are needed for further selection. The sketches will be done individually depending on the project scope. 4 sketches of practical fuselages has been proposed that provide basic overview of a full airplane.

Although 4 sketches have been produced, supervisor had requested more sketches up to 5 preferably. From these 5 sketches, only one will be selected for final design and selection. Having more sketches at this stage is better as every idea of fuselage will be evaluated later. The selection of one appropriate design is further defined by its cost, material availability and fabrication process.

3.1.6 Engineering Design Approach

At this stage, ONE appropriate design will be selected from the proposed concepts and ideas in the previous styling work. Selection of the appropriate design is done by using selection matrix. Weighting is put on every selection criteria to show how every idea is being evaluated. The best design should be having the best overall weightings. Feedback and revision are necessary at this stage to confirm the selection made. The confirmation is made by theoretical basis and engineering calculation. It is necessary to use virtual tool to verify the parts integration feasibility of the designed airplane.

Selection made was confirmed with other project members. Although the selection is made from predefined criteria, it is final because parts and components integration is more important. During build-up approach later, some modification is needed based on supervisor revision.. This means that the dimension and maybe the appearance of the fuselage might need to be changed a little to accommodate the components. Of course, validation must be made for structure and strength of the fuselage to carry all the components.

The selected design must come along with its technical drawing for reference. For the first semester, only the sketches are available because parts integration is not confirmed yet and most of them still not verified. Technical drawings for the fuselage are developed in 3-dimensional (3D) and 2-dimensional (2D) drawings. Tolerances should be practiced in every aspect of dimension to ease fabrication method and process although it is not shown in the drawings. This design will look at the function of every parts embedded with the fuselage and how they are located to enable them to perform the individual function. Assembly of the components is also important as to see them working as alone parts and as an assembly.

Scaled 2D drawings in are produced to show the fuselage's full dimension. Basically, the final product must look merely the same with what have been indicated in the drawing. Some minor differences between the fabricated product and the one showed in the drawing are acceptable considering that tolerances have been practiced during the fabrication stage. Also, due to lack in experience and crafting skills, the final product should not be expected to look exactly the same as in the drawing because human error factors influenced most in the fabrication process.

3.1.7 Product Build Up Approach

Several fuselages are to be built according to the selected design. The fabrication of the fuselage will be hand-made using available tools. Earlier planning of outsourcing the product build up cannot be justified as mould has to be made first and this will cost a lot. Hand-made fabrication is necessary to follow applicable manufacturing stages used by crafters worldwide.

More than one model of fuselage need to be built next semester in order to have the final product to be more or less the same with the product specified in the drawing. To come up with such fuselage, more practice is needed. Tools and material for fabrication needs to be familiarized. This approach will take a lot of time and patience if the product to be in good shape and conform to the drawing. Detail drawings made earlier will be used as a reference and in the fabrication process. Product dimension during fabrication should be tolerated in order to reduce the possibility of human error.

The simplest tools will be used for product fabrication. More or less, the tools will be the same being used by crafters in other countries such as wire-cutter, glues, epoxy and knife. These basic tools are used because they have been used before in other works. The same tools are also recommended by supervisor but the fabrication method should be altered. Instead of moving the cutter to the foam, it should be done in reverse way. More likely, the cutter is being fixed at a table while the foam is shaped using the hot wire. This will ensure the foam is cut following the dimension needed. Other than wire-cutter, tools like glues and epoxy should be used to attach the fuselage with other components or to strengthen the fuselage body.

Foam will be used to make the fuselage main body and other material can be used to make other parts of the fuselage. For example, the tail section of the fuselage can be made using bamboo stick or carbon-fiber rod to ease the fabrication process. At this stage, reinforcement should be attached onto the fuselage to ensure its strength and crash worthiness. Of course, the usage of reinforcement must be verified by testing the fuselage before and after the installation of reinforcement. Any positive result after the flight might gives good impression that the reinforcement is working beneficially towards the design. But, if the result is negative, the reinforcement method is likely to be studied more and confirmation has to be made whether or not to use reinforcement for the fuselage.

3.1.8 Product Testing and Confirmation

Validation of the product is made practically and virtually. By practically means that the actual fuselage will be tested in static and in flight conditions. Statically, the fuselage will be tested in empty weight and in full weight. Empty weight condition is when the fuselage is not loaded with any other components such as batteries, servos and motors. Fuselage will be tested using finger tips determine its stability. The same method will be applied to the fuselage when it is fully loaded. The purpose is the same that is to look at its stability.

In flight condition, the fuselage will be flown as a complete airplane to determine its stability during flying. The airplane should be flown in empty loading and in full loading in order to see the differences of having load on the airplane. Flight testing should be done during night and day time to look at the differences in flying characteristics. This is because the air density will be higher during nighttime as it is colder. During daytime, the air density is lower and theoretically, it is more convenient to fly the airplane during nighttime as the plane will have more up thrust compared to daytime. This is because the propeller can provide more thrust during nighttime due to higher air density.

From the testing, any comment and mistake must be noted and further correction must be made to the design to improve its flying capability. The airplane should be tested frequently to look at its endurance during several flights. Other configurations of fuselage should also be built and tested although the detail drawing is not made. This is because other configurations might give flight characteristics compared with the selected design. The design is selected earlier more to cost and material value, not because of its flying capability as at earlier stage; many components have been confirmed yet.

Virtual testing of fuselage structure for static analysis will be conducted using CATIA software. The design will be imported from the CATIA drawings. In this virtual testing, loads are applied to the drawings, anticipated that the airplane will have crashed vertically or frontally.

3.2 Tools

Equipment: R/C Electric Powered Airplane

Software : CATIA v5.9 - to produce 3D drawings and static analysis

Fabrication Tools: Hot Wire Cutter, Glues, Crystal-clear Epoxy, and Tapes

3.3 Schedule and Work Distribution

3.3.1 First Semester Schedule

Table 3.1: First semester schedule

Weeks / Events	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*
Briefing/Introductory meeting																
Familiarization Research on RC Aircrafts																
Research on Mechanism of Flight																
Preliminary Report																
Research on Basic Shape and Design of Fuselage																
Sketches of Possible Ideas																
Research on Method of Fabrication																
Progress Report Submission																
Research on COG and Static Loading Analysis																
Discussion on Aircraft Configuration																
Submission of Interim report Final Draft																
Oral Presentation																
Submission of Interim Report																

3.3.2 Second Semester Schedule

Table 3.2: Second semester schedule

Events \ Weeks	1	2	3	4	5	6	7	9	10	11	12	13	14	15	16	17
Laboratory work on Foam	■															
2nd glider Fabrication Practice	■	■														
Determination of Fuselage Configuration			■	■												
Submisiion of Progress Report 1				■												
Research for next glider fabrication					■	■										
Material Search and Ordering of Components for Aircraft						■	■									
3rd glider fabrication practice and analysis								■								
Submission of Progress Report 2									■							
Software analysis (Catia) and Material testing										■	■	■	■			
Actual Aircraft Constrcution											■	■	■			
Actual Aircraft Test flight												■	■			
Final Preparation of Final Draft report													■			
Submission of Interim report Final Draft													■	■		
Oral Presentation														■		

CHAPTER 4
RESULTS & DISCUSSION

4.1 Fuselage Styling

Fuselage styling is presented in 4 different sketches. The sketches were produced from observation of available model. From the research made, it is found that design of the fuselage must satisfy the basic requirement of entertaining the loading of equipments and other parts. One consideration in designing the fuselage is the location of center of gravity (COG). Other than that, the fuselage is design to be a little bit bulky to support and contain all components needed like batteries, servos and cameras. Some of the sketches can be viewed as below.

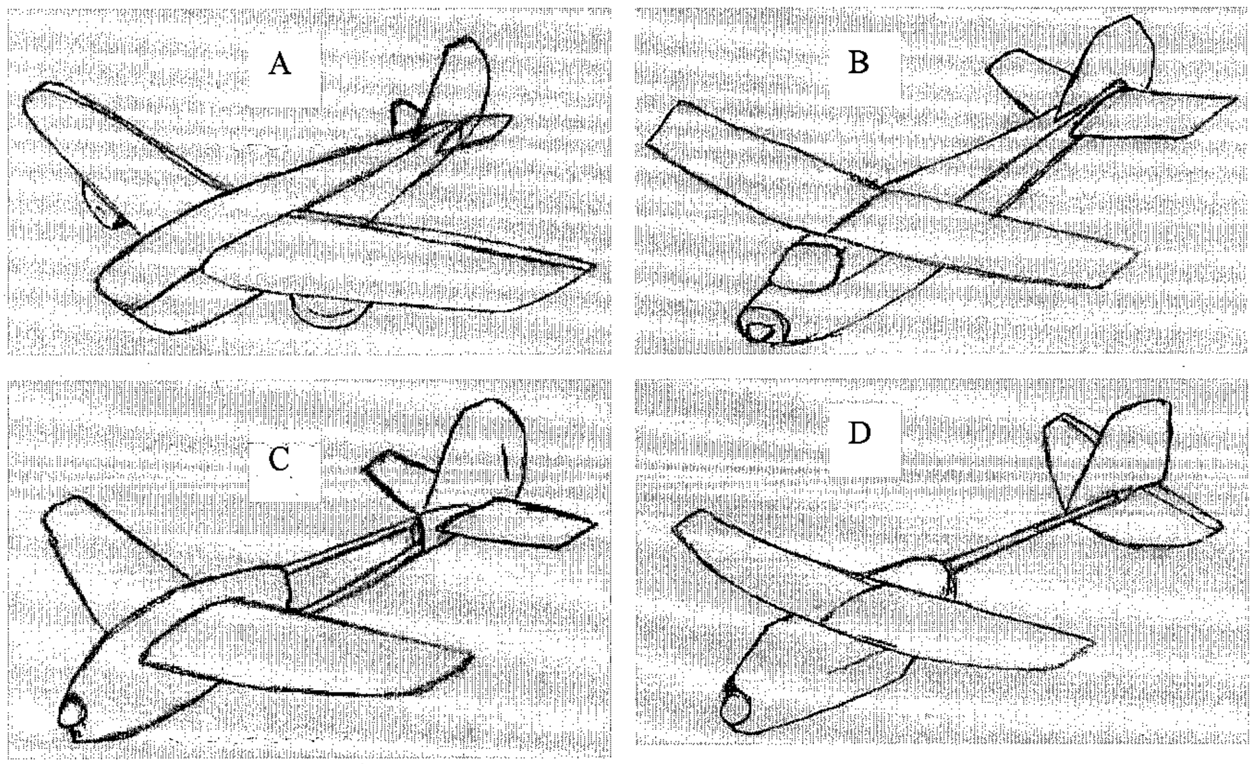


Figure 4.1: Fuselage Sketches

Note that these sketches are made from observation of existing model that suits one of the characteristic of wings. The airplane should fly slowly in speed but with great stability. Therefore, the wing selected must be in the condition of high-wing where it is embedded onto the fuselage at the top of it.

Table below shows the selection matrix used to select the suitable design of fuselage based on some criteria that have equal weighting. Hence, design B is selected for further work but it still needs confirmation from team members.

Table 4.1: Design selection matrix

	A	B	C	D
Low Weight	3	3	6	6
Cost	6	6	4	4
Ease of Assembly	6	7	4	4
Ease of Fabrication	5	6	3	4
Structural Strength	7	8	6	5
	27	30	23	23

4.2 Laboratory Practice on Foam Density

This laboratory work practices were done to determine empirically the density of foam that will be used as the material for fuselage structure. The material selection for the laboratory exercises was the plain foam which has smaller thickness. Earlier, in constructing the first prototype of the fuselage, the foam used was thicker but with less compact. For the wing structure, thinner kind of foam was used but with more compact structure. Somehow, the thinner type of foam is easier to be cut using plain cutting knife compared to the thicker foam. This is because the thinner foam is made from small particles. It was suggested by supervisor that later on, the fuselage and wing are to be fabricated using the thinner type of foam. This is reasonable because it is easier to cut the thinner foam into the desired shape and it requires less effort. Cost-wise, the thinner type of foam will not affect much the total cost of the whole airplane although its price is higher than the thicker type of foam.

The purpose of knowing the density of the foam to be used as fabrication material was to calculate the weight of the airplane frame later on. From this laboratory practices, not only the weight of the fuselage can be determined, but the wing too because the airplane frame should consist of the fuselage and the wing. Other loads added to the airplane come from the electrical components. Other than that, the density of the foam can be compared with the theoretical value given by a company that produces foam product. (Ref: http://www.energoterom.ro/energoterom/services.html).The company has already conducted a laboratory testing using standard procedures to gain the density of the foam. The value of density achieved by the company will be used as comparison to the value achieved from the laboratory exercises.

The first part of the laboratory exercises was to determine the steps to be taken in order to achieve a justifiable result. The first step was to look for precision weight scale and precision cylinder provided in the Mechanical Material laboratory. As the name suggested, the precision weight scale was used to determine the weight of the foam. The precision cylinder was used to determine the volume of the foam. Using these equipments, proper steps of conducting the laboratory exercises were made. Precision cylinder tube with the smallest increment was used because it was easier to detect any changes in volume. To do so, the foam was sliced into small, box-shape pieces so that it can be slotted in into the opening of the selected precision tube.

The laboratory exercises were divided into 2 sections. The first section was done to determine the volume of the box-shaped of the foams. The foam was divided into 3 pieces with different lengths. There were pieces with 2.0 cm length, 2.5 cm length and 3.0 cm length. The foam was divided into several pieces to determine the density of each piece of foam and to look into the variations of density. Although the width of the pieces will not affect the outcome of the laboratory exercise, the pieces were maintained at almost the same width which was adequate to slot them into the precision cylinder. The inner diameter of the precision cylinder was measured to be 1.5cm thus the width of each piece was maintained at 0.7 ± 0.1cm. The precision cylinder was filled with distilled water up to certain readable value and this value was recorded as the initial volume. One of the pieces was inserted into the distilled water and any change was recorded. Straighten wire was used to push the foam into the water. Without the wire, the foam will always float hence the volume cannot be measured. Earlier, the volume of the wire was measured by inserting it into the water to a certain extent but there was no change. Therefore, it is concluded that the volume of the wire is zero. The exercise was repeated to other pieces of foam. To make the result more valid, the exercises were repeated at different volume level of distilled water. From the result, the changes in volume at different volume level of the distilled water were the same. All the changes in volume of distilled water were taken as the volume of the foam itself.

The second section of laboratory work was done to determine the weight of the pieces of the foam. The pieces of foam that had been use earlier to measure the volume were used again for weighing purpose. Before that, the pieces of foam needed to be dried up first to ensure that the weight being scaled was the weight of the foam alone, excluding the water. Dried pieces of foam were put on a precision weight scale and the weights were recorded. This exercise was repeated 2 times to ensure the validity of the results. Although the precision weight scale gave the weight up to 5 decimals, only 2 decimals were sufficient for calculation purpose later.

With the all gathered data, density of each piece can be calculated using the equation below:-

$$\text{Density, } p = \text{Weight (gm) / Volume (cm}^3\text{)}$$

Volume of the foam as mentioned earlier was taken from the difference in volume reading of precision cylinder. 1 ml of distilled water is the same of 1cm^3 of water hence the volume reading can be directly changed into meter cubic instead of milliliter. The result of the experiment is shown in Table 4.2.

Table 4.2: Density of Foams

	Foam 3.0	Foam 2.5	Foam 2.0
Density (gm/cm^3)	0.0486	0.0519	0.0550

Using linear regression method, the average density of the foam is determined to be about 0.0503 gm/cm^3. From the reference site, the theoretical value of the value of density for foam is 0.061 gm/cm^3. Using standard equation to calculate percentage error, the error is about 17%. Therefore, the value of density determined from this laboratory exercises can be used for calculation purpose. Several factors might cause the result to be slightly different from the theoretical value. Firstly, the theoretical value of density was determined from a standard procedure of testing method namely STAS 9209-73 while the experiment had not refer to any standard testing procedures. Type of foam used to find the density might be different from what has been bought and used. Lastly, different inherent process to produce the foam might also contribute to the percentage error. The error calculation is shown as below:-

Percentage error = (0.061 – 0.0503)/0.061 % = 17%.

4.3 Cost Usage Analysis

To justify the usage of different type of foam in term of cost, it is appropriate to justify the total cost needed to build a complete airplane with all the components. From the price list provided by the store where the foam was bought, 1 board of thick type of foam cost at RM3.00. One board of thinner type of foam cost at RM6.00. The price list of electrical components including the propeller is given by Bunkyo Trading and it can be referred to the invoice as per order-date 16 February 2004. The price list is shown in Table 4.3.

Table 4.3: Components price list

Items	Price (RM)
2XNaro Servo,R6N,ICS300, W/TX&RX Crystal, Battery350MAH,7.2V	420.00
NiMH Battery, 8 cell	70.00
W/Oilless Metal	61.00
JST	24.00
FMS Cable	25.00
Propeller	12.00
TOTAL	612.00

From the table above, the total price of components alone is RM612.00. Assuming that the wing and the fuselage will be using the same type of foam, comparison can be done between the thin and thick type of foams with 10 boards for each type.

Table 4.4: Cost comparison

	Components' cost, C (RM)	Foam cost F (RM)	Total cost, F+C (RM)	Ratio, F/ (F+C)
Thick foam	612	30	642	0.05
Thin foam	612	60	672	0.09

Therefore, usage of 10 boards of thin foam contributes only 10% of total cost which is relatively small compared to the total cost itself. Still, most of the cost of building a complete airplane is contributed by the components' price. Thus, the decision of using either type of foam will not affect much the total cost. Of course, the less board used to build the airframe is better as more money can be saved. But, by knowing this fact, using as much material as needed is reasonable to complete the project.

4.4 Center of Gravity

Calculation for center of gravity (COG) is done using the basic theory as given in the literature view section. For this project, mathematical model to calculate the center of gravity is only done on the final airplane. Major reason for this practice is that the electrical components will only be used in the final airplane to be built. Note that for the final product, only certain components are made to be fixed at a certain location on the fuselage. Position for battery pack used in the airplane is not fixed as it can be used to locate the center of gravity to be as near as possible to the center of lift. Hence, with this certain freedom for the battery to move along the fuselage, any wrong practice or error in fabricating the final airplane can be compensated. Any error made in the fabrication stage can significantly change the location of balance point.

Before calculating the center of gravity, the position of each component on the fuselage must be determined first in the O-X and O-Z direction. The location of electrical components on the final airplane was determined according to the height and length of the fuselage to be built later on. The width of the fuselage is not considered in the calculation of COG because it is assumed that the airplane will be built in symmetrical manner. Therefore, the COG in the O-Y direction is determined to be at the O axis.

To determine the location of the components on the final fuselage, it has been previously assumed the location of these components on the third prototype fuselage. The reason of this practice is that there will be no major change from the third prototype design to the final fuselage design. Hence, after the completion of final fuselage fabrication, the components will be positioned accordingly. Figure 4.2 shows the location of each component on the final fuselage. The dots indicate the center (balance) point of the components.

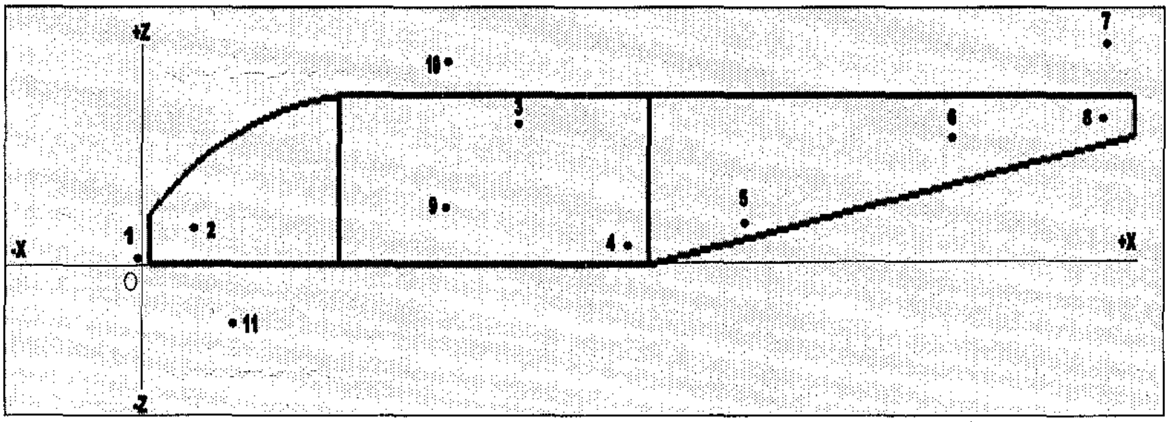


Figure 4.2: Components weight position on the fuselage

After knowing the distance of each component in the fuselage from Z datum and X datum, the weight of each components must be found. For the electrical components, precision weight scale was used to measure the weight of each component. For the parts made using foam, simple calculation is needed to determine their individual weight. Although scale measuring can be used, the practice was not practical because some of the parts are too big to be used on the laboratory scale. Roughly, the maximum size of items that can be used on the precision scale is 15 cm X 15cm X 20 cm. Cutting the parts into a smaller pieces is also not practical as it will become a tedious job to measure all the pieces one by one.

Therefore, calculation is opted for determining the weight of parts using foam. Sample calculation is shown overleaf.

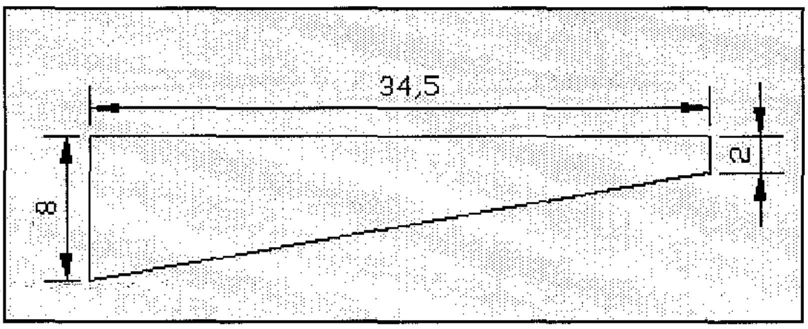


Figure 4.3: Fuselage part made from foam

Sample calculation of weight:

$$W = A \times t \times p = (10 \times 34.5)/2\ cm^3 \times 0.7cm \times 0.05\ gcm^{-3}$$
$$= 7.37\ gm.$$

The part used in the sample calculation is actually the side of fuselage. It cannot be measured using precision weight scale due to its size as the scale can only be used to measure small items. This calculation was repeated for other foam parts until the total weight was achieved. The summary of components weight is tabulated as below.

Table 4.5: Summary of components weight

Number	Components	Weight (gram)	Distance from center point to	
			x-axis (cm)	z-axis (cm)
1	Propeller	13.32	0.00	0.00
2	Motor	73.27	3.50	2.50
3	Regulator	9.81	6.75	25.20
4	Camera	68.35	1.30	34.35
5	Receiver	8.52	2.02	42.50
6	Servo	29.32	5.45	53.50
7	Tail	7.07	13.05	62.50
8	Rear wing	16.36	7.00	62.50
9	Fuselage	80.83	3.50	19.00
10	Wing	208.04	9.00	19.00
11	Undercarriage	30.11	-5.00	11.75

Table 4.6 shows the sample calculation of COG using Excel software. Although the calculation can be done manually, Excel software was use instead because of ease of editing later on.

Table 4.6: COG calculation using Excel software

No	wn	wn/w	xn	zn	x	z
1	13.32	0.02444	0.00	0.00	0.00000	0
2	73.27	0.13444	2.50	3.50	0.33610	0.470541
3	9.81	0.01800	25.20	6.75	0.45360	0.1215
4	68.35	0.12541	34.35	1.30	4.30793	0.163037
5	8.52	0.01563	42.50	2.02	0.66440	0.031579
6	29.32	0.05380	53.50	5.45	2.87820	0.2932
7	7.07	0.01297	62.50	13.05	0.81078	0.169291
8	16.36	0.03002	62.50	7.00	1.87615	0.210128
9	80.83	0.14831	19.00	3.50	2.81793	0.519092
10	208.04	0.38172	19.00	9.00	7.25277	3.435523
11	30.11	0.05525	11.75	-5.00	0.64916	-0.27624
	w=545		COG		22.04702	5.137652

Using Excel software, the center of gravity is located at 22.05 along X-axis and 5.14 along Z-axis. The location of COG for both axes was calculated without the battery pack. The battery pack functions as a counterweight to balance the airplane. A good COG should be located at 15 to 28% MAC from its leading edge because the center of lift (COL) is usually located within this range. The COG should coincide with COL to avoid coupling. In order to find the best place to locate the battery pack, the COG location must be found first using below equation.

$$COG_{MAC} = (COG - \text{MAC leading edge})/MAC$$

$$0.28 = (COG - 13.5) / 21$$

Hence, the COG calculated using the equation is equal to 19.38. Using Excel software, the result is shown in Table 4.7.

Table 4.7: Location of battery-pack on fuselage

No	wn	wn/w	xn	zn	x	z
1	13.32	0.02049	0.00	0.00	0.00000	0
2	73.27	0.11272	2.50	3.50	0.28181	0.394531
3	9.81	0.01509	25.20	6.75	0.38033	0.101873
4	68.35	0.10515	34.35	1.30	3.61203	0.1367
5	8.52	0.01311	42.50	2.02	0.55708	0.026478
6	29.32	0.04511	53.50	5.45	2.41326	0.245837
7	7.07	0.01088	62.50	13.05	0.67981	0.141944
8	16.36	0.02517	62.50	7.00	1.57308	0.176185
9	80.83	0.12435	19.00	3.50	2.36272	0.435238
10	208.04	0.32006	19.00	9.00	6.08117	2.880554
11	30.11	0.04632	11.75	-5.00	0.54430	-0.23162
12	105	0.16154	5.534		0.89400	
	w=650		COG		19.38	4.307724

The battery pack should be located along the fuselage at 6cm from the Z datum, which is very near to the front in order to get the range of 28% MAC. In actual this is not possible because it will intervene with the motor. An additional weight must be inserted along the fuselage so that the location of COG can be achieved.

There are several assumptions made in order to calculate the center of gravity. The fuselage's COG along X-axis is assumed to be the same as wing's COG. The datum point for both Z-axis and X-axis was located at the center point of propeller. Hence the distance from propeller to X-axis and Z-axis was both zero. For calculation purpose, this point is located at the nose of the fuselage.

Another big assumption made was to accept that every component's center of gravity is at the center of the product itself. This theory is true if the components are a solid box but most of the components have complicated parts in it. Assembly of each component is different hence the location of component's COG cannot be at the center of the component. This is one major factor why COG calculation at the first place leads to error.

It is better to determine the COG location first rather than the location of the components so that the COG location can be made as near as possible to the center of lift to avoid pitching moment. Actually, the practice of giving some freedom to locate components along the fuselage is not desirable as it can lead to error as shown in the calculation. But, due to error in product fabrication where it cannot meet the exact shape of the design, the practice is considered necessary when balancing point is not meet.

4.5 Prototype Build Up Practices

4.5.1 First Airplane

4.5.1.1 Design and Build Up

The first design of fuselage was made at the end of first semester. The fuselage was intended for a complete glider. This glider was fabricated in order to introduce and be familiar with basic build-up practices. In this stage, basic tools used in fabricating the fuselage such as hot-wire cutter, knife and tapes were introduced. From the practices, some experience in fabrication methods were achieved and hope to be useful in the next semester.

Material used to build the fuselage was actually readably available in the hardware shop. The team member has decided to use rough foam for the fuselage and fine foam for the wing. The glider was build referring to the sketches in Figure 4.4.

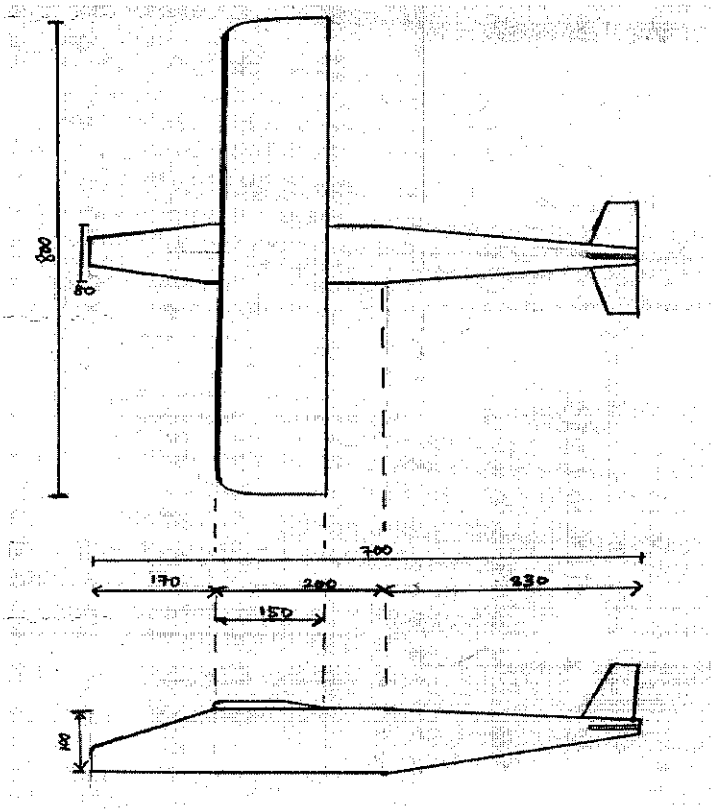


Figure 4.4: Glider Sketches

The fuselage was made by applying subtraction modeling method. A board of rough foam was cut into several pieces with the same height and width. These pieces were stacked together using white glue and shaped using knife and wire cutter. After the glue has dried up, a slot was made at the rear of the fuselage to hold the rear-wing and tail. The fuselage was then assembled with the wing at the designated location.

After assembly, the wing section was reinforced using a light cloth-hanger. The hanger was tied underneath the wing using rubber band. To adjust the center of gravity of the glider, the team used a stapler as ballast for counterweight effect. The COG was adjusted so that it is located 23% chord length aft from the leading edge, in line with the wing's COG. The glider's COG was made in-lined with wing's COG so that the lift provided by the wing would push the aircraft up at the wing's COG. If both COGS are not made to be in-lined, moment will occur at the glider and it will become whether nose-heavy or tail-heavy. Figure 4.5 shows the pictures of the glider.

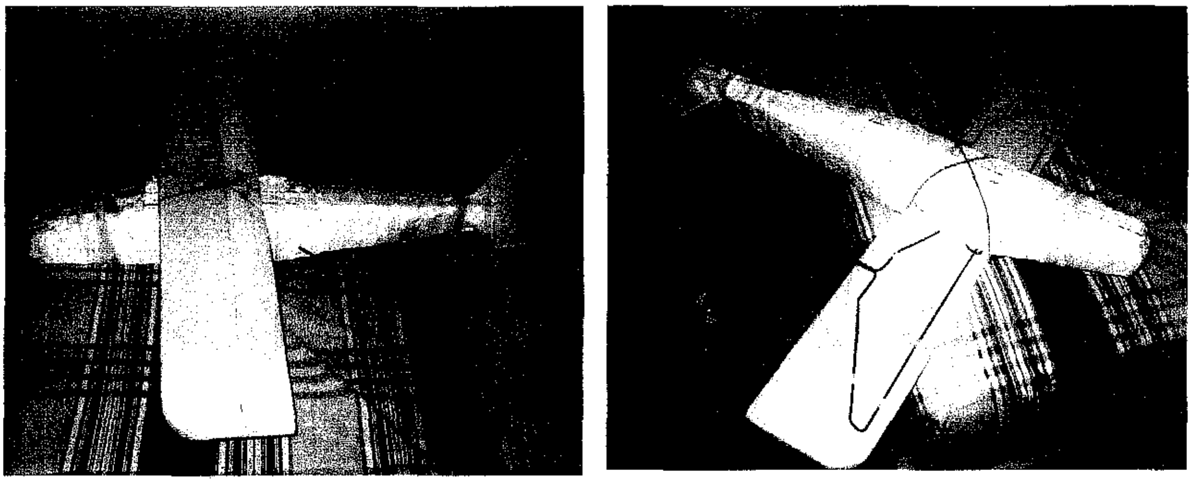


Figure 4.5: Pictures of first glider

It is obvious form the pictures that fabrication method of the both fuselage and wing needs some enhancement. It was not practicable to shape the outer skin of the fuselage without any heat-treatment as it resulted in rough skin. The surface roughness will only increase drag during flight. Usage of hanger was not desirable as it also added drag. The rear wing surface area needs to be made larger to aid in lift during flight.

4.5.1.2 Test-Flight Analysis

During the test-flight, first problem encountered was the glider tends to dip-up during flight, indicating that the glider was tail-heavy. As the COG location was checked to be correct, the rear wing was actually inclined with too much angle. The rear wing was pushed downward during flight that made the glider dip-up.

The rear wing was adjusted to be parallel with the body, having less angle of inclination. After the adjustment, the plane glided quite well. Figure 4.6 shows the flying characteristics of the glider.

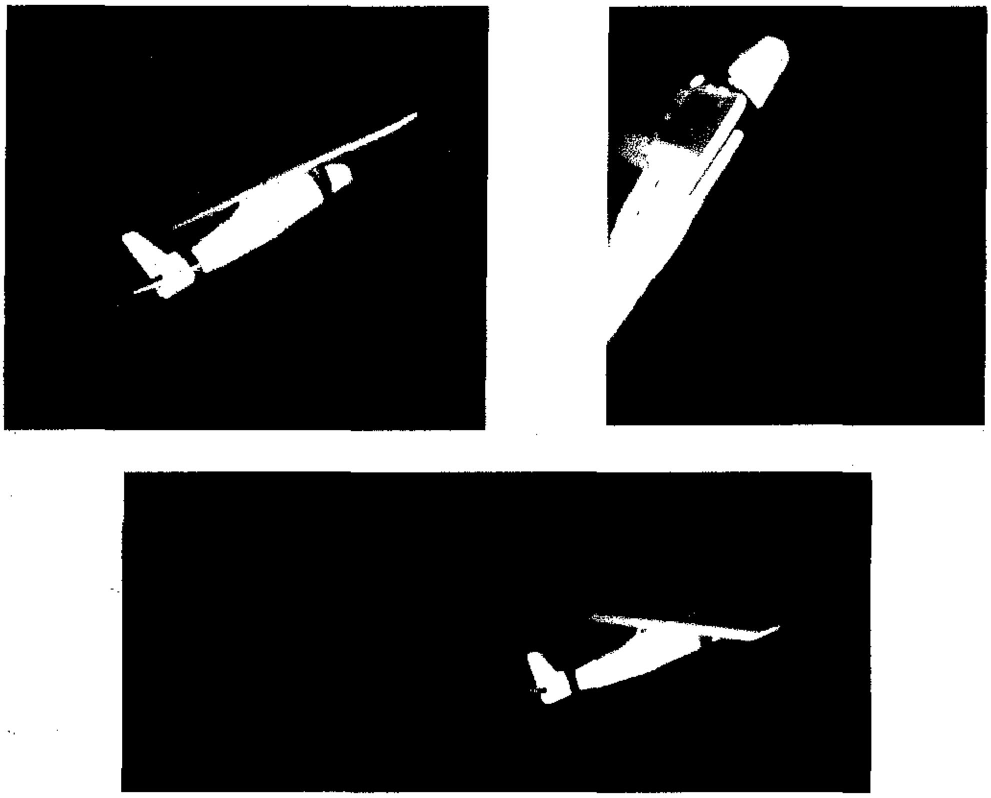


Figure 4.6: Flying characteristics of first glider

The plane crashed heavily after several successful flights when it dove onto the ground. It was noted that the wing moves further forward after several landing as there was no slot to hold the wing onto the fuselage. Furthermore, the hanger used to reinforce the wing slide easily on the fuselage during each landing. For the next build-up, slot needs to be provided for the wing to hold up.

Much tape was added onto the glider to tie up various parts that had been badly affected during the first test-flight. This increase the weight of the whole plane but it managed to fly for the second test-flight. The test-flight was stopped after the glider was heavily crashed as for this time; the team just wants to see whether it can fly after several modifications.

4.5.2 Second Airplane

4.5.2.1 Design and Build Up

The first 2 weeks of the second semester was spent to fabricate the second complete air plane. This airplane, like the first one, was intended to be a glider due to the fact that there was no component available at this time. The purpose of the build-up was to enhance the skill of team members in fabricating the wing and fuselage of the airplane. The skills and experience learned from the early build-up will be advantageous during the final design fabrication.

The configuration of the whole glider was made very much similar to the first airplane because the first airplane had good flying characteristics. Only some adjustments needed to make the airplane glides well, with better flying characteristics. This time, the fuselage and the wing used the same basic material; the fine foam. A major difference in design for the second fuselage is that the fuselage was made using several foam connected with plywood and wrapped using white paper.

Rather than using subtraction modeling method, the second fuselage was made by applying union modeling method. The exact shape of each side of the fuselage was fabricated using knife and wire cutter. Crystal clear epoxy was used to join the pieces and it worked very effective as adhesive after some time. Parts being glued using epoxy can be handled after 2 hours but for maximum effect, it should be left for minimal 8 hours before being used. Pictures in Figure 4.7 are the second model of the airplane build by the team.

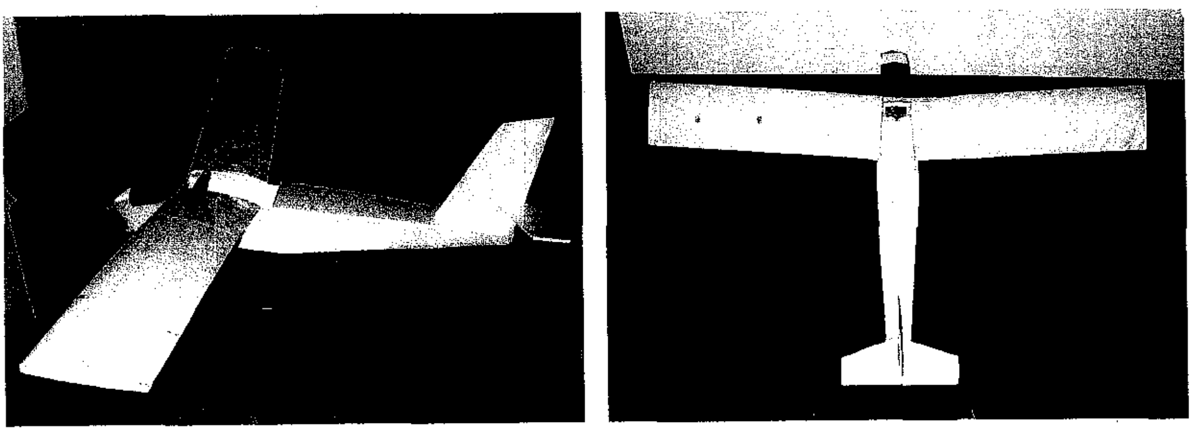


Figure 4.7: Pictures of second model

From the design, the wing and rear wing surface area needs to be increased in order to have maximum possible lift during flight. The designated wing is not compatible with the fuselage length and the airplane might be tail heavy. Same as the first model, stapler was chosen to be the ballast for counterweight effect. Determination of the COG location was done by balancing the airplane on finger.

Using the union modeling method, the fuselage became hollow inside and the weight has much decreased. Another factor that decreases the weight of the fuselage was the usage of fine foam. Fine foam is easier to shape using either knife or hot wire cutter compared to rough foam and it resulted in smooth skin surface. Surface area needs to be shaped decreases using union modeling method and this leads to the possibility of having low surface roughness.

4.5.2.2 Test-Flight Analysis

The airplane glided quite well during flight and it landed better on the ground compared to the first glider. This is due to the light weight of the airplane. The airplane experienced several minor crashes but the airplane still not broken. The team was quite surprised with the structural strength of the airplane especially the fuselage as after several damages, it has not broken even once.

However, the minor crashes have affected the wing setup. Using single spar, the wing tends to swing forward and it cannot hold the wing onto the fuselage. Double spar should be used in the next build up. Bamboo rather than plywood should be used as the spar because it is lighter and easier to shape. Bamboo has comparable tensile strength with plywood but it is more elastic. The paper use to wrap the wing was easily torn and cannot support high loading.

It is appointed by supervisor that epoxy is much heavier than white glue and this should be taken into consideration when doing the fuselage or wing fabrication. Obviously, the fuselage build up will need a lot of glue in order to stick the pieces. By using white glue in fabrication, it can handsomely reduce the overall weight of the plane. But, white glue needs more time to really sticking the pieces before the parts can be used. Moreover, treatment is needed to reduce the time for the white glue to settle down. One good advantage in using white glue is it is cheaper than epoxy.

Additional to the stapler, pebbles need to be used as ballast to balance up the airplane. The airplane was tail-heavy hence the initial COG was further aft. By putting additional pebbles at plane's nose, the COG was brought forward near under the wings. For further work, the COG of wing and fuselage must be found and locate the both parts where the COG coincides with each other. This will minimize the counter weight needed to balance up the airplane.

4.5.3 Third Airplane

4.5.3.1 Design and Build Up

The third glider was made as the final prototype model because there was no enough time to fabricate another prototype model. Hence, this final prototype was made to assemble as much as the final design although we were not able to do so. This build-up determines what can and what cannot be done in fabricating a practical airplane later on. Throughout these practices of build-up, problem faced can be tackled earlier and will not be repeated in the final design. Being familiar with fabrication method will help in reducing process time and the process can be done efficiently.

The configuration of the third airplane was very much different than the previous models. The most noticeable changes in the usage of biplane wing mode. Hence, the airplane has become biplane in configuration. By the use of biplane wing mode, the lift of generated will become doubled and it will make the plane easier to fly. From previous test-flight on models, it was concluded that single plane mode cannot produce much lift and insufficient compared to the loading. Rather than plywood, this time bamboo was used as spar and white paper used to wrap the wing.

Fine, covered foam was used to fabricate the fuselage to make it more attractive. The yellow colour of the foam cover makes the airplane look more appealing rather than having single white colour. One of the disadvantages of using covered foam was it is more expensive than common fine foam. The configuration of the fuselage has not much different compared to the second model. Major difference applied to the third model was the size where this model is longer, wider and taller. The size was amplified to a certain scale in order to compensate with the large wing build-up. The pictures below show the third model made by the team.

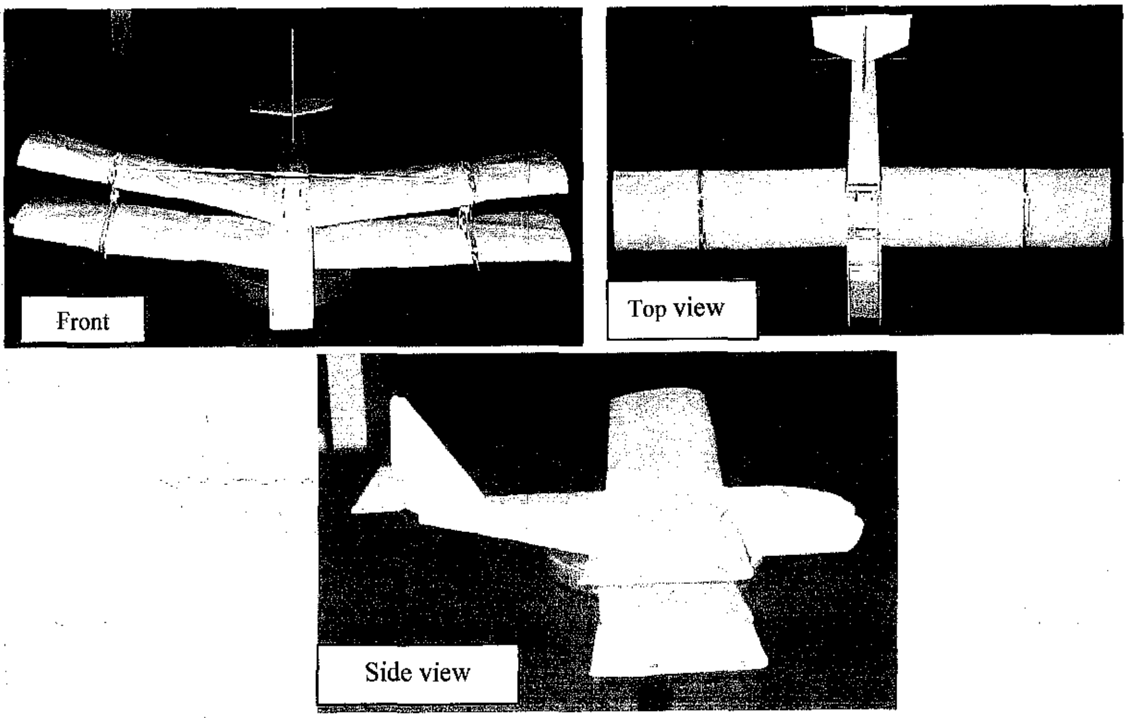


Figure 4.8: Pictures of third airplane model

From the design, the rear wing still needs to be enlarged to occupy the large size of the airplane. From the design alone, the airplane tends to be nose-heavy but it is compensated with the location of wing further aft compared to the second model. One big disadvantage of this model is it was too heavy. The bamboo stick used as spar for wing build-up was not cut to its minimal size hence adding to the weight. Usage of covered foam was actually not practical enough as it is heavier than common foam.

Other than being heavier, covered foam was also harder to shape using basic knife and hot-wire cutter. Covered foam is actually common foam glued to a hard cover that made it becomes hardened. It was noticed that other than being hardened, the hard cover makes it difficult to cut the foam using knife as the knife kept trapped at the cover. Therefore, it was decided to use the common fine foam in order to make wing and fuselage.

4.5.3.2 Test Flight & Analysis

The first attempt of test-flight showed that the airplane can glide smoothly. As components still being tested, the airplane was only made to glide. Because of the weight, the airplane needs to be launched at high speed so that it would not lose so much power. Amazingly, the airplane landed in vertical manner without any pitching hence protecting the wing structure. But after several flight attempts, the flying characteristics started to decline because of several factors.

Cotton string used to keep the dihedral configuration of the wing was too thick and this adds to weight a drag. Thread is a better option in tying the wings as it is thinner and generate less drag during flight. The discontinuity of wing build up was not covered by paper hence the bamboo used to hold the upper and lower wing was exposed to air. Having this discontinuity leads to more drag. Usage of stationery glue was not effective as epoxy hence the paper covering the wing tends to rip up. Although after fixing, the airplane cannot glide as good as before.

The fuselage was not joined well because of improper usage of epoxy. The ratio between resin and hardener was not accurately 1:1 hence it has problem to stick well. Usage of books or any hard material is needed to stick the pieces firmly during drying period. Other than books, tapes are needed to hold the pieces together in the early gluing stage.

4.6 Final Airplane

4.6.1 Fuselage Design

4.6.1.1 Design and Structure

The team has finally come to the final design stage of the complete airplane. This time, the airplane is to be built with the arrangement of electrical components. For the fuselage, only a little change was made to the final product. It was agreed by team member to follow previous basic design with some modification on the size and shape. The same fabrication method as in prototype 3 was followed in producing the final fuselage. The 3-dimensional drawing was done using CATIA software with the help of team member. Previously, during the 3rd prototype build-up, AutoCAD software was used to produce such drawing. Eventually, with the help of team member, CATIA software was used instead of AutoCAD as it has more advanced features in 3D product drawing and the advantage of drawing analysis built-in the software. Figure 4.9 shows the final design of the fuselage in 3D drawing.

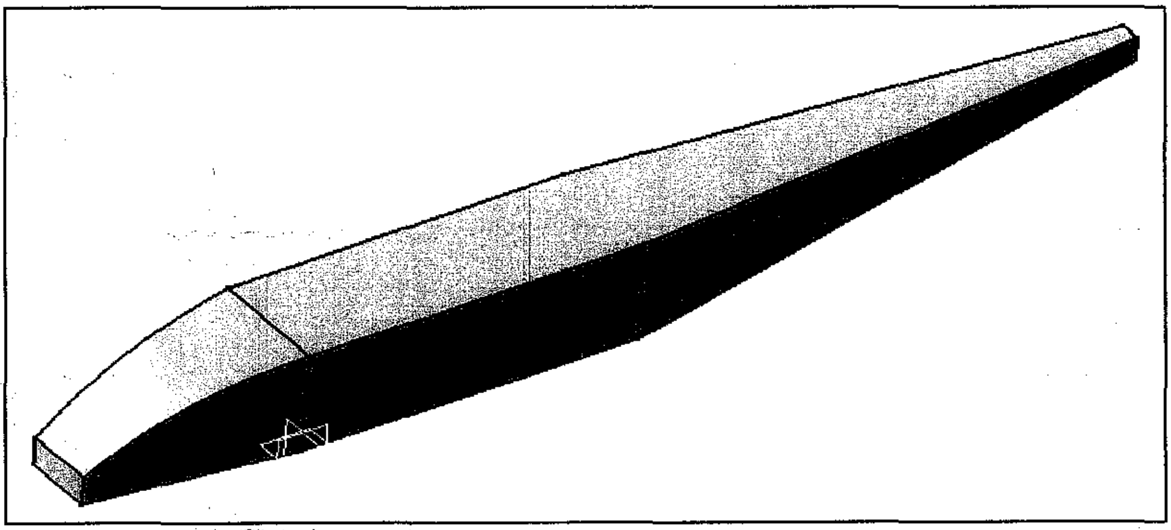


Figure 4.9: Final Design of Fuselage

Figure 4.10 below shows the inside structure of the fuselage.

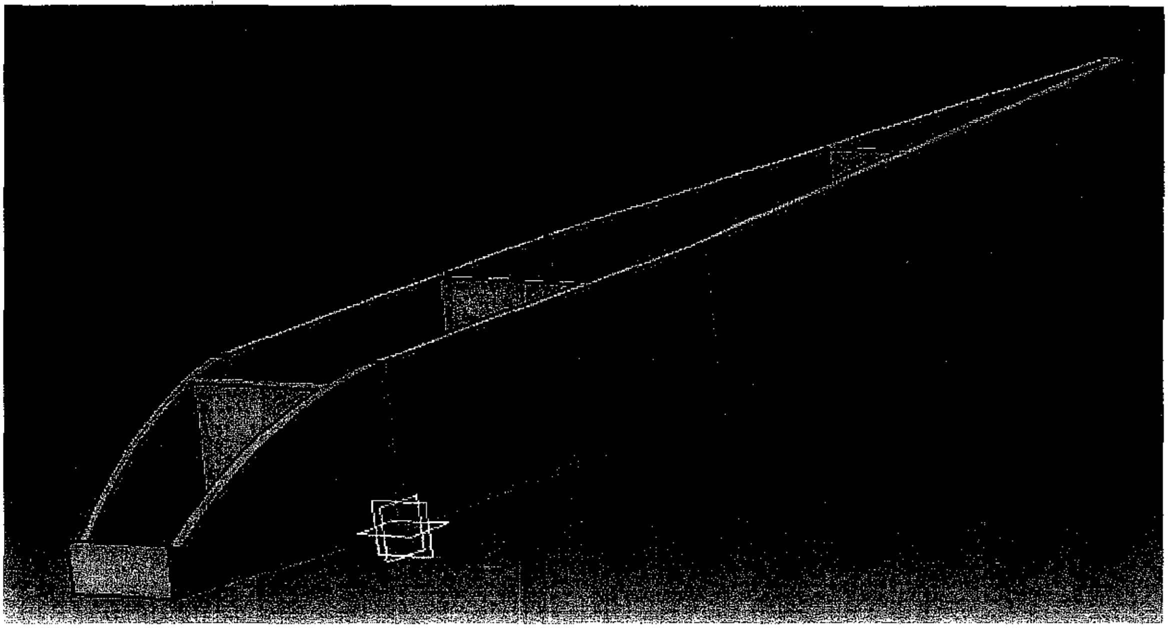


Figure 4.10: Inner structure of fuselage

Same as previous model, the design of final fuselage must be included with some inner material to strengthen the structure of the fuselage. In another word, the additional material acts as a structural reinforcement. This reinforcement is much needed to ensure that the fuselage product will not suddenly crash just after several flight attempts. The reinforcement material will act as divider of the fuselage so that it creates compartments in the fuselage itself. This compartment later will be useful in determining the location of components and wings attached onto the fuselage.

These additional materials for reinforcement will not affect much the overall weight of the fuselage because they are made from the same material which is considerably light. Some basic modifications were made to the final design compared to the previous prototype airplane. These modifications were made in order to reduce the weight and to incorporate electrical components onto the fuselage.

Figure 4.11 shows the basic dimension of the fuselage.

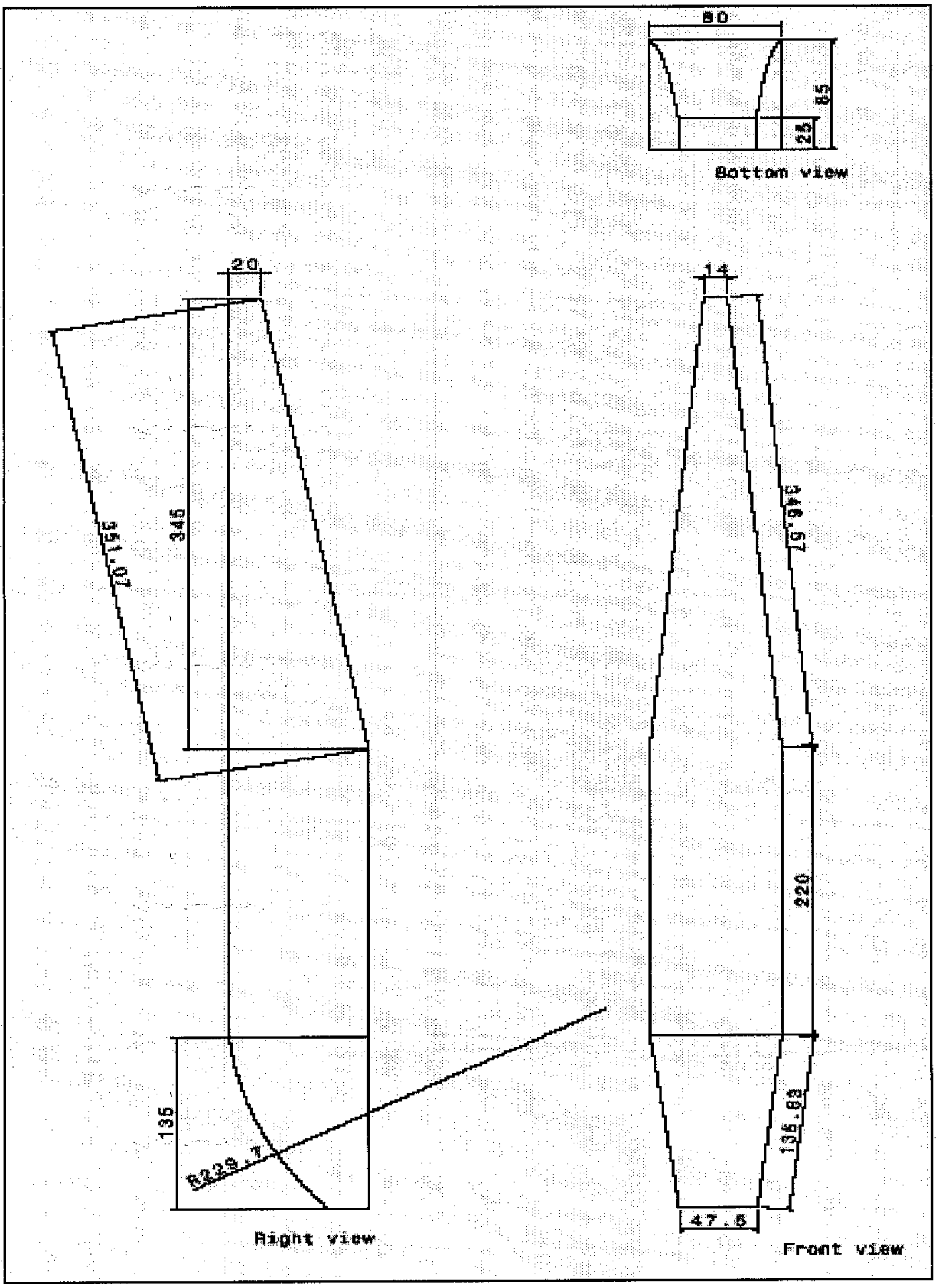
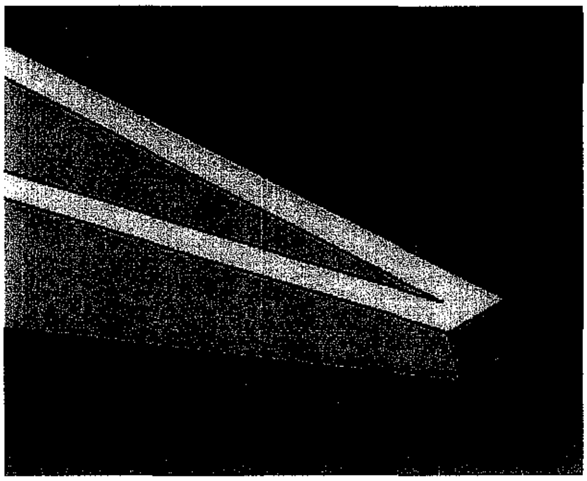


Figure 4.11: Basic dimension of fuselage

One of the basic modifications made to the design is to taper down the frontal-side and tail-side of the fuselage. Figures below shows the changes made to the final product compared to the 3rd prototype at the tail-side.



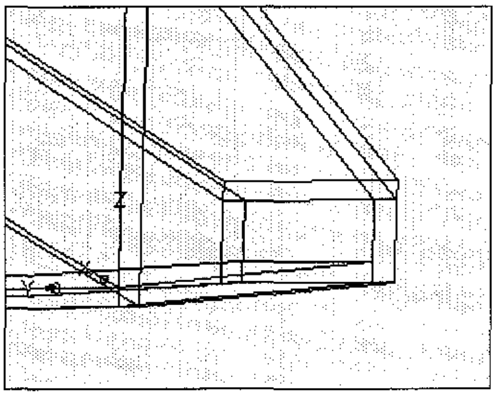


Figure 4.12: Tail-side end tapering

For the final fuselage, the side was tapered down at the tail-side until both sides meet each other. In order to joined both sides, tape needs to be used other than epoxy because the surface area of contact was not much. Using epoxy alone will not help to keep the tail-side intact. The width of tail-side of the final product is only double of the material thickness, about 1.2 cm. For the 3rd prototype, the width of tail-side was about 3.2 cm.

The same situation can also be viewed at the frontal-side of the fuselage. Figure 4.13 below shows the changes made to the final product at the frontal-side.

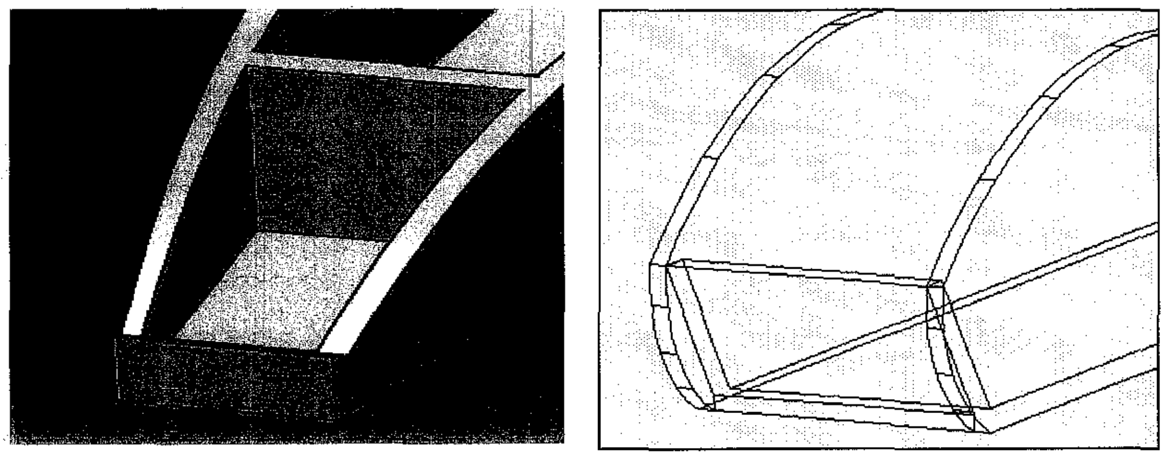


Figure 4.13: Front side tapering

For the final product, the front-side was tapered down until the distance between sides is 2cm whereas for the 3rd prototype, the front-side was not tapered down at all. The tapering practice would reduce the weight of the fuselage at both front and tail side. For the tail-side, tapering down will help in reducing the drag during flight. That is another reason of the practice.

Another modification made to the design is to give some allowance for the electrical components' wiring and harness. Figure below shows the modification made to the structure in order to compensate for wiring.

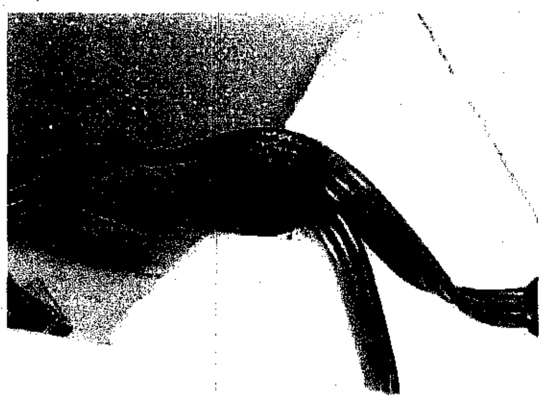


Figure 4.14: Modification for wiring

4.6.1.2 Material Selection

Same as previous prototype build-up, it is decided to use fine foam available at market and hardware shop. The advantage of foam is it is light in weight and easy to work with. Most foam can be cut with ordinary knives or hot wire cutter. Fine foam has good compressive strength hence it is considered strong enough to hold the mass of electrical components.

In building the fuselage, one major aspect should be looked into is the weight of it. The lower the weight of the fuselage, the higher weight can be allocated for other components that make to the total weight of the airplane. Therefore, the usage of fine foam helped much in reducing the fuselage's weight. Another consideration is the cost of the material because the project was only allocated with small amount of money. The ratio of foam's cost compared to the total cost is about 0.09. Hence, foam can be used as much as possible without having to worry much on the cost.

In order to fasten the pieces of foam together, it was decided to use crystal clear epoxy. The mixing ratio between the resins to hardener is 1:1. The curing time allocated for the epoxy to be hardened is 8 hours. Although the fuselage was ready to be used after 5 hours curing time, the additional 3 hours allocation is to ensure that the parts really joint together. Although using white glue will be much cheaper, it takes longer time to be cured. Epoxy is better in handling high load shear stress compared to white glue.

White tapes are also useful in tying the pieces of foam before the epoxy completely hardened. The tapes were then removed after the curing time has completed. Other than tying the foam pieces, white tapes are also used to attach the electrical components onto the fuselage. Black tape is used instead of white tape to hold the motor because of its weight and vibration effect. The camera was protected with sponge that can absorb the vibration produced by the motor. This is to ensure the pictures taken from the camera will not be shaky or blurred.

4.6.1.3 Structural Analysis on the Fuselage

One of the added advantages of using CATIA software in producing the 3D drawings is that it has built-in features of structural analysis. For the fuselage design, 2 types of loading impact that might happen to the fuselage were analyzed; the vertical landing impact and the frontal landing impact.

For the vertical landing impact, the load applied on to the fuselage was 6.5 Newton, or approximately 670 grams. The clamp was located at the bottom tail-side, as shown in Figure 4.15. The same figure shows the loading and deformation experienced by the fuselage in the analysis. Loading is shown by the yellow arrows.

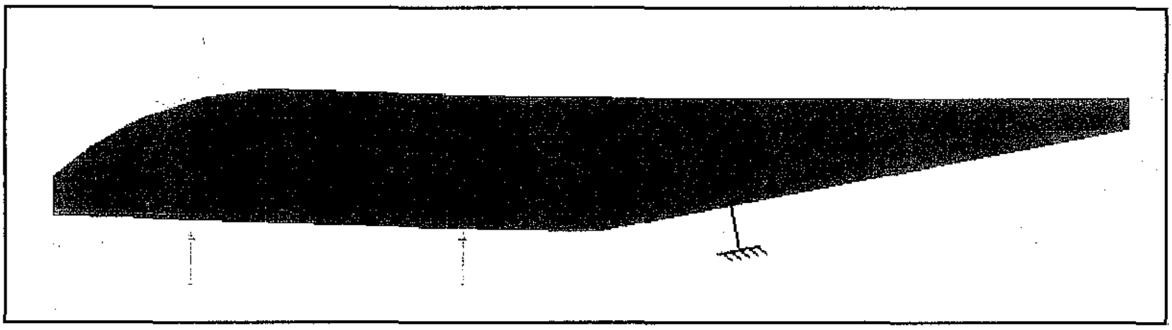


Figure 4.15: Deformation of fuselage in vertical landing impact

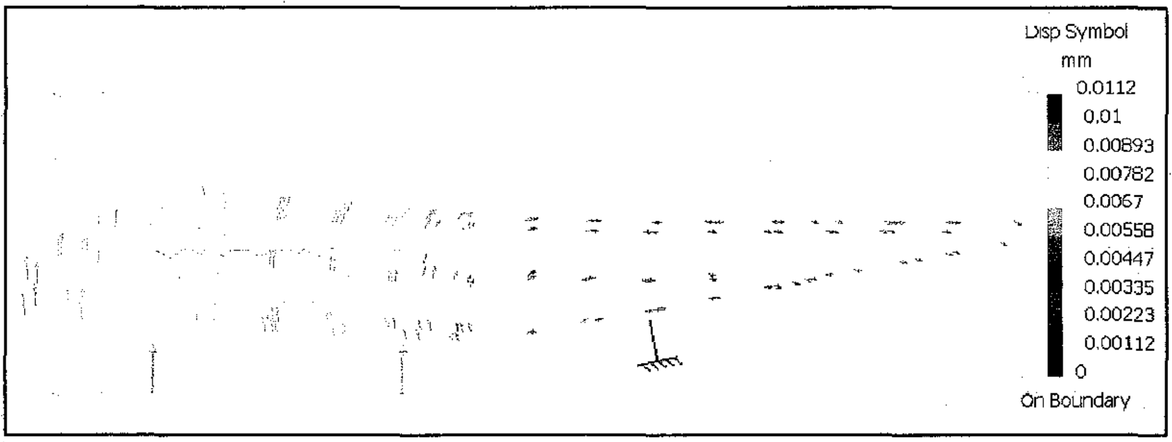


Figure 4.16: Deformation data in vertical landing impact

Figure 4.16 above shows the deformation data of the fuselage under vertical landing impact. The maximum deformation is 0.0112mm, occurring at the tip of the fuselage's nose. The highest deformation is indicated by the red arrows. The deformation becomes less further to the middle point of the fuselage. This data indicates that if the fuselage experienced vertical landing, it can withstand the weight of the airplane. The deformation is so small that it has no real affect on the fuselage structure.

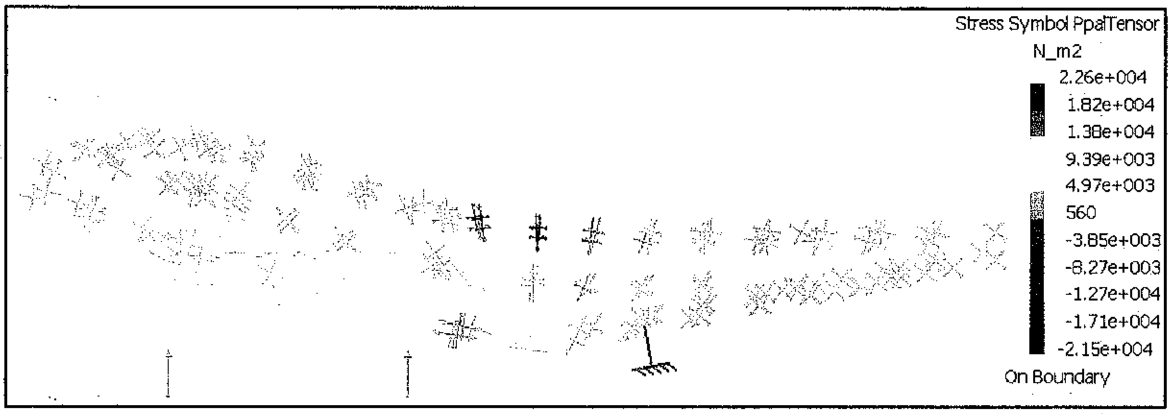
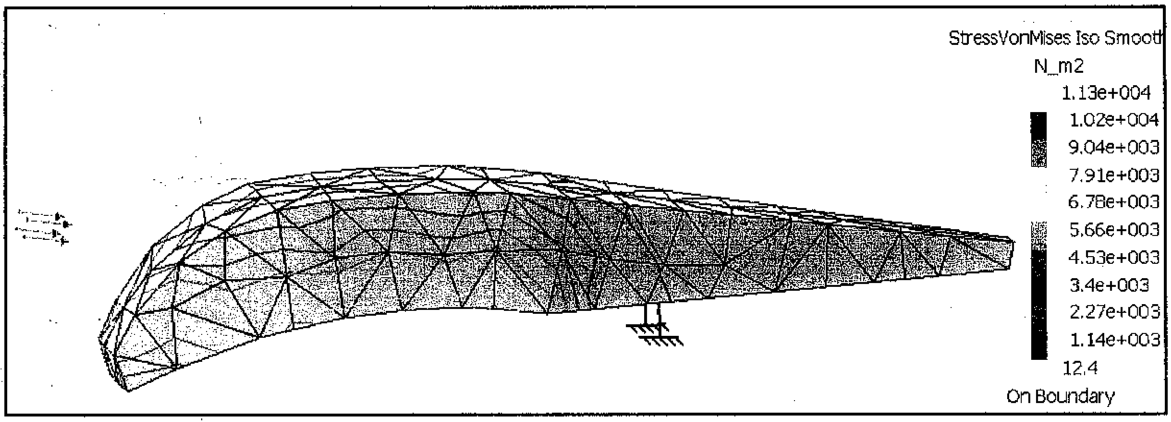


Figure 4.17: Stress analysis in vertical landing impact

Figure 4.17 above shows the stress distribution data throughout the fuselage under vertical landing impact. The highest stress is 2.26 x 10^4 Nm^2, experienced at the bottom of the fuselage near to the bottom tail-side. The location of the highest stress is indicated by red crosses. This data suggested that reinforcement is needed to connect the bottom part with the bottom tail-side in incident of vertical crash.

For the frontal landing impact, the consideration was made if the plane crashed while diving. The load applied onto the nose of the fuselage was 10N, approximately 1kg. Although the plane's weight is about 670g, higher impact can be attained during crash depending on the height of the airplane when it flies. Hence, 10N here can be considered at the impact when the plane dove at certain height. Below are the pictures showing the deformation and stress distribution data.



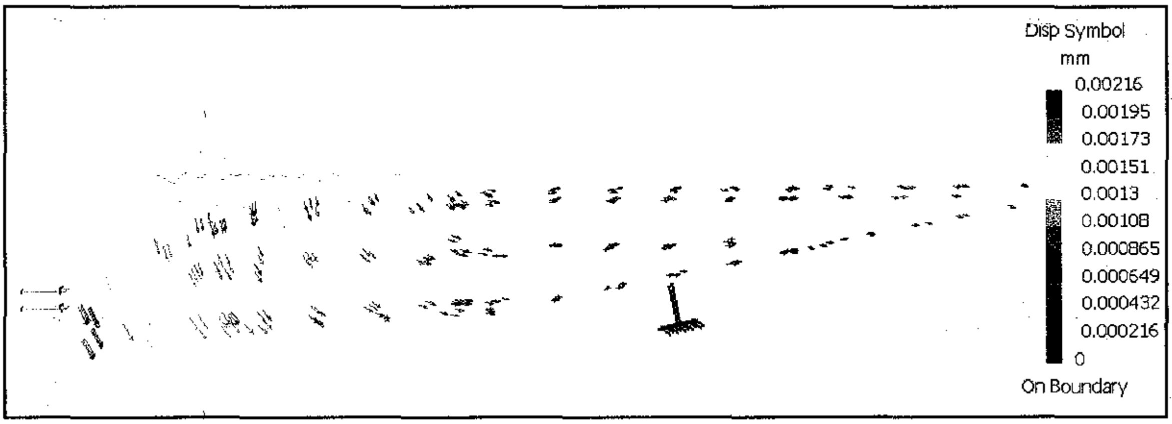


Figure 4.18: Deformation and stress analysis data in frontal landing impact

Highest deformation occurred at the nose of the fuselage with 0.02mm deformation. Highest stress also occurred at the nose with maximum value of 1.13 x 10^4 Nm^2. The maximum deformation was not high indicating that under 10N loading crash, the fuselage will not experience total crash. Minor chips might happen under this loading but such incident should be avoided because the higher the airplane flies, the higher impact it will experience if such crash occurred.

4.6.2 Final Airplane

4.6.2.1 Specifications

Specifications below were agreed for the final airplane design.

Wing span = 120 cm = 47.24 in

Chord = 21 cm = 8.27 in

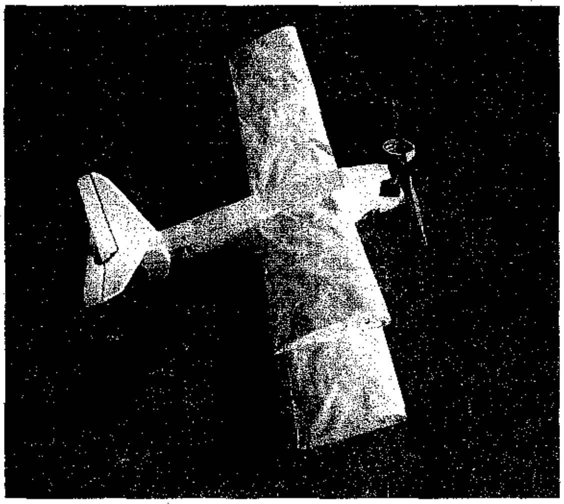
Aspect ratio = 120/21 = 5.714

Wing area = 0.504 m^2 (biplane) =781.35 in^2 = 5.426 sq-ft

Weight = 650g = 22.93 ounces ->excluding camera

Wing loading = 22.93 / 5.426 sq ft = 4.23 oz/ sq ft

The final airplane is still heavier than the target total weight which is 500g. From calculation earlier, the part contributes much to the weight is the wing. Although the bamboo used for wing structure was made thinner, it is still not enough to reduce the weight of the wing. The pictures below show the final design of the airplane.



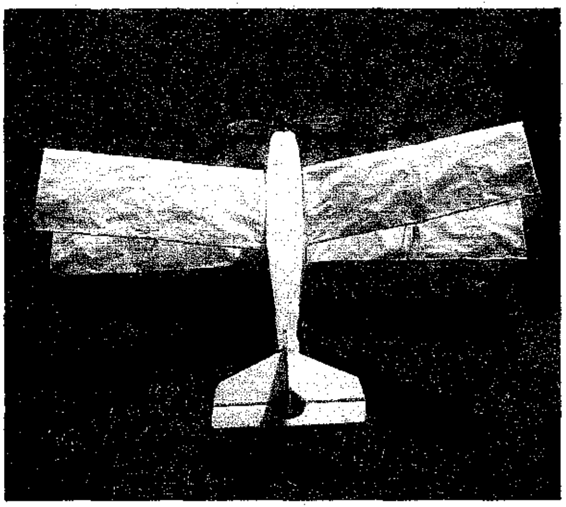


Figure 4.19: Final design of airplane

4.6.2.2 Wing

Biplane configuration wing is used for the final airplane. Some modifications were made to the wing such as making the upper wing dihedral to increase the stability of the airplane during flight. Using biplane configuration, the amount of lift generated during flight will be doubled. The wings were fabricated using spars and ribs method, the same as previous practice in building 2nd and 3rd prototype. Bamboo was used as the spars that connect the ribs, which is made from fine foam. Both are chosen due to their light weight and durability. White paper is used to wrap the ribs along the spars and glued using white glue.

4.6.2.3 Rear Wing and Tail

Team member has taken the responsibility to produce the rear tail using Bantam flyer and Fatty sparrow design. To simplify the fabrication process, elevators on both rear wing and tail was extended from the fuselage.

4.6.2.4 Undercarriage

Landing gear was made using landing tires and interconnecting wire gauges. Rear slider was made using foam. Both were installed to protect the plane during landing. Because the airplane was launched during flight, adding a wheel on the rear slider was not necessary. It is only needed when the airplane is made to take-off from ground. Without the slider, the tail might be broken and without the landing gear, the propeller will be smashed into pieces.

4.6.2.5 Electrical Components

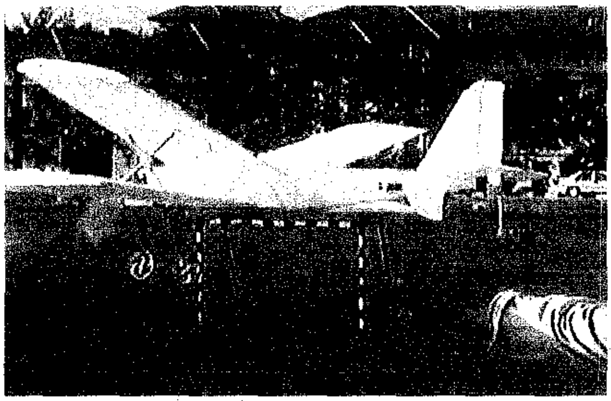
Selection and testing of electrical components was the responsibility of Electrical Engineering student, Mr. Nurizwan. Decision on suitable components was made according to the budget and plane specifications. Specifications on the components were already available from the supplier and using this information, the components were bought on-shelf.

4.6.3 Test –Flight Analysis

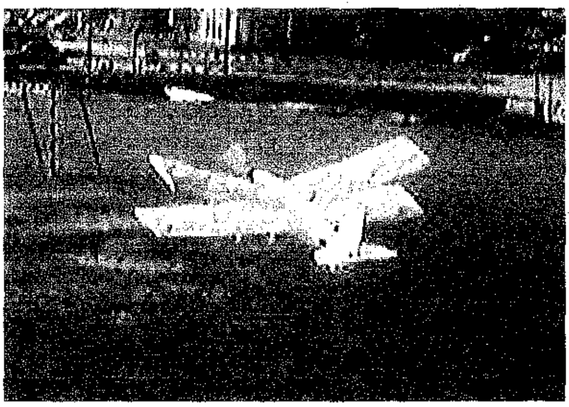
The timing for the test-flight was done on morning, under low-wind condition. Unfortunately, the airplane was unable to fly. It could only glides down until landing. The airplane crashed twice. The first crash was caused by wind gush that made the airplane unstable and not be able to pull up until it crashed. Second crash was caused by dislocation of the battery that changed the balance point of the airplane.

There are 2 possibilities that made the airplane failed to fly and eventually crashed. The first possibility is that the propulsion power generated by the propeller cannot withstand weight over 500g. The weight of the airplane is about 650g, 150g more than the specified weight. The motor has become underpowered and not able to provide enough power to generate sufficient lift for the airplane to fly.

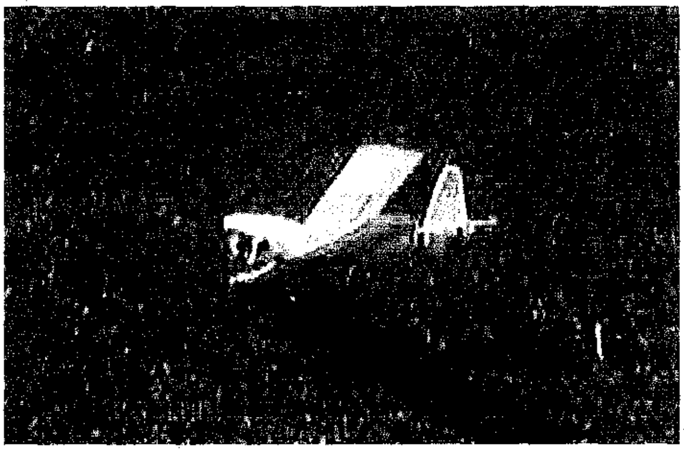
The second possibility is that the wing design was made with small angle of attack. The airplane acted as if it was tail heavy. Changes made to the balance point could not help in flying the plane. As the tail was hanging down, it creates drag and more power is needed to overcome this effect. Pictures below show the events of (i) launching, (ii) airplane gliding and (iii) crash.



(i)



(ii)



(iii)

Figure 4.20: Events of test-flight

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From the test flight, it is obvious that this project did not manage to achieve the intended end result. After all, the fabrication of fuselage and the wing was practiced and applied in order for the plane to fly. Because the complete airplane could not fly, it is unfortunate that the final goal was not accomplished. However, the project team managed to work together and able to decide on the final product specification. Given the time constraint and tight budget, the team managed to produced a complete airplane within the budget although the airplane did not function as desired by the team.

The team member managed to achieve other objectives intended for this project such as working with cross-functional department personnel, learning the basic design and fabrication process in producing an airplane and gaining knowledge in aerodynamics matters. Moreover, the supervisor has specified that for this project, it is not a must for the airplane to fly. Only that if the airplane can actually flies, it will be a value added to the team and the team will be much respected.

Individually, several fuselages were able to be built using the most basic tool and limited knowledge. Actually much can be improved and much can be done to produce a better product but because of lack of knowledge and skills, the project heavily depends on supervisor's guidance in completing the project. As in the problem statement, the project has completed with the design and fabrication of a fuselage for remote controlled electric powered airborne imagery platform.

It is looked forward to to see a better airplane produced by the next batch of final year student who will be taking final year project. There is still a lot of room for engineering approach and analysis for this project. Hopefully, the continuation of this project will enhanced the status of University Technology of Petronas as one of the best engineering institution.

5.2 Recommendations

To improve the project output, several recommendations are made and to be considered for the next practices by other project team.

1. Usage of advanced engineering tools and software in determining the best fuselage design for the airplane. Engineering software might include ANSYS and StarCD for the analysis works. Other than commercial software, the team member might want to use airplane simulation program to justify the design. Additional tools that should be considered in the project approach are like manufacturing machines and laboratory equipments. Automatic manufacturing machine like Mazak can be used to make the product exactly according to the drawing under the supervision of technician. Laboratory practices should be conducted to determine the properties of material used in the project.

2. The team should be more familiar with fabrication practices. For this, it is better to get a project member who is already experienced in doing airplane fabrication. A good product comes from the capability of the producer. Having one team member who knows overall on airplane fabrication will be an advantage to the team because he can act as the leader and gives guidance to other members. Moreover, the project lead time will be less in term of data finding and material selection and the fabrication can be started during the first semester.

3. Guidance from expert and experienced personnel will help the project team to come up with a functional airplane. Depending solely on own findings is not very

practical as there is more than just theory in designing and fabricating a fuselage. Expert can help in theory and mathematical analysis of the airplane while the experienced can help in fabricating the product using the most common, practicable and cheap method.

4. The team members must work together in doing the project and update with each other personal assigned works. This will help the team members to comprehend others' scope of work hence having better understanding of the complete airplane. Rather than focusing on individual scope, the team members should look into the matter as a whole because sometimes, ideas from team member can be used to improve the project output.

CHAPTER 6

REFERENCES

Book Literature

1. David Thurston," *Design For Flying, Second Edition*", McGraw Hill,1994
2. Darrol Stinton," *The Design of the Aeroplane*". Blackwell Science Ltd, 1997
3. Darrol Stinton," *The Anatomy of the Aeroplane, Second Edition*", Blackwell Science Ltd,1998
4. Ronald J. Wanttaja, " *Kitplane Construction Second Edition*", McGraw Hill,1996

Internet Websites

5. http://www.rcgroups.com/

   A web-based group forum for aircraft enthusiasts who want to know more details about aircrafts in theory and its practical construction.

6. http://www.ezonemag.com/

   A good starting page for beginners in the world of air crafting. Learners and guest can browse through various sites for different level of beginners, amateurs and experts and links to other helpful websites are provided

7. http://www.energoterom.ro/energoterom/services.html

   A website that give a table on foam properties

8. *http://www.aerospaceweb.org/question/cog*

   Basic guidelines to calculate center of gravity

9. *http://www.uoguelph.ca/~antoon/hobby/pmdesign.htm*

   Rules of thumb in designing remote controlled airplane.

APPENDIX : LAB REPORT

1. Objective

To determine the density of foam used to build the airplane fuselage

2. Procedures

A. Determining volume of pieces of foam

1. The foam was cut to 3 near rectangle shapes namely 3.0, 2.5 and 2.0. Names were given after the length of each rectangle. Each rectangle has the same thickness.
2. A measuring cylinder with 0.2ml scale (smallest) was poured with distilled water and a thin wire was soaked into it to a certain length. Any changes in volume were detected.
3. Foam 3.0 was soaked into the distilled water using the thin wire. Any changes in volume were detected.
4. Procedure 3 was repeated for other pieces of foam.

B. Determining the weight of pieces of foam

1. Foam used in Procedures A was let dry.
2. Foam 3.0 was put onto a precision weight scale and the weight of the foam was measured.
3. Procedure 2 was repeated for other pieces of foam.

3. Results

Table 3.1: Volume Reading for Foam 3.0

Readings	Initial (ml)	Measured (ml)	Difference(ml)
1	6.6	8.2	1.6
2	8.0	8.7	1.7
3	6.8	7.2	1.7

Average Volume for Foam 3.0 = 1.67 ml

Table 3.2: Volume Reading for Foam 2.5

Readings	Initial (ml)	Measured (ml)	Difference(ml)
1	6.8	8.05	1.25
2	3.6	4.80	1.20
3	4.6	5.85	1.25

Average Volume for Foam 2.5 = 1.23 ml

Table 3.3: Volume Reading for Foam 2.0

Readings	Initial (ml)	Measured (ml)	Difference(ml)
1	4.6	5.3	0.7
2	5.2	5.9	0.7
3	8.1	8.8	0.7

Average Volume for Foam 2.0 = 0.70 ml

Volume of the portion of thin wire was undetermined. It is assumed the volume of the thin wire was 0.

Table 3.4: Weight Reading for Foam

	1(g)	2(g)	3(g)	Average(g)
3.0	0.0811	0.0811	0.0813	0.0812
2.5	0.0637	0.0640	0.0639	0.0639

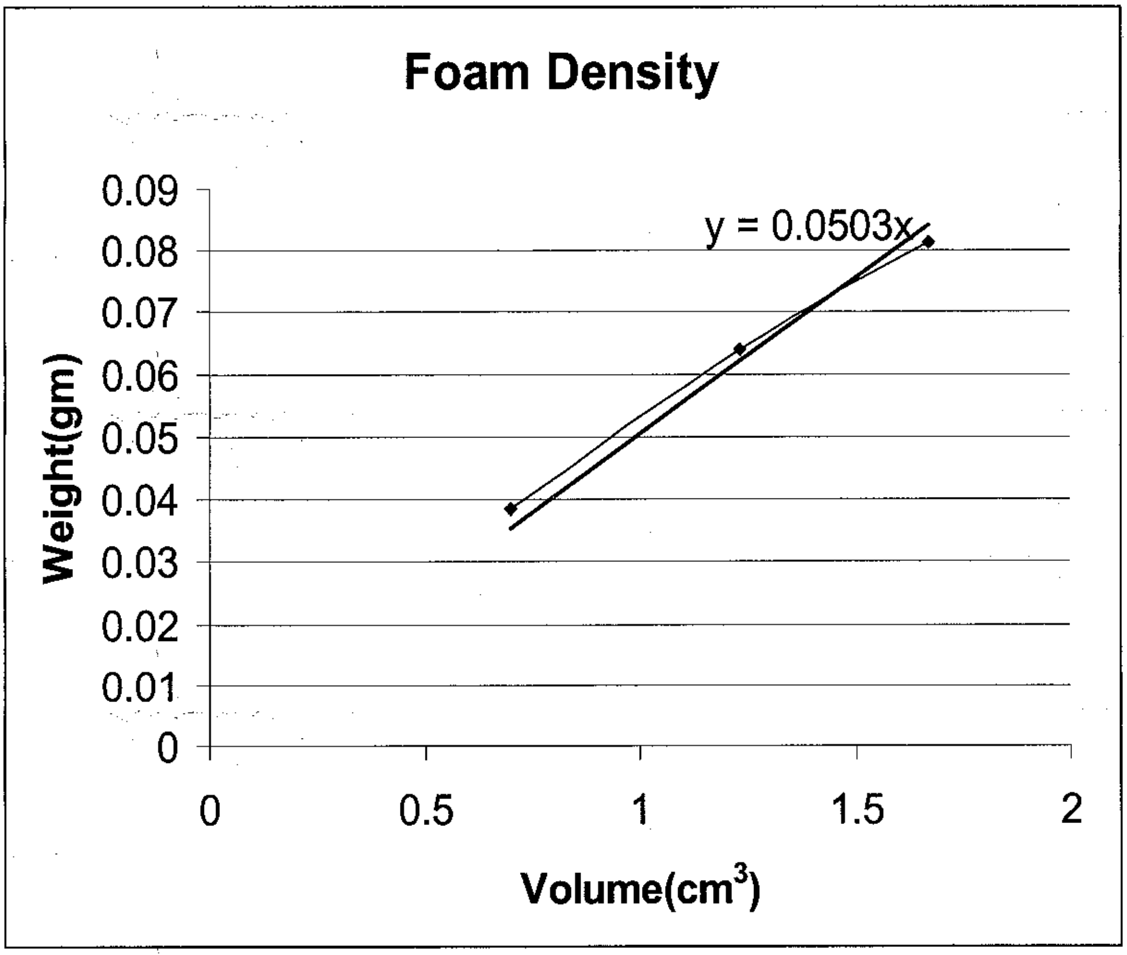
2.0	0.0383	0.0387	0.0385	0.0385

Sample Calculation to Determine Density of Foam

Density = weight/volume

= 0.0812/1.67 = 0.0486 gm/ml

	Foam 3.0	Foam 2.5	Foam 2.0
Density	0.0486	0.0519	0.0550



4. Comments

The weight of each foam was measured in dry condition, without any air influence. The reason to wait until the foams dried up was their weight continues to decline as the water evaporated. Inconsistent reading for the earlier weight of the foams was cancelled out.

It is safe to assume that the average density of the foam is about 0.0503 g/cm^3. Firstly, the reading of volume and weight does not compatible as the weight was precise to 5 digit numbers while the volume was only precise to 3 digit numbers. The density for each pieces of foam will not vary much if their weights were only taken up until 3 digit numbers. Using linear regression, the density of the foam is 0.0503 g/cm^3.*The theoretical value of polyurethane foam is 61kg/m^3 or 0.061g/cm^3. (Ref: http://www.energoterom.ro/energoterom/services.html). Thus,

$$\text{Percentage error} = (0.061 - 0.0503)/0.061\ \% = 17\%$$

From the reference site, the value of polyurethane foam density was determined by conducting STAS 9209-73 testing method. The testing was not done based on any standard method thus the result might differ a little bit. Furthermore, the material of foam being used in the test might differ from the foam bought by author from the store. Different inherent process to produce the foam might contribute to the percentage error in determining the foam's density.