CERIFICATION OF APPROVAL

Design and fabrication of a Wing for a Remote-Controlled Electric Powered Airborne Imagery Platform

by

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Approved by,

(Mr. Rahmat Iskandar)

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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.

SYAHRILUZWAN B HJ SULAIMAN

ABSTRACT

This documentation basically explains in detail about the project's planning, progress and achievement throughout the two semesters project duration. The report began with introductory and background information of the project. This section generally explains what the project is all about. The general objective is to gain experience in handling engineering projects from the start to the end. After that, the scope of study involved was laid down to summarize what aspects of the project would be tackled. Engineering projects in the real world involves numerous engineers from different fields, each handling different parts of the project. This project was divided into 3 parts. The one in context of this report is to design and fabricate a wing for a remote controlled electric-powered airborne imagery platform. Hence, corresponding with this topic, the scope of study is mainly the aerodynamics of the wing, the fabrication process and the structural strength of the wings. The wing should be able to generate enough lift for the aircraft to fly, and at the same time being light and robust enough to support the aircraft during flight and landings. The report then continued with the literature review done on the project. In this section, various related information extracted from articles was included and elaborated. The next section is the methodology section of the project. This section explains the planning involved for this project, which includes process flows for both semesters, tools used, and the detailed Gantt chart which shows the exact time-planning of the project. Then, in the results and discussion section, important findings and results of project activities was discussed and analyzed. Decisions and choices that were made was discussed and analyzed to show that they are verified. Finally the report was ended by the conclusion of the project and recommendations for future continuation of this project and also for the UTP future final students as a whole.

ACKNOWLEDGEMENT

Alhamdulillah, in the name of Allah, The Most Gracious, The Most Merciful. First and foremost, I thank Allah, as with His blessings I was able to complete my final year project.

I would like to take this opportunity to express my greatest appreciation to my supervisor, Mr. Rahmat Iskandar for his patience in providing guidance and advice for the team to complete the project smoothly throughout the two semester duration.

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To my beloved parents, thank you for your full support and advice that have kept me straight and on the right track, keeping me going when the going gets tough. My special thanks to my beloved fiancée, Marliana Ismaon for her endless support and patience throughout the project period. Also to all my colleagues, thank you for your support and cooperation.

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CHAPTER 1
INTRODUCTION

1.1 Background

Basically, this project as a whole is a combination of several projects, which their final and general objective is to create a remote controlled, unmanned aircraft that carries an operable imaging device. The project generally consists of 2 separate main divisions; the mechanical side and electrical/electronics side. The mechanical side handles different physical aspects of the airplane; the wing, fuselage and propeller. On the other hand, the electrical and electronics division would be responsible with all the electrical and electronics involved in the project, including servos, battery, wiring, transmitters and receivers, (EPC) Electronic Power Control units, and the engine (DC motor).

The mechanical side consists of 4 students, and each was assigned the responsibility of designing and fabricating different aspects of the aircraft; fuselage, wing and propeller. The electric and electronics side on the other hand would only be handled by one student. Thus, his scope would not cover all the electronics side of the project. Some of the components or system would just be picked out from the market.

The supervisor, Mr. Rahmat Iskandar had stressed to the team members that it is not compulsory for the final product to be able to actually fly. Instead, the team members need to provide sufficient engineering proof through calculations and trustworthy resources, that the design should work and satisfy the projects objectives. However, if the aircraft can fly, the feat would be a great bonus to the team and would be a really great achievement.

1.2 Problem Statement

The problem statement given as the project title was:-

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

The most important part of an airplane is its wings. An airplane can fly even without the propulsion given that the wing design is 'spot on' and also with the right weather conditions. Such aircrafts are called gliders. There's even designs of airplanes that looks as if it consists of only wings, which shows evidence that the wings is the most important aspect of an aircraft. However, other sections of the aircraft should not be undermined as they can greatly affect the capabilities of the aircraft, and may critically determine the successfulness of the project.

The final product of the project could be used for various applications in the real world. One of the most suitable applications is that it could be used by the military as an espionage craft over enemy territories. To cater to this purpose, the aircraft design could be improved to produce less motor noise, and can be dismantled and carried in backpacks by the soldiers to be assembled when needed. Furthermore, the aircraft should also be able to be painted on so that camouflaging is possible.

Besides that, the aircraft could also be used by local authorities such as police and rescue teams to assist them in doing their duties. These planes could be deployed straight away at the scene of an incident before any other backups arrive, such as choppers, etc. In very dangerous conditions, the aircraft could be an alternative that would reduce unnecessary fatality risks.

The successfulness of this project will enhance the university's name as a prestigious engineering institute in Malaysia. In return, the university would gain the respect of the population and be acknowledged as a very capable academic institution.

1.3 Objectives

The objectives of the project have been lined up as: -

- to gain experience handling an engineering project from the start to the end

- to design the wing segment of the remote controlled imagery airplane

- to fabricate the wing of the remote controlled imagery airplane

- to insert the engineering in unmanned aircraft designing, instead of just using experience to design the aircraft

- to be able to work together in a group and ensure that everything done by each members are synchronized with each other

- the finished fabricated and assembled airplane preferably should be able to fly

1.4 Scope of Study

Basically, the scope of this project is limited to only the wing of the airplane. This means that this project will be concentrated mostly on the aerodynamics of the airplane. It would be most important to ensure that the wing design would be able to provide enough lift and also provide good control characteristics to the airplane.

In the first semester of the final year, the main goal of the project team is to finally agree with a final configuration of the plane. The layout should be so that it complies with the target characteristics of the aircraft, which should be able to fly stably at low speed. It is not as simple as it may sound. There are many characteristics that have to be determined to best suite the problem. Among other things, they are: -

1.4.1 Amount of Load that the Aircraft has to carry

It is very important to know exactly how much load the aircraft has to carry. Thus the weight of the camera, electric components and the aircraft itself needs to be determined. With the total load been determined, the team can determine how much force and lift would be needed to fly the aircraft. From here, the team must ensure that the motor, propeller and wing configuration used can generate enough force and lift to fly the aircraft.

1.4.2 Speed Range of Aircraft

The speed range of the aircraft should also be determined. This is to ensure that with the wing configuration chosen, the wing can effectively generate enough lift at the speed range determined. A wing configuration that is suitable for high-speed application creates less lift and less drag, which will not fly well at low speed. For a low speed wing configuration, the wing generates a lot of lift but also gives a high amount of drag, which in turn is not suitable for high speed flying. Furthermore, the amount of surface area of the wing also contributes to the lift generated by the particular wing. With all other aspects being equal, more wing surface area would mean more lift, and vice versa.

1.4.3 Material Used to Make Aircraft

The material aspect of the project is also very important. In selecting the right material, there are a few characteristics that need to be looked into, which are: -

- *Method of fabrication*
- *Cost and availability*
- *Weight*
- *Durability*
- *Ease of maintenance*

One more important aspect is the reinforcements that would be needed on the final product. The team should find methods of how to help strengthen the structure of the aircraft. The team should figure out what kinds of materials are suitable, with the primary concern being its strength and ultimately its weight.

1.4.4 Financial Limitations

The actual budget for this project is only about RM1500. This is due to the 3 student team members who were entitled to RM500 each for the Final Year Project. This is quite a low budget for this project. However, the supervisors, particularly Mr. Rahmat has many associates and close friend which are involved in this RC aircraft sport. Thus, he would try to get sponsorships and support from suppliers or at least maybe help the team to get components at cheaper prices compared to the real market value.

Then, in the final semester, the team concentrated on actually coming up with the final integrated design of each section of the airplane. The designs chosen should be proven to be effective in achieving the objectives of the project. Hence, they should be supported and verified by sufficient engineering analysis and proof. In the final part, the body parts would be fabricated (they may be made by professionals, but following the team's design) and the electrical/electronics components would be bought off the shelf. All of these items would then be assembled together and tested for flight ability.

CHAPTER 2
LITERATURE REVIEW

2.1 Lift and Drag

2.1.1 Bernoulli's Principle and Lift

(refer to Reference 7)

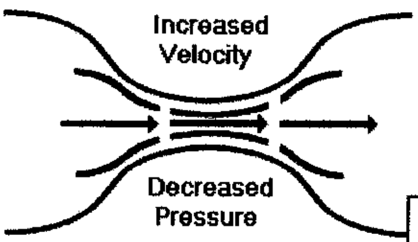


Figure 2.1

To understand how lift is produced, we must examine a phenomenon discovered many years ago by the scientist Bernoulli and later called Bernoulli's Principle: The pressure of a fluid (liquid or gas) decreases at points where the speed of the fluid increases. In other words, Bernoulli found that within the same fluid, in this case air, high speed flow is associated with low pressure, and low speed flow with high pressure. This principle was first used to explain changes in the pressure of fluid flowing within a pipe whose cross-sectional area varied. In the wide section of the gradually narrowing pipe, the fluid moves at low speed, producing high pressure. As the pipe narrows it must contain the same amount of fluid. In this narrow section, the fluid moves at high speed, producing low pressure.

An important application of this phenomenon is made in giving lift to the wing of an airplane, an airfoil. The airfoil is designed to increase the velocity of the airflow above its surface, thereby decreasing pressure above the airfoil. Simultaneously, the relatively lower air velocity on the lower surface of the airfoil increases the pressure below. This combination of pressure decrease above and increase below produces lift.

Probably you have held your flattened hand out of the window of a moving automobile. As you inclined your hand to the wind, the force of air pushed against it forcing your hand to rise. The airfoil (in this case, your hand) was deflecting the wind which, in turn, created an equal and opposite dynamic pressure on the lower surface of the airfoil, forcing it up and back. The upward component of this force is lift; the backward component is drag.

Figure 2.2

Pressure reduction is due to the smaller space the air has above the wing than below. The airflow splits at the leading edge. The above-wing airflow deflects the most. The small space the above-wing surface airflow has to pass through is because of the outer layers of air (above-wing) pushes down on the surface (due to the deflection), thus leaving only small space for the surface air to pass. The surface air molecules push between the wing and outer layers of air. Due to the smaller space the airflow has to go through, as in figure 2.1, the airflow will increase speed. According to Bernoulli's Law, faster air has lower air pressure, and thus the high pressure beneath the wing pushes up to cause lift.

(Refer to Reference 8 for the section below)

The lift and the drag formulas for a wing offer a valuable tool for analyzing aerodynamic relationships.

$$\boxed{L = \tfrac{1}{2}\rho V^2 S C_L \qquad D = \tfrac{1}{2}\rho V^2 S C_D}$$

where:-

L = Lift   D = Drag ρ = Air density   V = Velocity

S = Wing area*   CL = Lift coefficient   CD = Drag coefficient

It should be noted that the wing area (S) and the air density (ρ) are constant for any given altitude while both CL/ CD and the velocity (V }are variables. The area of a wing is the product of the wing span and the Mean Aerodynamic Chord (MAC). The mean aerodynamic chord is an imaginary chord line that is derived from the length of the chord line at various locations of the wing. The air velocity is a major contributor to lift and drag because both are proportional to square of the velocity. From the lift and drag formulas, it follows that the velocity and the angle of attack (represented by either CL or CD) are inversely proportional. For example, an increase in the angle of attack at constant power will decrease the speed. Conversely, high speed at constant power will require lower angle of attack.

2.1.2 Drag

i) Parasite Drag

The drag on the airfoil is only a part of the total drag of an airplane. Reducing drag is essential for flight efficiency. The total drags on an airplane consist of all the drag contributing elements. It is customary to refer to drag caused by the airplane parts which are not lift producers as *Parasite Drag*. To minimize the parasite drag it is desired to design in airfoil shape all aircraft parts such as struts, wheel fairing, etc. The two major contributors to parasite drag are the *form drag* and the *skin-friction drag*. The shape or form of objects being exposed to airflow determines the magnitude of drag. The flow around round objects is smoother than around square objects and the airflow around a symmetric airfoil is almost ideal. The form drag (fig 4.1) results from the applied pressure on moving objects and depends largely on the generation of wake. To reduce the parasite drag aircraft parts that come in contact with the airflow have an airfoil design.

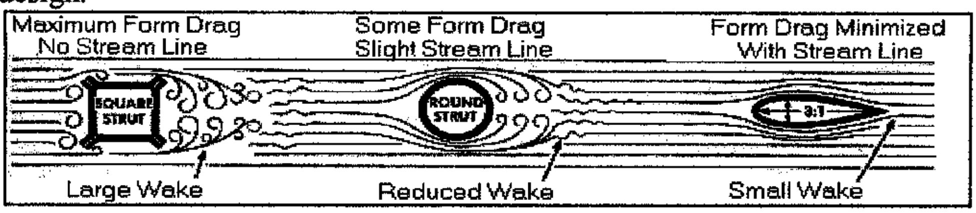


Fig 2.3) Form

The skin smoothness of aerodynamically structures determines the resistance of the skin to airflow. If such resistance exists, the stream line of a thin layer (also referred to as the boundary layer) is disturbed and affects the adjacent layers. This form of drag is known as Skin-friction Drag.

ii) Interference Drag

It is not enough to add all the form and the skin-friction drag values of parts that had been separately tested to obtain the total parasite drag. Interference drag is obtained from testing parts assembled rather testing them separately. As this test is conducted, the wake of one part may affect the drag of another. This effect may be favorable as well as unfavorable.

iii) Induced Drag

From Bernoulli's Principle we know that the pressure below an airplane wing is higher than the pressure above it. As a result, there is a constant tendency of air to flow from bottom to top (a). Since the airplane is constantly moving the air is forced up at the wing tips.

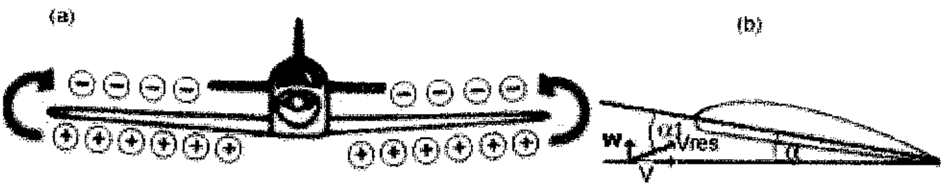


Fig 2.4) The effect of pressure differential on the angle of attack

Considering an airfoil at each wing tip, as demonstrated in (b), the airflow (V) is deflected upwards (w) resulting in airflow (Vres), thus increasing the angle of attack. Angle of attack α is greater than angle of attack $\alpha 1$ (refer to figure 2.4). As a result, both lift and drag are increased at the wing tips section.

The original explanation of lift and drag assumed an ideal airflow. Induced drag results from imperfection in the airflow caused by lift. Two theories offered here to explain the induced drag. As explained earlier, the pressure below an airplane wing is higher than the pressure above it. As a result, there is a constant tendency of air to flow from bottom to top. Since the airplane is constantly moving the air is forced up at the wing tips (spillage).

iv) Induced Drag Reduction

Induced drag is inversely proportional to the speed (velocity) of the air. As explained earlier, the angle of attack (represented by CL and CD), is inversely proportional to the air velocity. As a result, flight at higher speed requires smaller angle of attack. The decrease in angle of attack reduces the pressure differentials on the airplane's wing thus reducing the air spillage and the induced drag. It should be noted the under flight conditions that require a reduction of speed, one can expect higher angle of attack, larger wing tip vortices and greater induced drag.

Induced drag can also be minimized by design. This can be accomplished by high aspect ratio or by mechanically limiting the air spillage around the wing tips. Aspect ratio is defined as the quotient of the wing span squared and the area of the wing. In other words, it is equal to the power of 2 of the wing span divided by the wing area. When the wing is rectangular, the aspect ratio can be simplified to become the wing span divided by the chord line. The definition can be expressed mathematically by:

$AR = b^2 / S$ or $AR = b / c$ when the wing is rectangular.

Where: AR = Aspect Ratio b = Wing Span
S = Wing Area c = Wing Chord

Increasing the aspect ratio, i.e., maximizing the wing span while minimizing the wing's chord, reduces the down wash and the effect of the air spillage around the wing tips. Though increasing the aspect ratio decreases the induced drag, it imposes other limitations on performance specifically at high speeds.

2.2 Remote Controlled Aircraft

Below are the types of remote controlled aircrafts (refer to Reference 9) currently in the market:-

2.2.1 High Wing Trainers

Designed for easy building and flying, trainers allow first-time pilots to learn the basics of controlling an airplane in a relatively stable environment. The construction of flat-bottom airfoils that provide high lift and stability, generous dihedral (the "v" shape of the wings when viewed from front of the aircraft), wide-stance tricycle landing gear for stable ground handling and high-wing positioning are all typically simple. All of these features combine to produce a gentle, slow-flying craft that offer generous amounts of reaction time and elbow room to learn from mistakes.

2.2.2 Low Wing Trainers

Often students find it easier to transition from their high wing trainer to a low wing aircraft with more performance, but that still has forgiving flight characteristics. These planes extend the students capabilities into the world of more complex aerobatics and higher speeds, but at the same time keeping the stability in check to allow room for mistakes, that can help the learning process of the students.

2.2.3 Biplanes

Nothing beats a biplane for classic appearance. Modern biplane models can also recreate the high performance aircraft seen at air-shows around the country. The Pitts Special and Ultimate are just two high performance modern designs that bring classic appearance with gut wrenching performance. These aircraft can do unbelievable rolls and flips and fly at relatively high speeds. Their unchallenged acrobatic abilities are unparalleled.

2.2.4 Indestructibles:

Designed for durability over everything else, these planes - crashed into trees, cars, other planes and the ground - show a remarkable ability to survive and fly again. Of course you sacrifice aesthetics for survivability. Typically they look like sticks with wings, tail & an engine.

2.2.5 Warbirds

Typically this term refers to models of World War II era aircraft. High performance fighters and behemoth bombers are favorite subjects of model aviation. Many good kits are available of aircraft from this era including the P-51 "Mustang," the Messerschmidt ME-109, the Focke Wulf 190, the Mitsubishi "Zero" or the P-47 "Thunderbolt.".

2.2.6 Jets

This exciting aspect of radio control allows experienced modelers to fly replicas of the highest performance aircraft currently flying. Model jets generally have one of three propulsion systems -- real miniature turbine engines, ducted fans with piston engines or high performance electric motors. Jet models can fly from 30 to over 200 miles per hour. Jets are only recommended for those pilots who have a good amount of both flying and building experience.

2.2.7 Gliders

Enjoy the thrill and challenge of "quiet flight" -- flight without an engine. As a model glider pilot you will learn the skill of finding lift. Full scale glider pilots must master this skill in order to stay aloft without an engine.

2.2.8) Sport

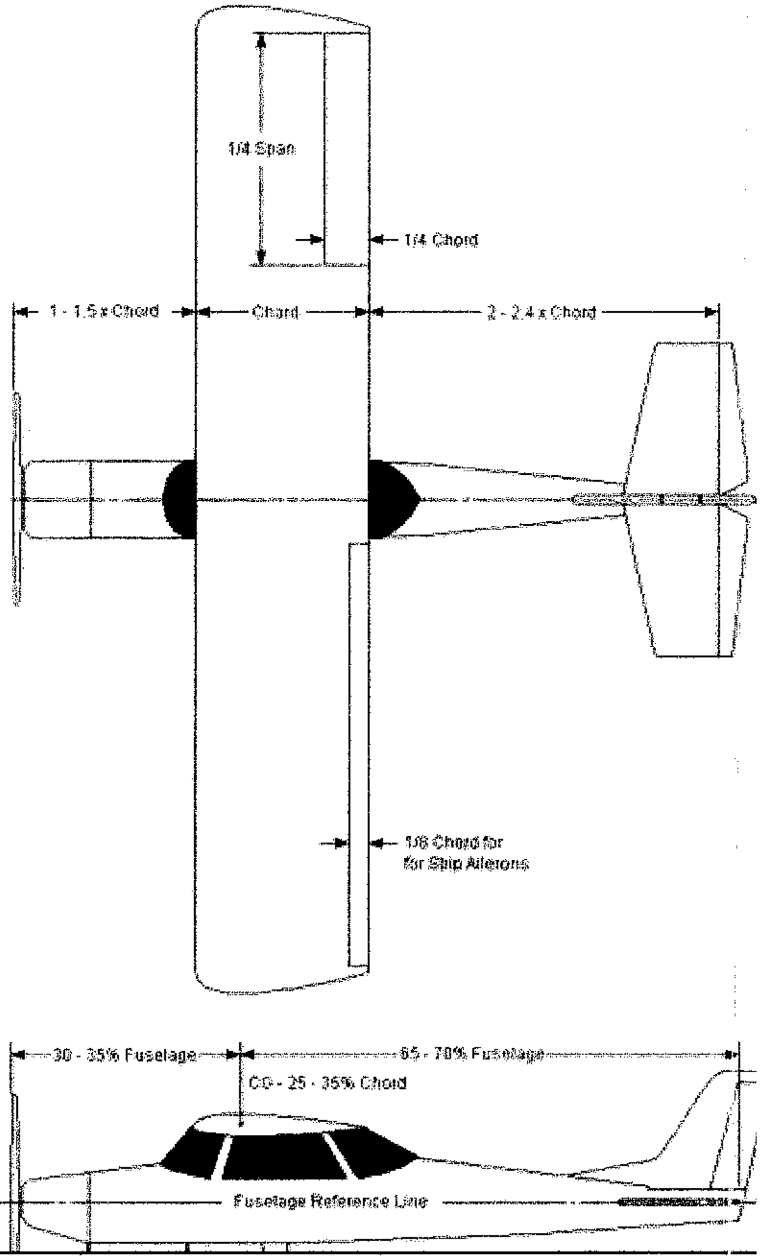
Sport airplanes are generally built either to vaguely resemble an airplane that actually existed, or simply designed to fly well. Generally sport airplanes are where we all start in the hobby.

2.2.9) Scale

Scale modeling is that avenue of the hobby in which builders try to recreate in reduced size an actual aircraft that existed or that exists. Scale modeling can be as simple as building an aircraft that from a distance looks like an aircraft that actually existed or that exists (stand-off scale), or as sophisticated as producing a model that in every detail down to rivets, panel lines, retracts, gear doors, etc. is an exact duplicate of the real aircraft.

2.3 Remote Control Aircrafts Basic Design

Radio controlled model aircraft can be designed using some basic rules of thumb or more appropriately, design parameters. (Refer to Reference 10) These basic design parameters can be applied to a trainer or sport model. There is no complex or magic formulas to solve. These parameters have been proven to work by a multitude of sport models that have been developed using these rules. A modeler who has built a few models and has gained some knowledge of common structures can design a plane that suits his individual needs. Here are some of the rules, shown in the diagram on the right.



These design parameters were originally collected by Romney Bukolt an 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 2.5

After selecting the engine size and wing area, the next step is to determine the wingspan and wing chord that will give this wing area and an aspect ratio between 5:1 and 6:1. The next step in determining the configuration of the wing is selecting the airfoil according to the purpose of the model.

Flat Bottom - Slow, docile, forgiving, poor inverted flight

Semi-symmetrical - Good lift, penetration, aerobatic, and inverted flight

Symmetrical - Best aerobatic and inverted flight

The information given about the wing area needed was based on gas engines sizes that the designer wants to use. This project will not be using such engines as propulsions, but only electric motors. Hence, the team members must find a way to know how to determine how much wing area is needed for a particular model that is being built which would be electrically powered. Kindly refer to the section *4.3 Parameters and Rules of Thumb's* for the proper electric flyer guide.

2.4 General Types of Airfoils

Conventional airfoils and laminar flow airfoils are in common use in airplane design.

Laminar flow airfoils were originally developed for the purpose of making an airplane fly faster. (Refer to Reference 11) The laminar flow wing is usually thinner than the conventional airfoil, the leading edge is more pointed and its upper and lower surfaces are nearly symmetrical. The major and most important difference between the two types of airfoil is this, the thickest part of a laminar wing occurs at 50% chord while in the conventional design the thickest part is at 25% chord.

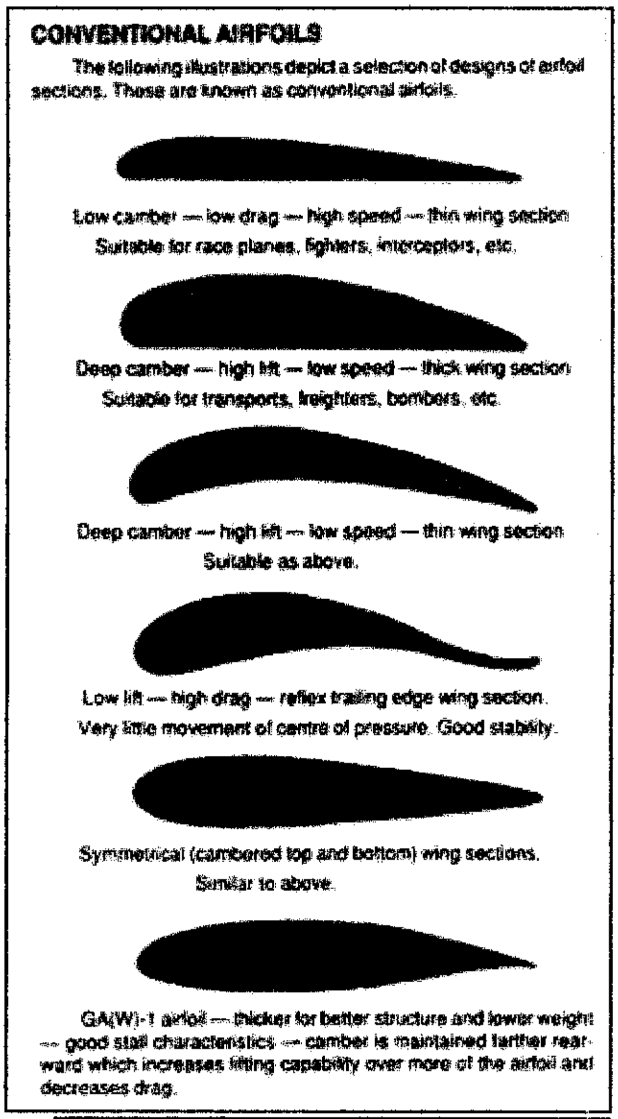


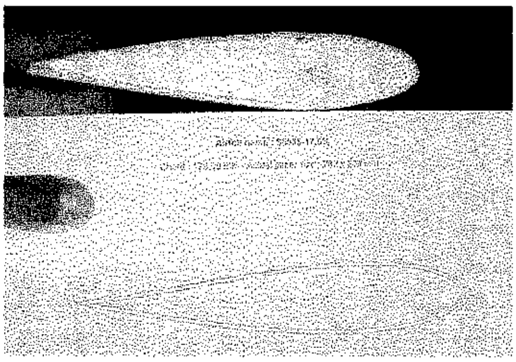
Fig 2.6 : General shapes of airfoils

The effect achieved by this type of design of a wing is to maintain the laminar flow of air throughout a greater percentage of the chord of the wing and to control the transition point. Drag is therefore considerably reduced since the laminar airfoil takes less energy to slide through the air. The pressure distribution on the laminar flow wing is much more even since the camber of the wing from the leading edge to the point of maximum camber is more gradual than on the conventional airfoil. However, at the point of stall, the transition point moves more rapidly forward.

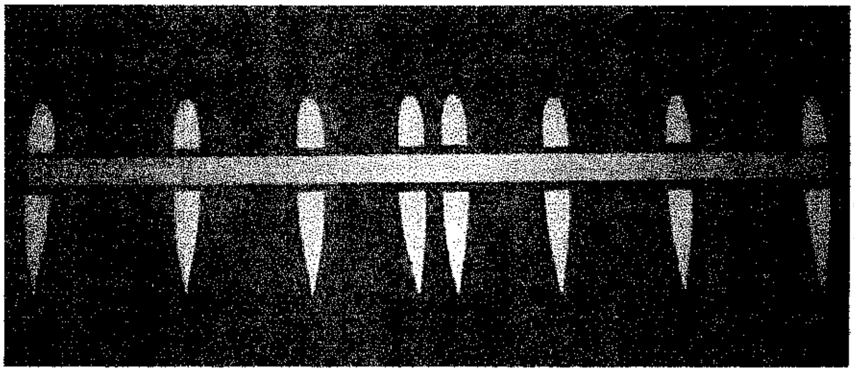
2.5 Template Method

This method is for making wings using ribs and spars. This information was taken from a discussion thread in www.ezonemag.com hosted by 'mkb' from Dunwoody, GA.

1. First, an airfoil is selected. Thicker airfoils will be more stable at lower speeds but produce more drag. Thinner airfoils will increase flight speed, but lessen control at lower speeds. So select your airfoil based on your style of flying.
2. Print a paper copy of the airfoil. Here is the Selig 8035 with a 7" chord and 1.25" thickness. As this does not include the ailerons, the effective airfoil thickness is somewhat smaller. Then, the airfoil template was cut out of thin plywood. The plywood template is a convenient tool when cutting wing ribs with an X-Acto knife. After all the ribs have been cut, they are lined up in a "sandwich" and fine grit sandpaper is used in a sanding block to smooth the edges of the ribs and to make them virtually identical in size and shape.

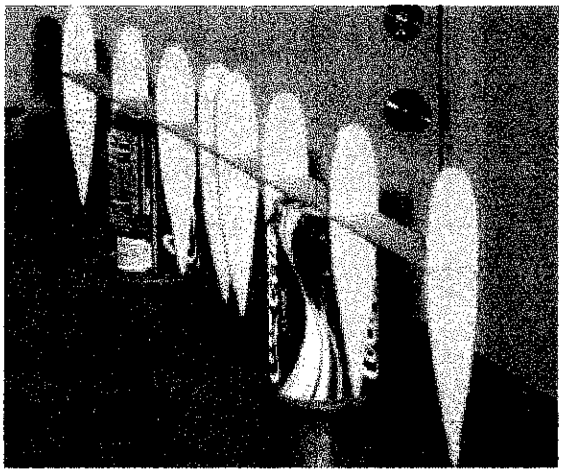


3. To increase wing strength, balsa wood spar is used. For this wing, a piece 34" long is selected. Note below how the rib positions are marked. Ribs should be more closely spaced near the middle of the wing.



4. After that, the ribs are further cut in half where they are the thickest. Note again the general placement of the ribs along the spar.
5. The back portions of the ribs to the spar are glued, making sure the ribs line up straight and true. 5 minute epoxy were used for this step. Then the front portion of the ribs were glued to the spar. After the glue dries, the ribs and spar are solidly joined.

6. The wing covering is cut out, then draw a straight line down the center of the foam at where the leading edge will be. This will help to ensure the covering and the ribs are properly aligned when they are glued together. Then work the foam over the edge of a counter top to ease the bonding



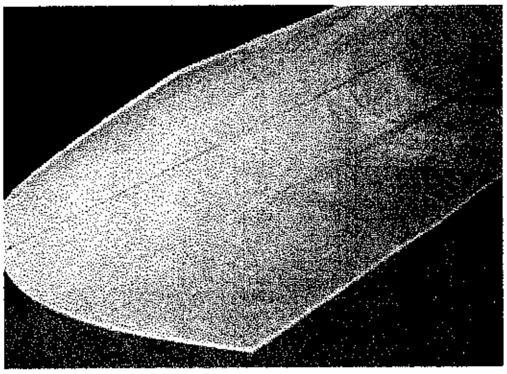
and to add curvature to the foam. A piece of pipe can also be used to carefully bend the foam so it conforms to the following shape. Be sure that the centering line is on the inside of the resulting curve.

7. Then, checks are done to ensure the foam covering properly conforms to the dimensions of the spar and ribs. Bend the covering over the spar assembly and check to see if the length and the width of the covering mates with the ribs. If either the length or width overhangs too far, the excess are cut off using a knife and straight edge, but being careful not to cut too much. Remember the trailing top and bottom edges of the wing covering will be glued to one another where they meet.

8. Once the parts mate properly, they are ready to be glued together. Line up the front of the ribs with leading edge line of the covering. Then trace a glue line where the spar and ribs will be attached to the top and bottom of the wing covering.

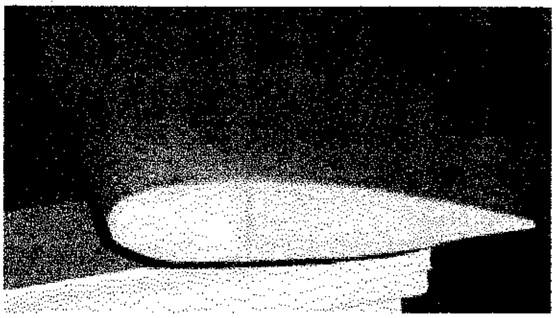
9. Once the glue line has been traced, the glue is sparingly applied.

10. A thin layer of polyurethane glue is used at joining points when gluing the wing. Be sure the wing lays on a flat surface during the cure or the resulting wing will be warped. Then, some weight id



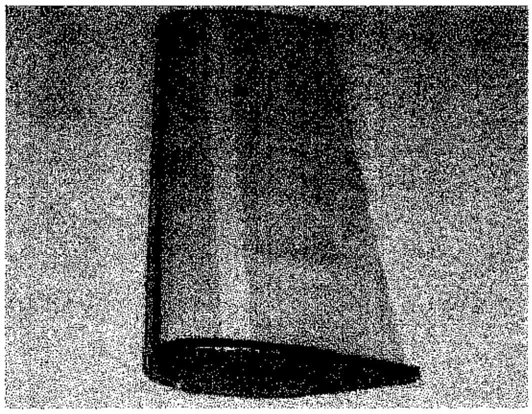
placed onto the assembled wing to keep the pressure on all the glue joints. The phone books work well as weights, since they conform to the top surface of the wing. Also note the foam strip placed under the trailing edge that maintains pressure on this seam as the glue cures. Wax paper is used to separate the wing from the flat table surface and the weights to guard against excess glue bonding the wing to either of these items. Polyurethane glue does expand as it cures.

11. Once the glue has cured, the wing should look something like this. →



12. A strapping tape is used to reinforce the spar at the top and bottom of the wing. This further guarantees wing strength to handle the stress of aerobatic flying.

13. Finally, all of the edges of the wing is taped with packing tape. Foam is not particularly durable, and any exposed blue foam edges will chip quite easily.



2.6 Tail designs – Pros and Cons

From a discussion thread hosted by 'Ollie' from Punta Gorda, Florida, at www.ezonemag.com, he mentioned that the T-tail (figure 2.7) has the advantage of making the vertical area more effective by the end plate effect of the horizontal tail. This allows a slightly smaller vertical tail area. Another advantage is that the horizontal tail has plenty of ground clearance. The disadvantages are that the mass of the horizontal tail puts a severe inertial load on the vertical tail in the event of a hard landing or ground loop. As a result, the vertical tail structure and fuselage tail cone have to be stronger and heavier. The elevator control linkage is more complex and often adds mass to the tail. The added structural and control linkage mass results in more nose weight to balance, which increases the wing loading.

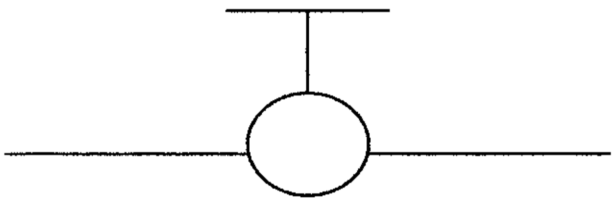


Figure 2.7

The conventional cross tail (figure 2.8) is the easiest to design, modify during the development process and adjust during set up of a new model. The horizontal tail location can be easily adapted to an all moving horizontal tail, which facilitates control linkage design, and decalage adjustments for pitch trim coordination with CG adjustments. The cross tail configuration is the most popular configuration for contest models as well as sport models.

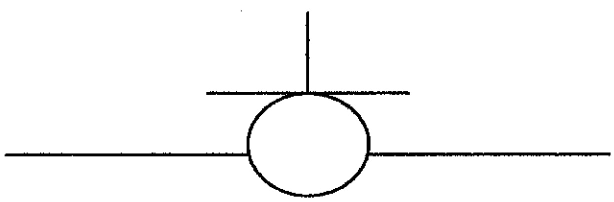


Figure 2.8

The V-tail (figure 2.9) is the most complex to design, develop and adjust. This is because there is interaction between the pitch and yaw functions of the tail for both stability and control. When the V-tail is properly designed and adjusted it is equal to the cross tail in function and can sometimes have a slightly better strength to weight ratio and better ground clearance. The fuselage tail cone has to be designed for torsional stiffness in order to avoid aero elastic effects at high speed. It is a poor choice for entry level models because of the added complexity and cost of the mixing function and the difficulties associated with proper adjustment. It is rarely seen in aerobatic models because of its yaw to roll coupling (dihedral effect).

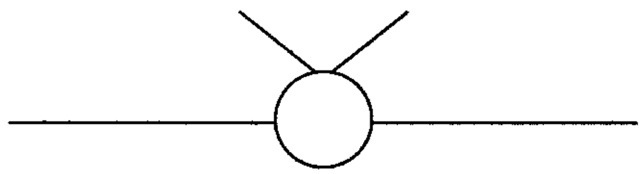


Figure 2.9

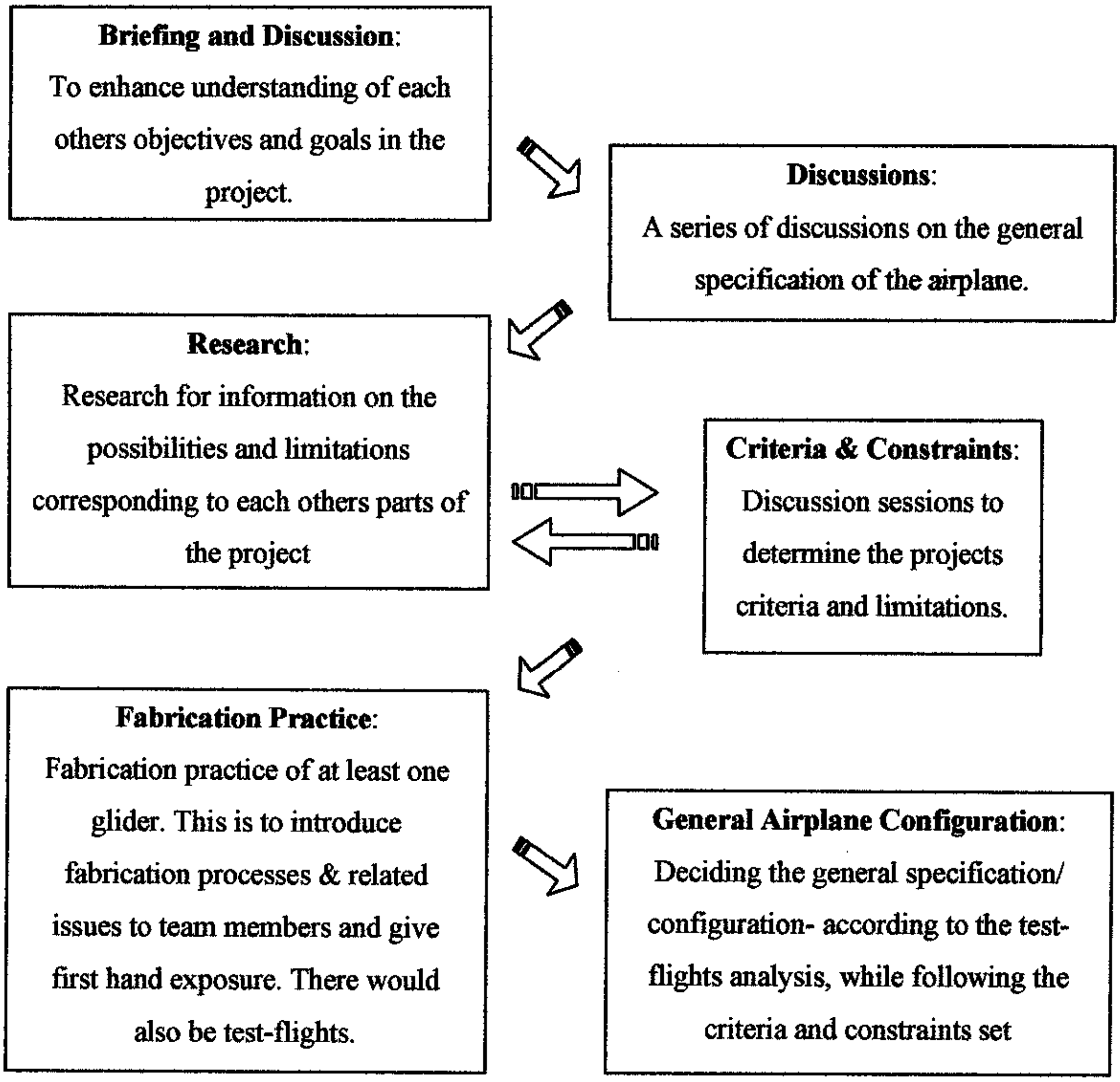
CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

Each team member had different scope of study that compliments each other and helps the team to integrate their work together to produce a good product in the end. To ensure this, the team tried to be well synchronized with each other through discussions and frequent meetings to ensure that everyone was going in the same direction. Without adequate interaction among the team members, the team would have a big problem integrating each other's design together. When this occurs, there would tend to be design specifications of the parts that could not be combined with each other. This would lead to more time consumption due to the design modifications needed to amend the specification mismatch.

In the 1st half of the final year project, the team had determined the general characteristics of the aircraft. During this period, each of the team members had to collect as much information as possible related to the project. From there, the information was used to help the team members develop ideas and more importantly increase their understanding about each others role in the project. With proper understanding, the development of each of the components would be more successful, subsequently conforming to the target of the project well. Through discussions, the team had to decide on the characteristics that the aircraft should have. From there, each team members concentrated their work on designing alternatives of their parts that comply with the agreed target characteristics.

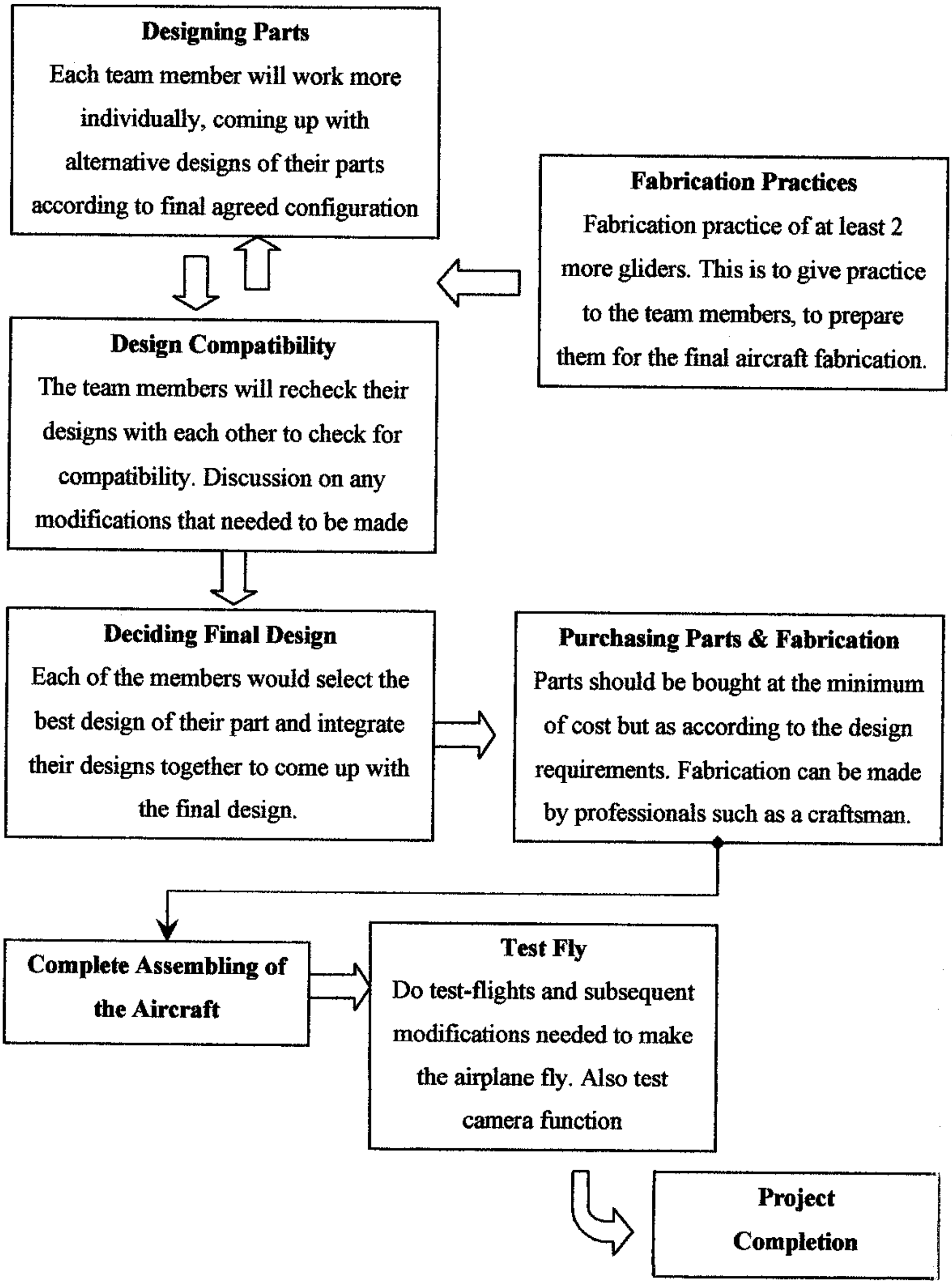
Below is the procedure flow for the project for the first semester:-



In the 2nd semester, the team concentrated more on the calculations involved, design detailing and fabrication process. The team had to justify the design cues and characteristics that have been opted. In other words, more 'engineering' would be put in the project, so that as much details as possible could be justified.

Besides that, because the objective of the project was to design and fabricate, hence fabrication's a part and parcel of the project. Thus, the proper fabrication techniques of the final product must also be mastered by the team. Therefore, the team had decided that the only way to get a better feel and understanding of the fabrication process was to build up on the hands on experience. Several gliders would be built by the team before the final product was produced. By these extensive hands on experience, the team will be able to know limitations of each of the fabrication techniques and also know which materials can be used or not on different sections of the aircraft.

Next is the procedure flow for the project for the second semester:-



3.2 Tools

There are a few softwares that could be used for the design process of the wing:-

- AutoCAD – for the basic drawing of the air foil.
- Catia – this software can import AutoCAD files, and then run finite element test on it to find out the resulting airflow pattern and ultimately know how much lift and drag are created from different wing configurations.
- Ansys – this software is also a finite element analysis software
- Winfoil V22/ Profili – simple airfoil design softwares

Furthermore, some of the materials used were strength tested to know their limitations and suitability to a particular design chosen. These strength tests were done at the material lab, with the help of the lab technicians on duty. This information is important in the process of finding the right material for the wing.

In the first semester, Mr. Rahmat had instructed the team members to have a go at constructing a glider from scratch and try to make it glide well. The activity was to improve the team members understanding of the concept. From there also, the team members also improved their understanding on how their respective design could affect the flight characteristics of the aircraft. Thus, the exercise may be able to open up the team members' minds, so that with the understanding, they would be more effective in completing each of their respective parts as well as could be done. Therefore, in the second semester, the team practiced more on this through the fabrication of 2 more glider prototypes. The objective of these exercises was for the team to learn new things about fabrication much quicker than just reading the information about it in a book or internet. Besides that, by practicing like this, the solving of any problem encountered then would prepare the team in facing similar problems during the fabrication of the final product. When problems do occur then, the experience would help the team to solve the problems quicker thus saving precious time.

3.3 Schedule

3.3.1 First Semester Gantt Chart

Weeks / Events	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Briefing/Introductory meeting								M								
Familiarization Research - on RC Aircrafts								I								
Research on Mechanism of Flight								D								
Preliminary Report								S								
Research on Wing Configurations & Airfoils								E								
GWS Convofair Outlet								M								
Sketches of Possible Ideas								-								
Research on Method of Fabrication								B								
Progress Report Submission								R								
Research on Mathematical Analysis								E								
Discusiion on Aircraft Configuration								A								
Submission of Interim report Final Draft								K								
Oral Presentation																
Submission of Interim Report																

3.3.2 Second (Final) Semester Gantt Chart

Events \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
2nd glider fabrication practice and analysis								M									
Final determination of wing configuration- (airfoil, construction,reinforcement,etc)								I									
Submisiion of Progress Report 1								D									
Research for next glider fabrication																	
Material Search and Ordering of Components for Aircraft								-									
3rd glider fabrication practice and analysis																	
Submission of Progress Report 2								S									
Software analysis (Catia) and Material testing								E									
Actual Aircraft Constrcution																	
Actual Aircraft Test flight								B									
Final Preparation of Final Draft report								R									
Submission of Interim report Final Draft								E									
Oral Presentation								A									
Submission of Final Report								K									

CHAPTER 4
RESULTS & DISCUSSION

4.1 Wing Configuration

From the research, a few configuration patterns had been found among remote controlled (RC) aircrafts. These patterns differentiate the different speed ranges that they are suitable for.

After several discussions with the team members, it was agreed that the RC aircraft that would be built would have a low speed range. This was to make it suitable with the aircraft's purpose of taking imagery shots of the passing view below. It has been a rule of thumb among designs of aircraft that slow flyers are stable aircraft, but it lacks the maneuverability. However, high speed flyers have great maneuverability, but sacrificing stability. Hence, it is clear that the aircraft for this project should be a slow flyer because of its flight stability. Stability is very important for image capturing to avoid from blurriness.

The configuration pattern for slow RC flyers is that they tend to have wing configuration as shown in these following diagrams (fig 4,1 & fig 4.2):-

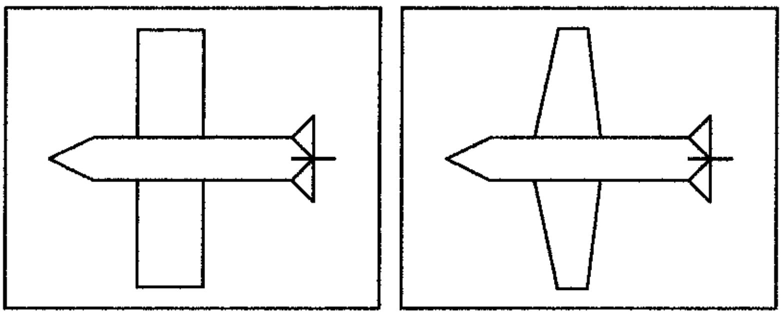


Fig 4.1) a) rectangular *b) tapered*

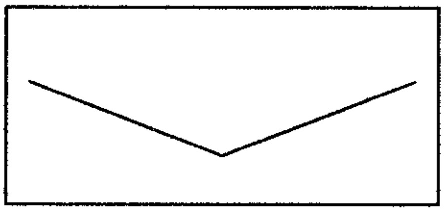
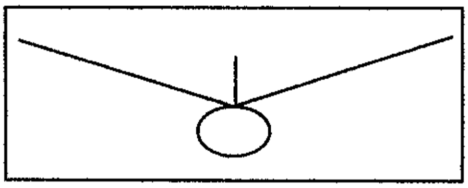
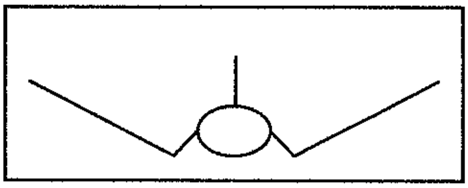


Fig 4.2) a) dihedral





b) Dihedral High wing *c) Gull wing*

(High Wing Configurations)

From the site http://www.mainehobbies.com/toys_rcplanes.html, as shown in the literature review section, the site gave many useful tips on which configurations are very suitable with this project's objectives.

For slow and stable flyers, the aircraft should have a high wing configuration (fig 4.2 b&c). The configuration is very stable because the weight of the aircraft is suspended below the wing. When the aircraft tilts, its weight tends to try to return itself back to a level position. A low-wing aircraft is generally the opposite: with its weight above the wing. It tends to be less stable, which is excellent for advanced fliers who want to perform rolls, loops and other aerobatic maneuvers.

Besides that, a dihedral wing (fig 4.2 a) was also recommended. Dihedral is the upward angle of the wings from the fuselage. Dihedral increases stability and decreases aerobatic ability, which will be great for slow flyers, especially as it will take aerial shots. This is why all aerobatic planes have straight wings, because of its lack of stability, which adds to maneuverability.

4.2 Airfoil Selection

4.3.1 Background Information

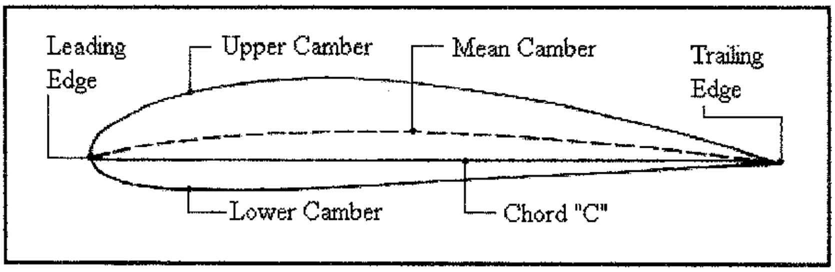


Fig 4.3) A general diagram of an airfoil

(Refer to the address at Reference 12)

Leading Edge:

The leading edge of an airfoil is the portion that meets the air first. The shape of the leading edge depends upon the function of the airfoil. If the airfoil is designed to operate at high speed, its leading edge will be very sharp, as on most current fighter aircraft. If the airfoil is designed to produce a greater amount of lift at a relatively low rate of speed, as in a Cessna 150 or a Cherokee 140, the leading edge will be thick and fat. Actually, the supersonic fighter aircraft and the light propeller-driven aircraft are virtually at the two ends of a spectrum. Most other aircraft lie between these two.

Trailing Edge:

The trailing edge is the back of the airfoil, the portion at which the airflow over the upper surface joins the airflow over the lower surface. The design of this portion of the airfoil is just as important as the design of the leading edge. This is because the air flowing over the upper and lower surfaces of the airfoil must be directed to meet with as little turbulence as possible, regardless of the position of the airfoil in the air.

Chord:

The chord of an airfoil is an imaginary straight line drawn through the airfoil from its leading edge to its trailing edge. We might think of this chord line as the starting point for drawing or designing an airfoil in cross section. It is from this baseline that we determine how much upper or lower camber there is and how wide the wing is at any point along the wingspan. The chord also provides a reference for certain other measurements as we shall see.

Camber:

The camber of an airfoil is the characteristic curve of its upper or lower surface. The camber determines the airfoil's thickness. But, more important, the camber determines the amount of lift that a wing produces as air flows around it. A high-speed, low-lift airfoil has very little camber. A low-speed, high-lift airfoil, like that on the Cessna 150, has a very pronounced camber.

You may also encounter the terms *upper camber* and *lower camber*. Upper camber refers to the curve of the upper surface of the airfoil, while lower camber refers to the curve of the lower surface of the airfoil. In the great majority of airfoils, upper and lower cambers differ from one another.

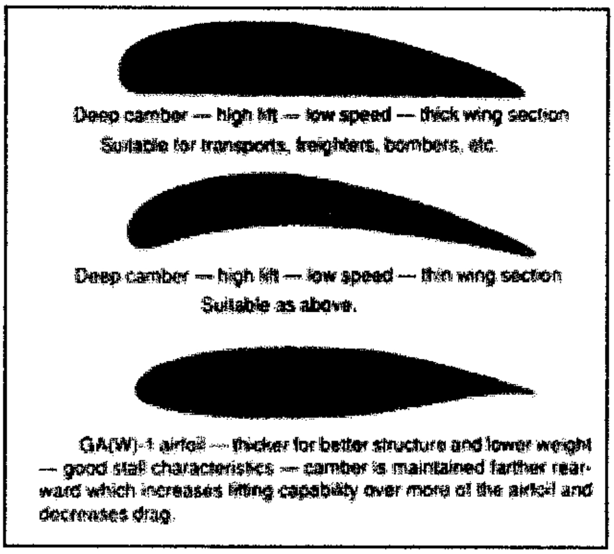


Fig 4.4) General Airfoils for slow RC flyers

Referring to websites such as http://www.mainehobbies.com/toys_rcplanes.html, most of them stated that a flat bottom airfoil would be the best choice for slow flyers. The *mainehobbies* website stated, "The flat-bottom airfoil will develop the most lift at low speeds. This is ideal for trainers and first-time pilots".

For symmetrical airfoils, the top and bottom have the same shape allowing them to produce lift equally when right-side up or upside down, which is suitable for aerobatic flying. Although this type of airfoil produces low amount of drag, but they also produce relatively low amount of lift. These characteristics are only favored by intermediate and sport pilots.

In addition, the thickness of the wing also plays a role in determining the aircrafts flight characteristics. A thick wing creates more drag, causing slower speeds and gentler stalls. A thin wing permits higher speeds and sudden stalls, which is desirable for certain aerobatic maneuvers.

Finally, wing loading is also an important factor. Wing loading is the weight that a given area of the wing has to lift and is usually measured in ounces per square foot. Generally, a light wing loading is best for beginners; the plane will perform better and be easier to control. Therefore, it would be best for the team to minimize weight as best as can be done to ensure that the wing loading is as low as possible.

Hence, the most probable airfoil that would be used is a flat bottom airfoil that has a relatively thick wing section. This type of airfoil would be easier to fabricate, due to the flat lower camber that it has. The long list of available airfoils that follow this pattern has been short-listed to just a few alternatives as shown below (fig 4.5): -

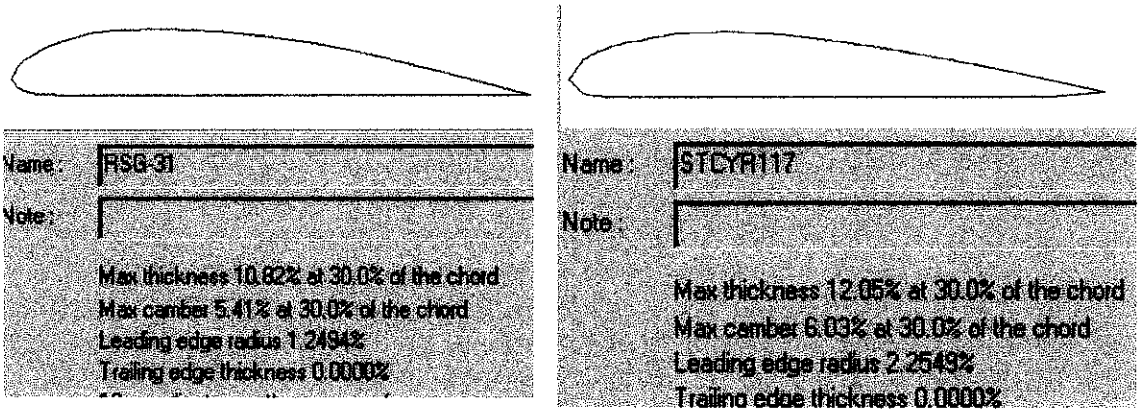


Fig 4.5) a)

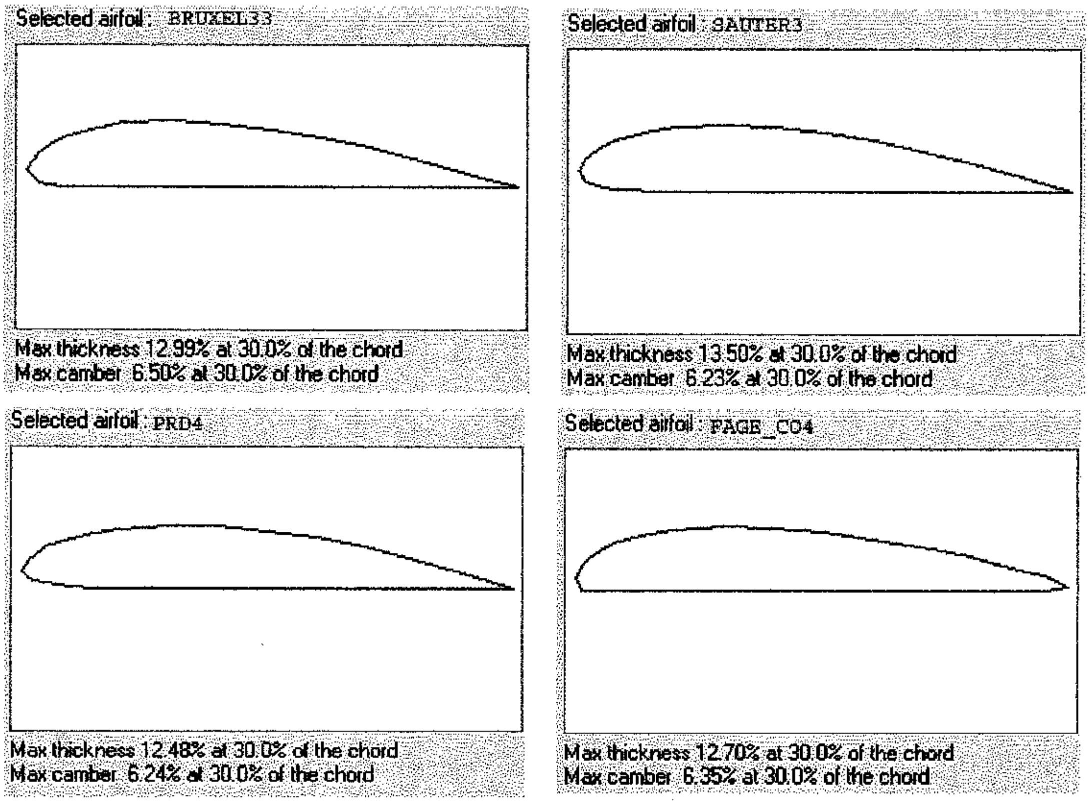


Fig 4.5) b)

4.3 Parameters and Rules of Thumb's

In designing a remote controlled (RC) aircraft for this project, one cannot start from scratch and expect that it everything would go well. The team needed a guide to lead the design in the correct path to avoid too many complications along the way. The following are the rules of thumb (Refer to reference 13) that can be used for the design of the project's aircraft:-

Wing area = SPAN × CHORD

Aspect Ratio = SPAN / CHORD

For a normal RC aircraft is around 7 – 9 to one, a sailplane has a greater aspect ratio, maybe even 20 to one.

Wing loading = WEIGHT (oz) / AREA (sq. ft.)

1 lb equals to 16 ounces. Normal RC aircraft generally need wing loading around 22-26 ounces per sq. foot. A very small rubber powered model on the other hand may have 3-6 ounce wing loading.

Horizontal Stab = 12-15% of the wing area with about a 3 to 1 Aspect Ratio.

Vertical Fin = about 33% of the Horizontal Stab

The rudder 1/3 rd of the area of vertical fin

Length of the Fuselage = about 75% SPAN

Nose Moment

= The distance from the balance point of the wing forward to the prop.

= around 25-30% forward of the wing balance point.

>Most wings should be balanced initially 25% of the average chord back from the leading edge of the wing.

Tail Moment = the distance aft to the tail from the 25% average chord of the wing
= around 65-70% of the fuse length (and aft of the balance point)

Fuselage height = around 10-15% of the fuselage length.

Aileron Area = about 10% of the total wing area with the length of each about 8 times its width.

Separation between wings for **biplane** wing configuration
= vertical separation by at least the Chord (width) of the largest wing

Most models need to be balanced 25% or more back from the leading edge of the wing. = is not affected by no matter what or how much is attached to the wing (--fuselage, tail feathers, landing gear, etc.).

= for biplanes then draw a line connecting the leading edge of the wings and make a mark at the half way point, then from that point move aft 25%.

= In addition you should balance your model fore and aft. Put one finger on the end of the crankshaft and the other finger at the tail. If it continually flops to the same side, then that side is too heavy. Probably because you have the engine set sideways with the head of the engine on one side or the other

To make the aircraft less sensitive to flight control movements:-
= you can balance at 25% aft from leading edge.
=The farther aft you move the balance point the touchier things get.

Sweep back wing:-
= normally helps stability whereas sweep forward is somewhat de-stabilizing.

= the sweep back adds to the Dihedral of the wing

Dihedral Angle

= Model sailplanes have about 6 degrees of dihedral

= low wing models may have up to 12 degrees

The shape of the leading edge:-

= a sharp leading edge = a sharp stall

= more rounded leading edge = mild stall

A rectangular wing needs no twist in it (wash) as the inner panel just naturally stalls before the outer panel. However, a tapered wing does need some wash out (twist).

Aerobatic airplanes have symmetrical airfoils (top & bottom airfoil curvature the same)

Trainer aircrafts have flat bottom airfoils.

Airfoil thickness

= 12 to 15% of the chord.

= The thicker you make it, the more drag but probably more lift

Wing placement in relation to the fuselage datum line

= The heavier the wing loading is, the more positive incidence is needed.

= This means that the leading edge of your wing, when viewed looking at the side of the fuselage drawing, needs to be up from 1 to 2 1/2 degrees.

>>For biplanes:

When the bottom wing to be more positive than the top wing, so that the bottom wing stalls first, letting the tail end come down first on landing and it also makes for better snap rolls.

When there are more incidences in the top wing so that it will stall first, causing the nose to drop and stall recovery will be quicker

During flight:-

If the tail hangs down, it means that there are not enough positive incidences in the wing. Thus, the leading edge needs to be raised a degree or so. (or lower the trailing edge). The behavior shows that the wing needs to attack the air at a higher angle, probably due to the overall wing loading of the model.

During engine mounting

There should be built in 2-3 degrees of right thrust (engine pointing to the right for a tractor set up (engine up front), and 2-3 degrees of down thrust. (crankshaft pointing down).

During first few flights, the engine thrust line might need to be adjusted:-.

- Get your model tracking straight and true at altitude, and then chop the throttle. The nose should drop some.
- If the model's nose pops skyward then you have too much down thrust.
- If you have designed a tail dragger, it will be very easy to tell if you have enough right thrust, when you try to take off. Your model naturally tries to turn to the left. If you have set up the right thrust just right, your model will track straight ahead on take off.

Neutral Point of your model (i.e.-where it will become unstable)

= The distance between the 1/4 chord point of the wing vs. the horizontal stab × the area of the horizontal stab divided by the wing area × the wing chord. *(Refer to Appendix 1)*

4.4 Fabrication Practice

4.4.1 First Glider

i) Design

During the first semester, the team had decided to start practicing fabricating of gliders. This is to introduce the fabrication processes involved to the team members. Besides that, the team also will have the chance to solve fabrication problems that arises, preparing the team with experience with e very fabrication exercise.

For the convenience of the team itself, the material that was used are materials that are readily available at the nearest shops and hardware store. After referring to numerous sites in the internet, the team finally came up with a design for this first glider, which is shown in this figure:-

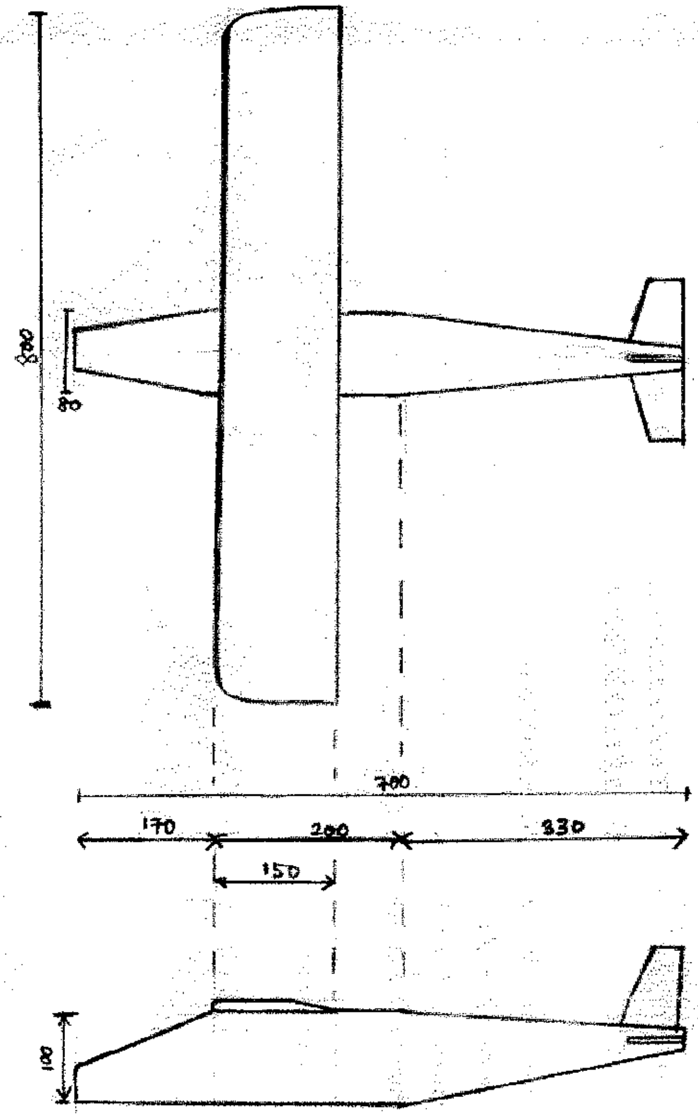


Figure 4.6

Rough polystyrene was used for the fuselage, and finer, denser polystyrene for the wing. After the fabrication has been done, it was obvious to the team that the wing seriously needed reinforcement. It was too soft and fragile. Thus, after some thought, it was decided that a cloth hanger should be used underneath the wing for the reinforcement needed. The lightest available hangar was used to minimize weight addition. The estimated cost of the glider was around RM20. Below is a photo of the glider: -

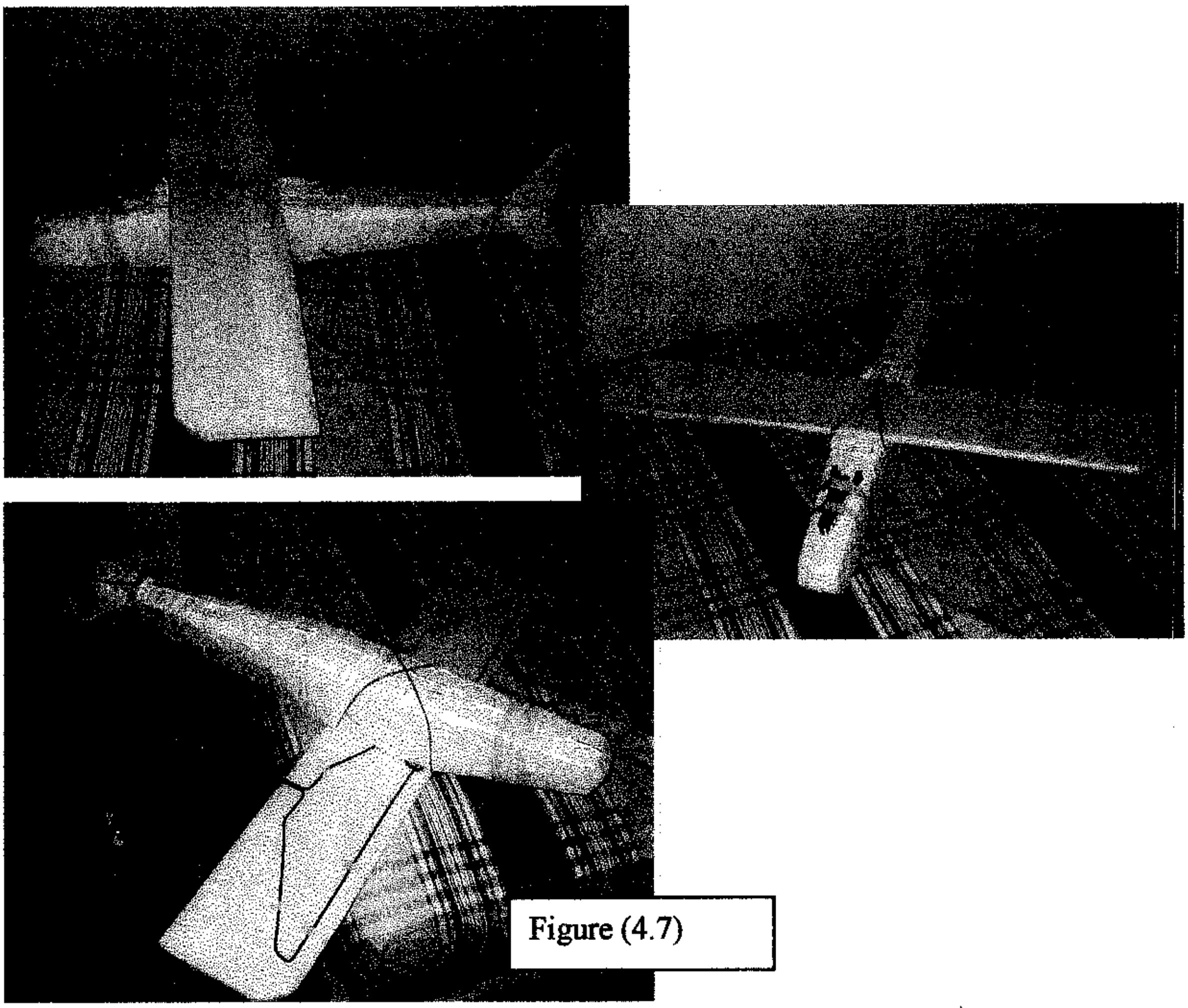


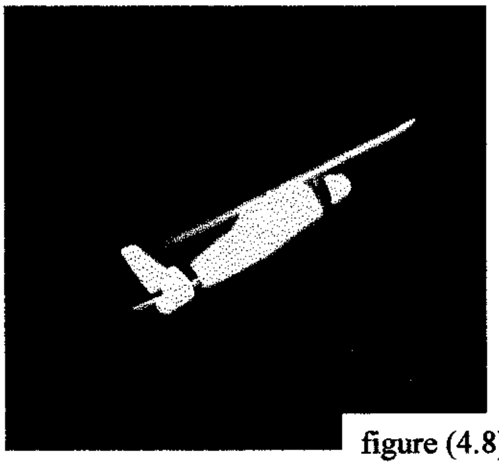
Figure (4.7)

After fabrication, the center of gravity (COG) of the aircraft was adjusted so that it lies around 25% chord length aft from the leading edge, approximately in line with the center of gravity of the wing itself. Balancing is very crucial for any kind of aircrafts. The aircraft was initially front heavy, thus tend to dive in its flight. However, if the aircraft was tail heavy, the aircraft will tend to dip up (tail will drop down, thus nose will dip upwards).

The COG of the aircraft should be in line with the center of lift (COL) of the wing, because the lift provided by the wing would push the aircraft up at the wing's COL. Thus, if the wing's COL and the aircrafts' COG are not in line, the lift provided by the wing will act as a moment to the aircraft's body.

ii) Test-flight Analysis

During the first test fly, one of the problems was that the aircraft tends to dip up during flight. Hence, the COG was rechecked and founded to be alright. With the benefit of doubt, we tried to adjust the center of gravity. After several adjustments, the aircraft still dips up during flight. Then, the team was enlightened, when one of the members realized that the angle of the tail wing was too much, that it pushed the tail downwards during flight. After modifications to the tail wing, the plane flew quite well. Below are photos of test flights. Figure shows the initial aircraft characteristic, which tend to pitch up



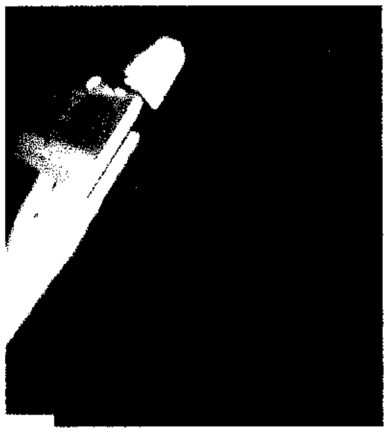


figure (4.8)

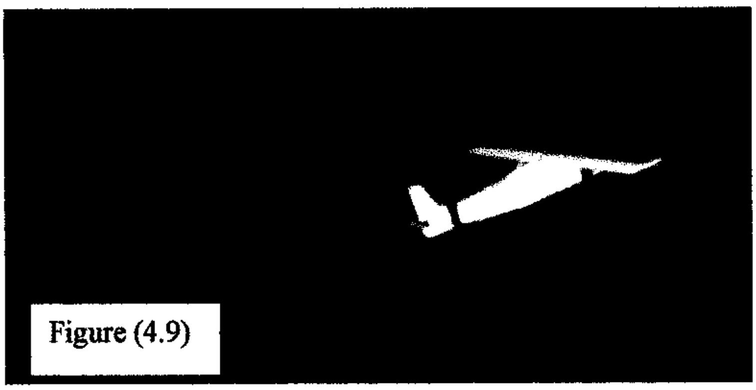


Figure (4.9)

Figure 4.10

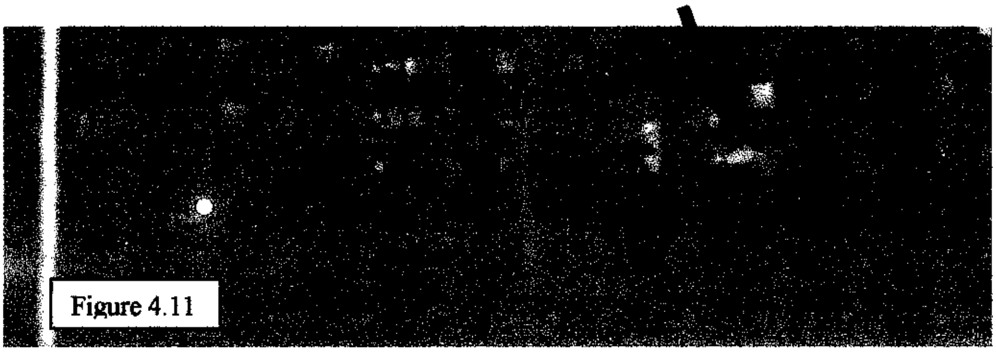


Figure 4.11

After numerous successful flights, the final flight ended up in disaster when the plane was thrown wrongly and then it just dove into the ground. The rubber band holding snapped and it was then realized that actually, with each flight, the wing moved forward bit by bit after each 'landing'. This was because there were no slots to hold the wing in place. The wing was held in place only by the rubber bands and the friction between the wing and the fuselage. The wing with the added weight of its reinforcement, have a relatively big inertia, which is why it slided forward with every impact of landing. Hence, the fuselage had to be modified to provide a slot to hold the wing in place.

After the modification had been done on the following day, the second test flight commenced. The characteristic of the flight changed a bit, as heavy duty tape was used to reinforce various parts of the fuselage. The aircraft as a whole became heavier. However, the aircraft did fly. Unfortunately, the same disaster the day before repeated itself, this time at a cost. The wing and the fuselage cracked and broke. Thus, the team decided that no further repair would be done and called it wraps for this first glider.

4.4.2 Second Glider

i) Design

During the first 2 weeks of the second semester, the team had attempted to build the second glider. The attempt was much better than the first done last semester in all aspect. Much weight was successfully reduced. Several different materials and also a new fabrication method was used compared to the first glider, with the purpose of reducing weight and also increasing the strength of the build.

This time, the configuration of the glider was quite similar to the previous because of the good gliding characteristics of the first glider. The only difference this time was that the wing was made dihedral. The second glider was still monoplane, and mainly made from foam. However, the wing construction is completely different from the previous. The spar and rib method was used this time. The spar was made from plywood, and the ribs were made from airfoil templates of foam. For the cover, wrapping paper was used, the reason being that it is light and relatively easy to repair if damaged.

For sticking together the bits and pieces of the aircraft, crystal clear epoxy was used. It was found that the glue was very effective. It took the glue about 30 minutes to set, and after 2 hours, the parts glued can already be handled. However, to achieve maximum strength, the parts glued should be left to settle for 8 hours.

Figures (4.12) shows the 2nd glider fabricated by the team:-

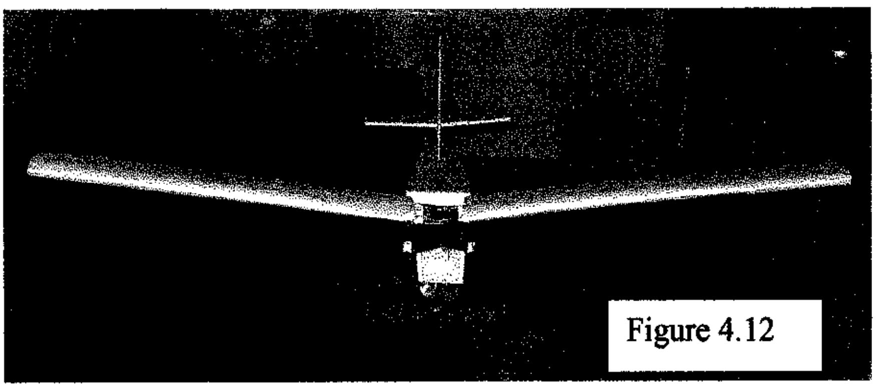


Figure 4.12

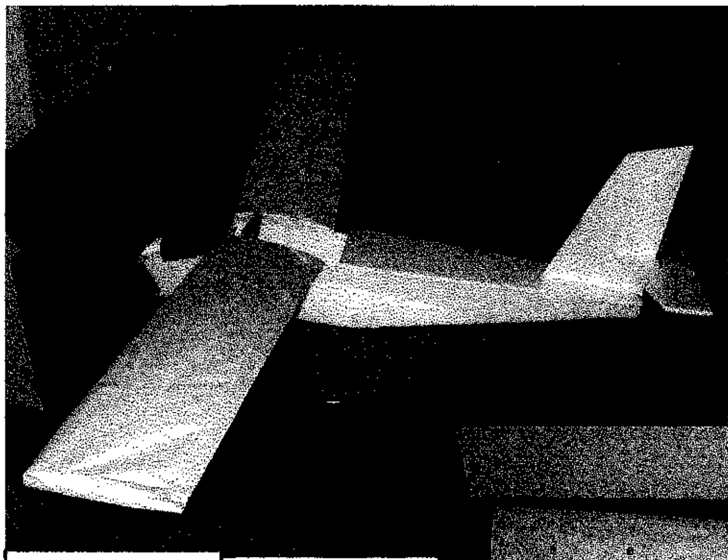


Figure 4.13

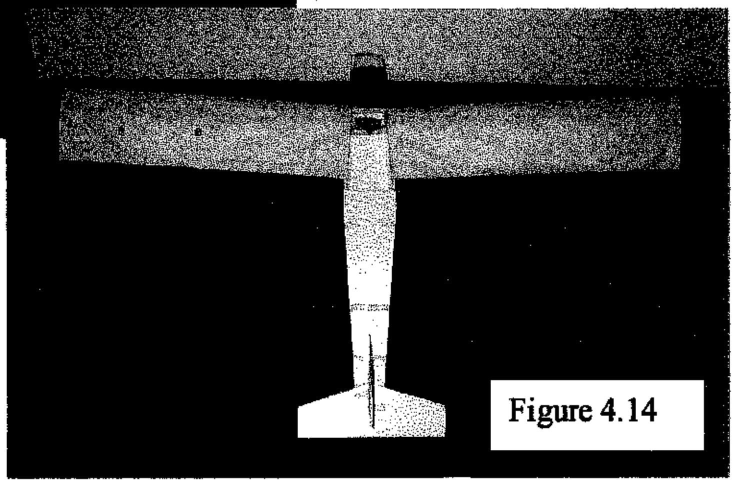


Figure 4.14

ii) Test-flight Analysis

After the aircraft has been completed, the team had tried to find its center of gravity (CG). From the exercise, the team got the chance to practically try the method. Previously, the method was only learned by the team heart without practical, thus it was a new experience for them. The team was quite surprised by the overall structural strength of the glider. The glider suffered several crashes during the exercise, but only experiencing minor chips.

However, looking at the wing setup, after several throws, the outside tip of the wings started to swing forward slightly, suggesting that the single spar was not enough to hold the wing solidly in place. Therefore, the team will try to use double spar for the next time. The spar in this glider was plywood, which is relatively heavy. Therefore, in the next fabrication exercise, the team would probably use bamboo, which is a bit more elastic but has more tensile strength.

In addition, the team also found out that the wing cover, which was made out of tracing paper, was too easily get torn when mishandled. Furthermore, it took a lot of effort to cover the spar and ribs with paper, let alone making the paper taut. Subsequently, the final finish of the wing cover was less than perfect. Besides that, it was observed that the wing could not handle high wing load. It may easily flex in or out during flight when exposed to too high a wing load, thus changing the profile of the airfoil. Hence, a new material must be used in the next fabrication exercise that can diminish these problems.

Additionally, in the discussion with the supervisor, Mr. Rahmat Iskandar, he pointed out that epoxy glue is heavier than white glue, but nearly as strong. In the quest of lightening the weight, this should be taken into consideration. However, one drawback of using white glue is that it takes much longer to settle down and really stick, but it is much cheaper than epoxy. The team will consider using white glue in the next few glider fabrication. But in the final aircraft, probably epoxy would be used to ensure that the adhesion is very strong, considering the extra load that the final aircraft would carry plus at the extra speed.

Finally, the final issue apparent in this glider, as well as the first one done previous, is that a lot of counterweight was needed at the nose to balance up the center of gravity (CG) of the whole aircraft. Therefore, one simple solution for this is that in the future, the wings should be positioned a bit further back than usual, thus lessening the counterweight needed. A further smarter solution is that, before attaching the wing to the fuselage, the fuselage and the wings should be checked for their CG's respectively. Then the wings should be positioned on the fuselage where both of their CG's coincide with each other. This will minimize or even eliminate the balancing weight needed to balance up the aircraft.

4.4.3 Third Glider

i) Design

The main purpose of doing this fabrication practice is to gain experience fabricating the real thing. It would help the team to be aware of what can be done and what can't in the fabrication process. Through these practices, the team would be able to explore the fabrication techniques used, so that any problems faced now can be tackled easily later during the construction of the final aircraft for the project. Familiarization to as much of the fabrication processes as possible is very important to help smoothen things up in the future.

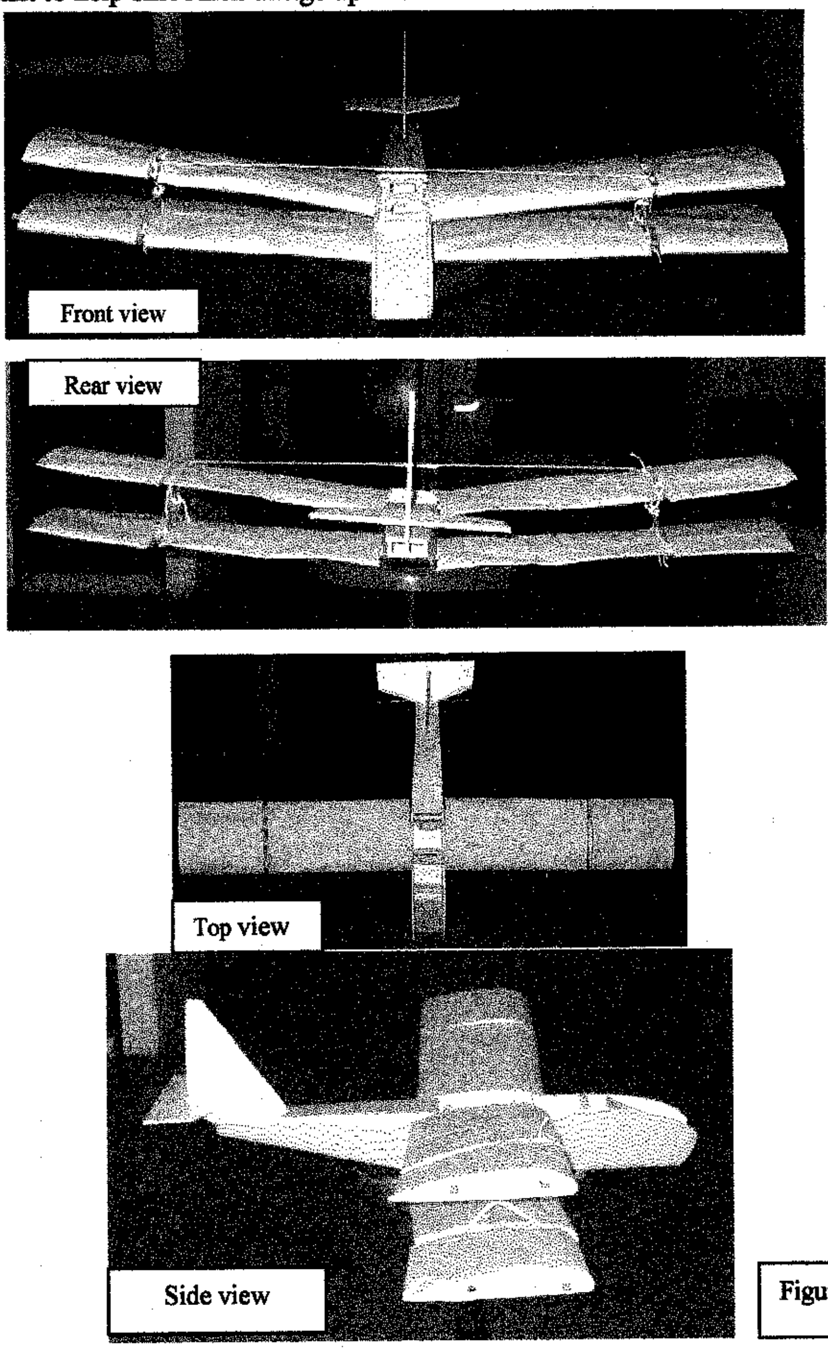


Figure 4.15

The fabrication of the third model glider (figure xxii) is very different to the previous done earlier this semester (2nd model). The team had decided to make a biplane, which have 2 wings; an upper and a lower wing. Mainly, this is because the team had realized that the lift provided by the wings of the previous gliders were insufficient. Thus, the most obvious step was to double the amount of wing area through a biplane configuration.

Generally, the wing construction method is similar to the previous, using the spar and ribs method. However the material used for the spar had changed. Now, bamboo is used instead of plywood. The ribs still use foam as before. For the cover, wrapping food plastic (cling film) was initially used, but it was a failure. It was a very tedious job, the film being very hard to keep taut it was a very frustrating task. After numerous tries, it was concluded that it was nearly impossible to cover the ribs decently and also the material was too thin and cannot be tautly and evenly stretched. It was finally decided that the previous material should be used, which was tracing paper as the wing's 'skin'

.

For gluing purposes, epoxy was still used, but only on the fuselage. For the wing part, which is the wing, mostly paper glue was used, especially for covering (wrapping) the tracing paper around the ribs. The epoxy was only used to hold the ribs onto the bamboo spar.

The final dimensions of the glider were as follows:-

- Wing span = 118 cm = 46.46 in
- Chord = 22 cm = 8.66 in
- Aspect ratio = 118/22 = 5.364
- Weight = 560g = 19.75 oz
- Wing area = 0.5192 m^2 = 804.76 in^2 = 5.589 sq ft
- Wing loading = 19.75oz / 5.589 sq ft = 3.534 oz/ sq ft

ii) Test-flight Analysis

During the test flight, it was fortunate that the first attempt of balancing the glider was successful. In the first test-flight, the glider glides beautifully before it started to stall because of speed loss in the end. The good thing was that when it stalled, it just dropped height vertically without pitching up or down. It was quite an experience seeing this big and overweight glider can glide nicely. However, because it was overweight, it had to be launch at a quite relatively high speed.

Initially the glider showed good flight characteristics, but after some time, the condition of the glider deteriorated due to several hard landings and one major crash.

Despite the fact that it glided surprisingly well, there were many things that were wrong about this 3rd glider. They were:-

a. The glider was too heavy. The construction of the wing was done too cautiously that it was overbuilt for structural strength. Bamboo is a good material to use as the wing spars because it has good strength for its weight. However, the spars used were too thick, thus contributing to the additional weight.

b. The cotton string used to keep the dihedral of the wings was too thick. Strings can be modeled as cylindrical tubes in moving air, which creates massive amount of drag. Thus, it would be a good idea to use as thin a string as possible to hold the wings up.

c. Several of the foam ribs broke during hard landings. This did not happen in the first two gliders. This could be due to the glider being overweight, thus exerting more than usual load on the wing during hard landings. But this matter will be looked into in the next model.

d. The wing had discontinuity where a bamboo structure holds the upper and lower wing together. This discontinuance will impose drag to the glider. Therefore, this continuance should be covered, so that the wing is one piece at each arm.

e. The normal stationary glue used to glue the paper wing cover to the ribs was not strong enough. After just a few flights, the wing cover had started to come off at several ribs, and had to be mended. Even though it could be easily mended but that particular wing portion will not be as taut as before anymore. Thus, other types of glues would be used in the future for the purpose.

f. From the fuselage perspective, the material used was covered foam, which is a bit heavier that normal foam. This is a disadvantage, as weight minimization is very important for an aircraft. Furthermore, the epoxy glue used was not applied properly as in the previous model. Previous model was very durable. For this current model, maybe the mixing of the glue was not well proportion 1:1 as before. Additionally, maybe the glue drying period was not properly done with care. The parts glued needs to be held together firmly during glue drying, usually by using heavy weights such as text books.

4.5 Final Aircraft

4.5.1 Wing Design and Structure

i) Design & Structure

After 3 fabrication practices, the time had come to fabricate the actual aircraft for the project. As a result of analysis of previous fabrication attempts, the team had finally came to agree on the final specification of the aircraft.

- 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

Furthermore, the team had decided to choose the biplane configuration, same as the third glider fabricated before. Mainly, this is because the team had realized that the lift provided by the wings of the first two gliders were insufficient. Thus, the most obvious step was to double the amount of wing area through a biplane configuration. The same fabrication method was used as the second and third glider, using the spar and ribs method. To add stability to the aircraft, the upper wing was made dihedral, which is the upward inclination, outwards from the center. Figure (4.16) shows the design of the wing of the final aircraft:-

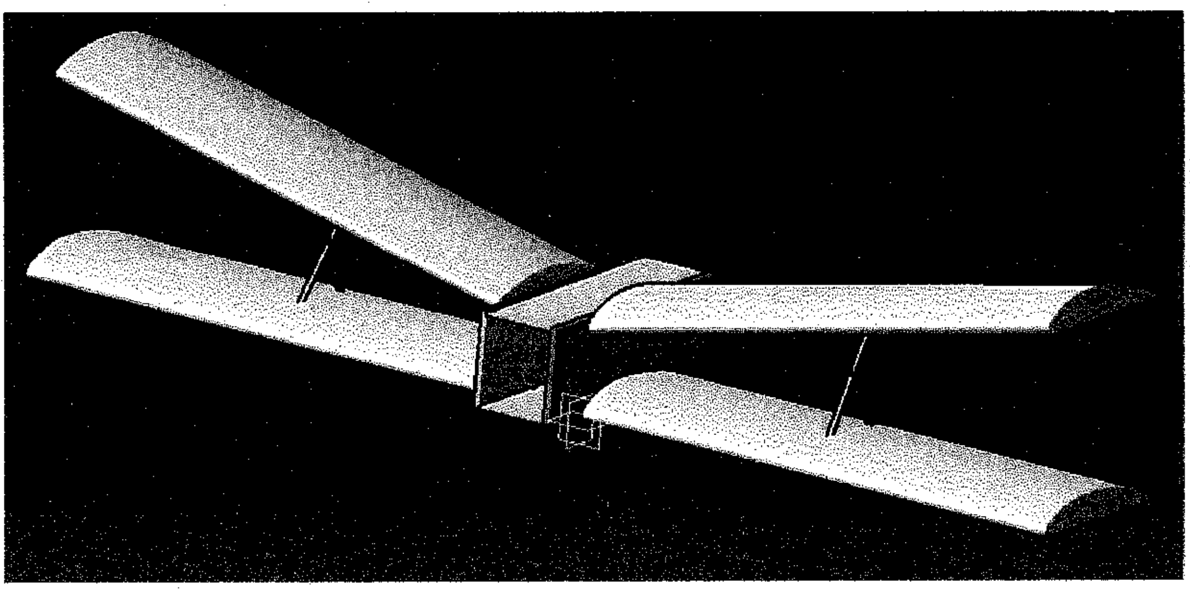


Figure 4.16

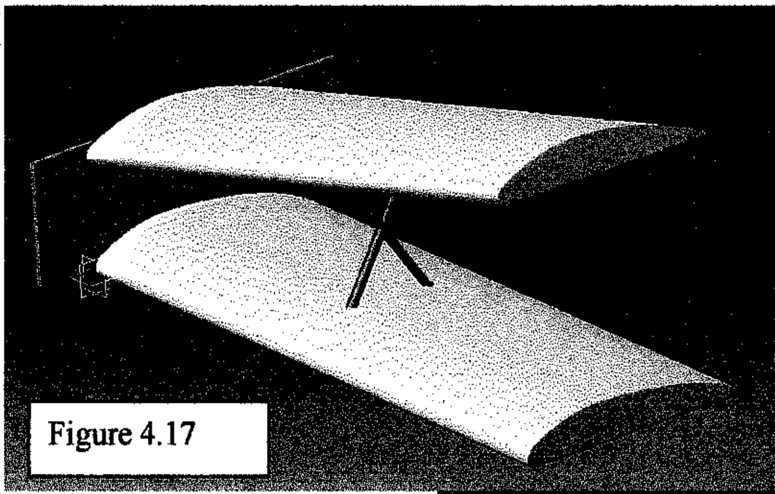


Figure 4.17

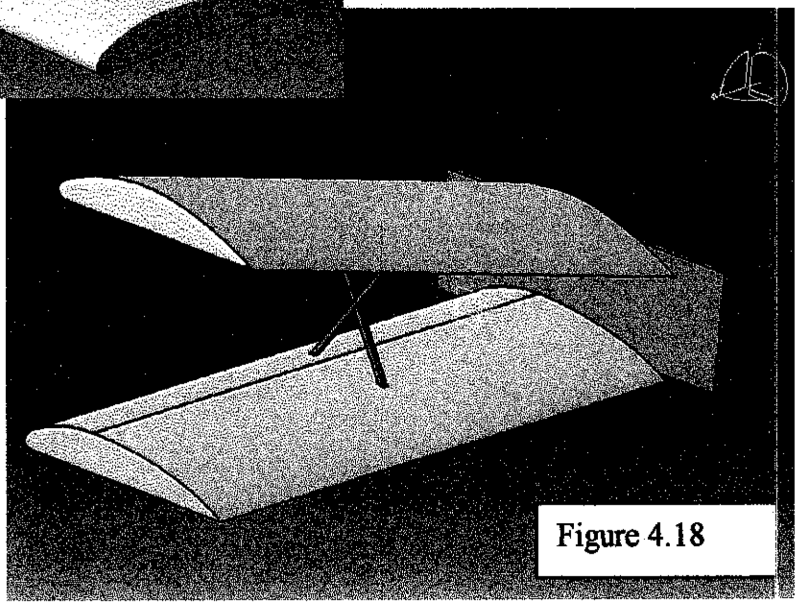


Figure 4.18

Figure (4.19) shows the inside structure of the wing, consisting of ribs and spars, and also leading and trailing arm reinforcement.

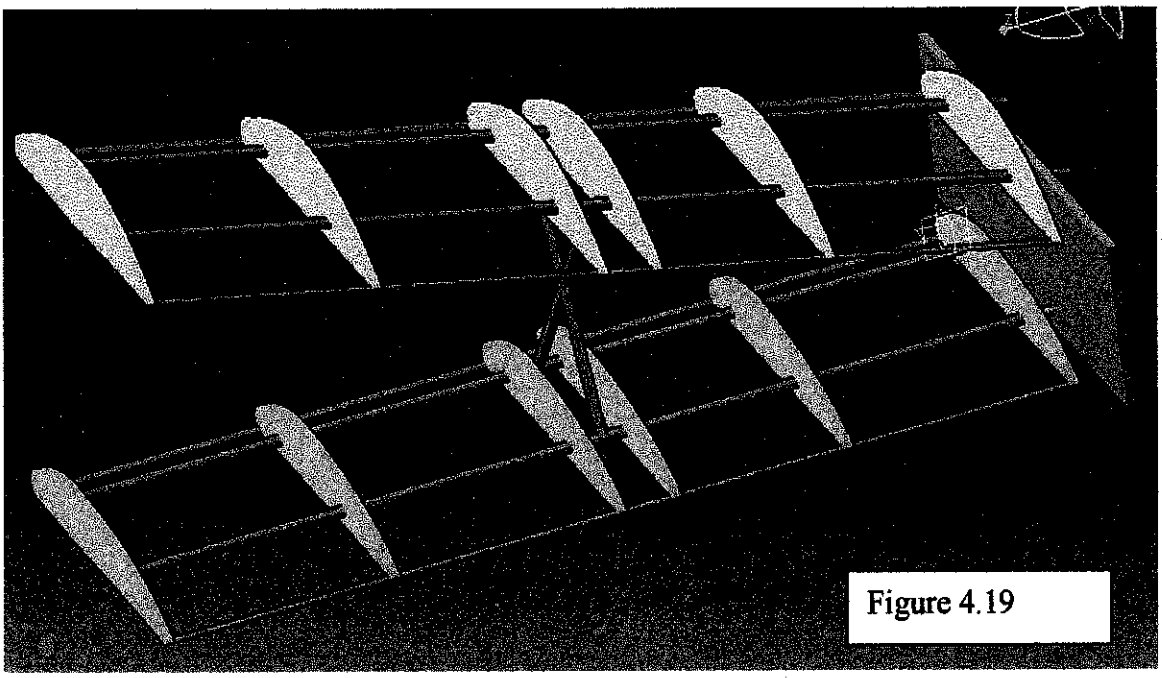


Figure 4.19

The reinforcement on the leading edge and trailing edge was added because of the observation from the previous two gliders. Previously, without the reinforcement, the leading edge and trailing edge tend to sag. It was hard to keep the wing covering taut. Furthermore, during hard landings, the leading and trailing edge would be fragile. The reinforcement also protects the ribs from damage. This is because each end of the rib is supported by the reinforcement, not just by the middle spars as in previous designs. This increases the durability of the wing section and also help keep the shape of the airfoil well throghout the span.

In the third glider design, the weight was too heavy, which is why the whole glider was 560g, even without components inside. The weight was kept down by using as minimum thickness of spar as possible. Throughout the wing, the thickness of the spars including the wing separator (holding the upper and lower wings together) are only between 3 and 4mm. Even thinner strip was used for the leading and trailing edge reinforcements. As a result, the weight for the wing section of the aircraft was succesfully trimmed down as much as 150.5g from the final fabrication practice.

ii) Airfoil Selection

For the final aircraft for this project, the same kind of airfoil was used as before, which is the flat bottom airfoil. Almost every remote control aircraft sites visited recommends this type of airfoil for stability at low speeds. Previously, the list of flat bottom airfoils was shortlisted to 6 alternatives. The are only slight difference between each designs, the only difference mainly are at the leading edge area, where the air meets the airfoil. Therefore, in the end, the RSG-31 (figure 4.20) was opted as airfoil for the project's final aircraft.

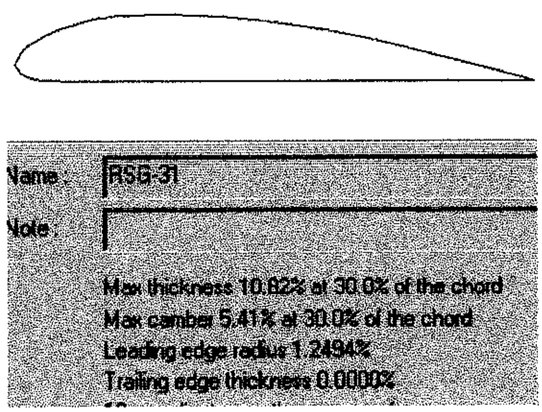


Fig 4.20

iii) Material Used

"Bamboo is attractive as a building material because it is very hard, strong and dimensionally stable. It is comparable in strength to northern red oak. This strength is why bamboo has traditionally been used for fishing poles. A fishing pole made from an oak or maple dowel would need to be three times the weight and twice the diameter to catch the same size fish, and the pole would snap with the slightest flaw in the grain. But a bamboo pole is light and flexible. I've seen surfboards and longbows made of bamboo also, which should give some indication of its strength and resilience. The key to bamboo's strength is that each strand of the grain is perfectly straight. There isn't a tree in the world that grows as straight as bamboo. And there are no branches so there are no knots. The only anomalies are the knuckles that occur every few feet. These slight variances are usually quite consistent and dense, and do not significantly weaken the structure of the material. And while bamboo is a light material, it is also remarkably stable with 50-percent less contraction and expansion than wood."

(Refer to Reference 14 for the source of the passage above)

From here, it is obvious that bamboo is among the most suitable material to be used for the spars and wing reinforcement for the aircraft. The material should be strong enough even when used in thin strands. No other readily available material which is low cost can compare to bamboo in fulfilling this criteria. In the design the spar used had a cross dimension off 7mm $\times$ 3.5mm, which is very thin for a spar. Thus, bamboo was the smartest choice to use.

(Refer to Appendix 3- paperwork on bamboo properties)

For the ribs, foam was used as it has good compressive strength, but at the same time being extra light. Lightness is very important as a lot of ribs would be used to support the airfoil shape of the wing. There are 24 ribs in the whole wing section of the aircraft. In addition, foam is easy to be shaped; by using foam cutter or just a sharp knife. Using foam really cuts down the weight as each rib weighing next to nothing.

For the cover, wrapping white paper was used, with the density of 60grams per square meters. This density is strong enough for the wing cover, and at the same time being light to save weight. In addition, the advantage of using paper is that it is much easier to be handled for the wrapping process compared to plastic film, plus it is more durable. Due to ease of handling, the wings skin could be made really neat and taut, compared to plastic sheets which tend to be untidy. Additionally, usage of paper gives ease of maintenance for the wing when there is damage to be repaired.

(Refer to Appendix 3- guide to covering wing with paper)

For sticking together the bits and pieces of the wing, two different glues was used; namely normal white paper/foam glue and crystal clear epoxy. The epoxy was used to hold the ribs to the spar. It took the glue about 30 minutes to set, and after 2 hours, the ribs and spar structure could already be handled. However, to achieve maximum strength, the parts glued should be left to settle for 8 hours. On the other hand, the white glue was used to hold the paper covering to the ribs. When the paper is stuck to the ribs, holding pins was used to hold the paper taut around the ribs until the glue had hardened and settled. Finally, the holding pin was removed in the end.

iv) Wing Structure Under Vertical Loading

The software CATIA was used to test the structural strength of the wing design. The parameters used for bamboo parts were Young modulus = 1.8×10^{10} N/m^2, tensile strength = 15 kN/cm^2, compression strength = 3.9 kN/cm^2 and bending strength = 7.6 kN/cm^2. The force loaded to the wing structure was 7.5N which was represented by the designated yellow arrows (figure 4.21). Usually, for a 650g aircraft, any point on the wing surface experiences much lesser than 7.5N at normal speeds, but the most it can be be is only around 4 to 5 N. The structure was clamped at the two blue symbols, on the fuselage surface, furthest to the right. The resultant deformation is shown in figure (4.21). In this setup, when the force is exerted to the wing, it simulates the aircraft flying with full load of components and hitting a gush of air, pushing the wing up at the tips.

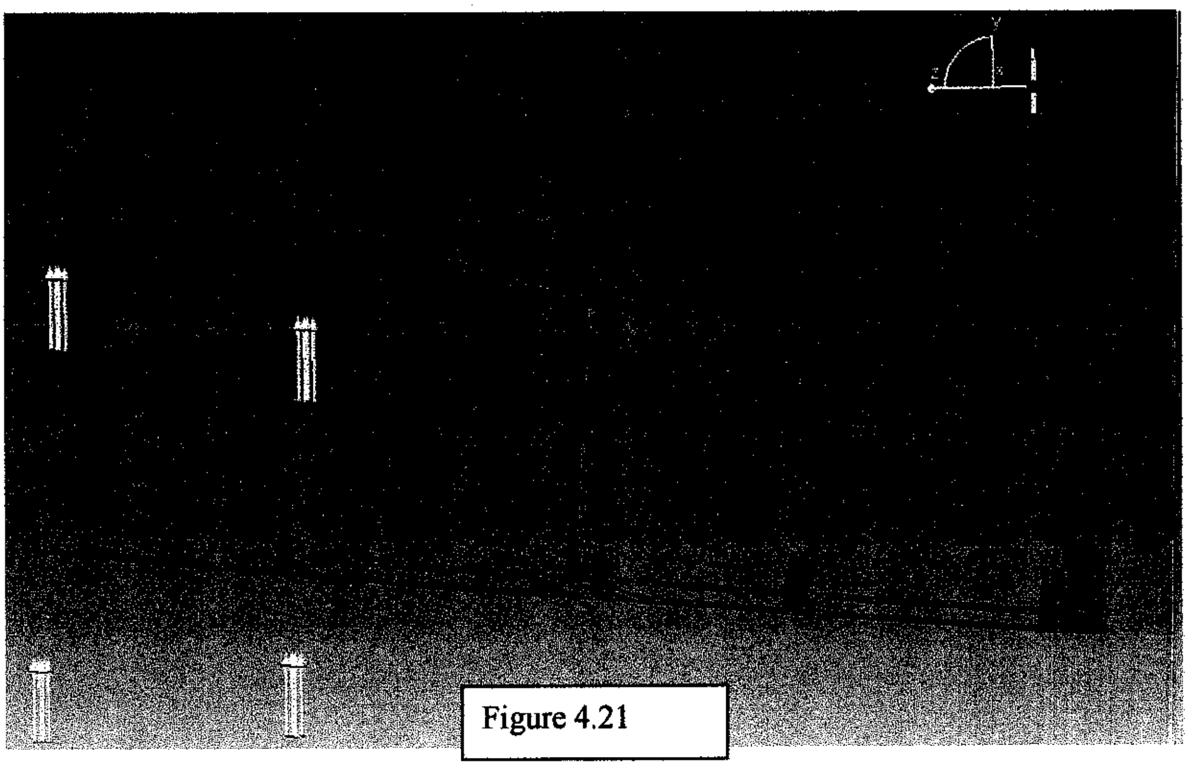


Figure 4.21

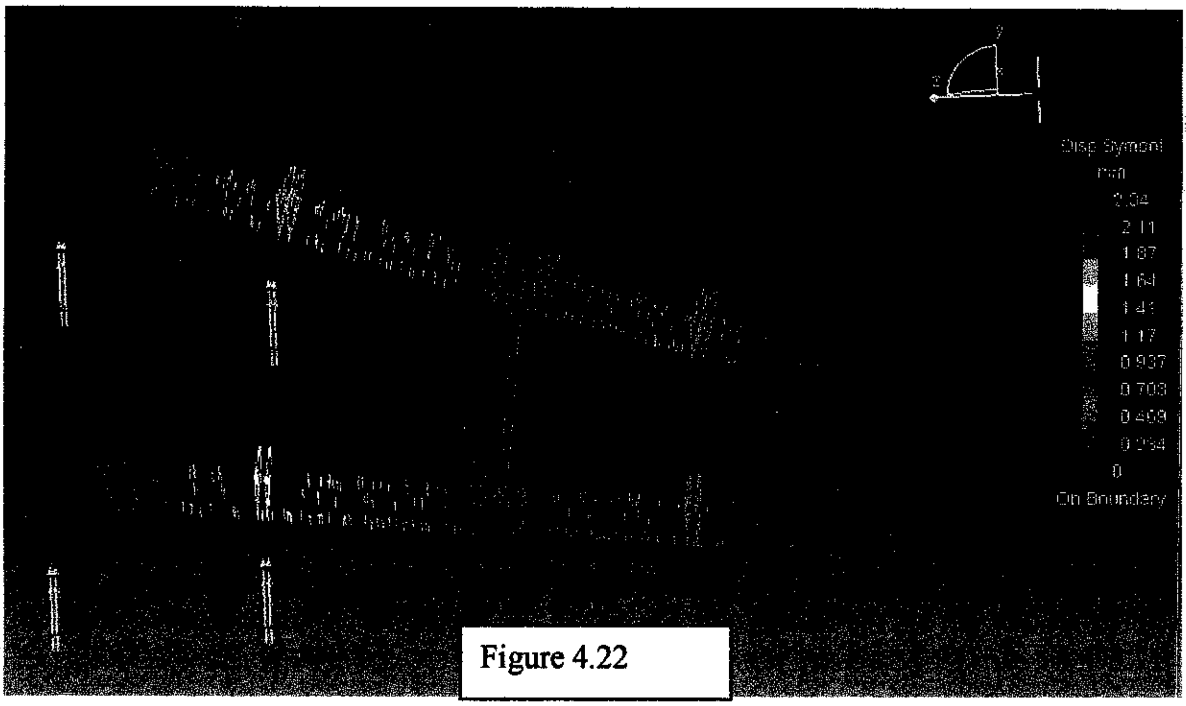


Figure 4.22

The figure (4.22) above shown here is a graphical analysis that shows how much deformation is experienced by the structure under the 7.5N load. As can be seen here, the most deformation is experienced at the tip of the wing, maximising at about 2.4mm. The deformation gradually lessens as the distance to the fuselage wall decreases. This deformation result shows that the wing rib and spar structure can withstand relatively high loads while flying.

In figure (4.23), the red spot which the arrow is pointing at, shows that spot is where the wing structure experiences the most stress during flight. Furthermore, the figure also shows that the lower wing structure experiences high stress all the way from the fuselage wall to the wing tip. Where as, the upper wing only experience high stress starting from the upper/lower wing connector (× structure) to the wing tip.

Besides that, in figure (4.24), the arrows show exactly which part of the structure experiences high stress. It is shown in this diagram that high stress is also located at where the connector (× structure) meets the spars of the wing. This is the area where the structure starts to bend up at a higher rate.

Also in figure (4.24), it also shows quite high stresses at the area where the wing spars are attached to the fuselage. This indicates that the area needs to be reinforced a bit to handle the extra stress. One option is to use paper tape to reinforce the hole so that the spar does not eat into the fuselage after frequent hard landings. .

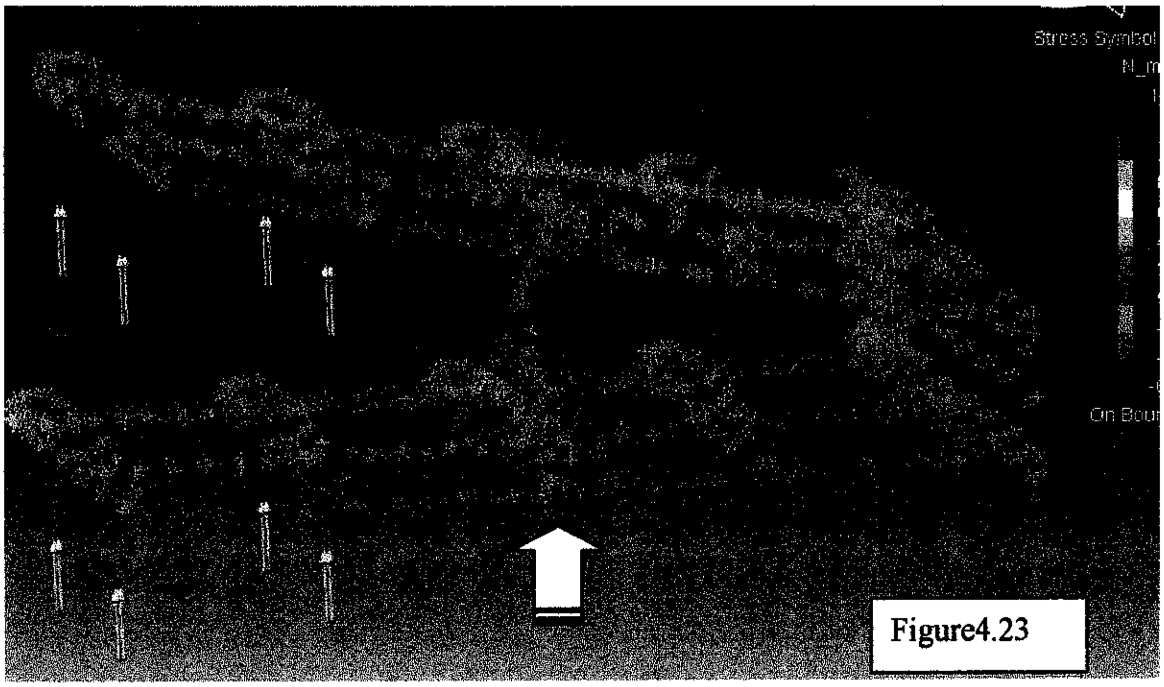


Figure4.23

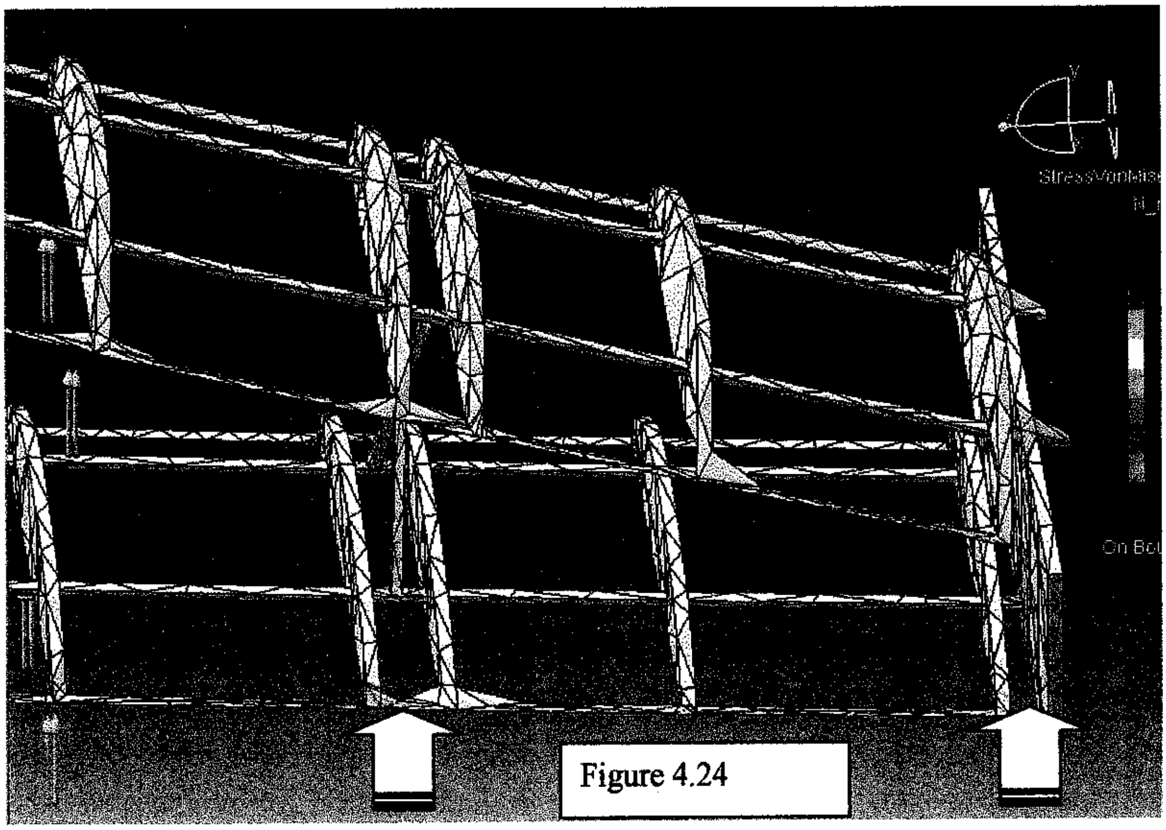


Figure 4.24

v) Wing Structure Under Horizontal Loading

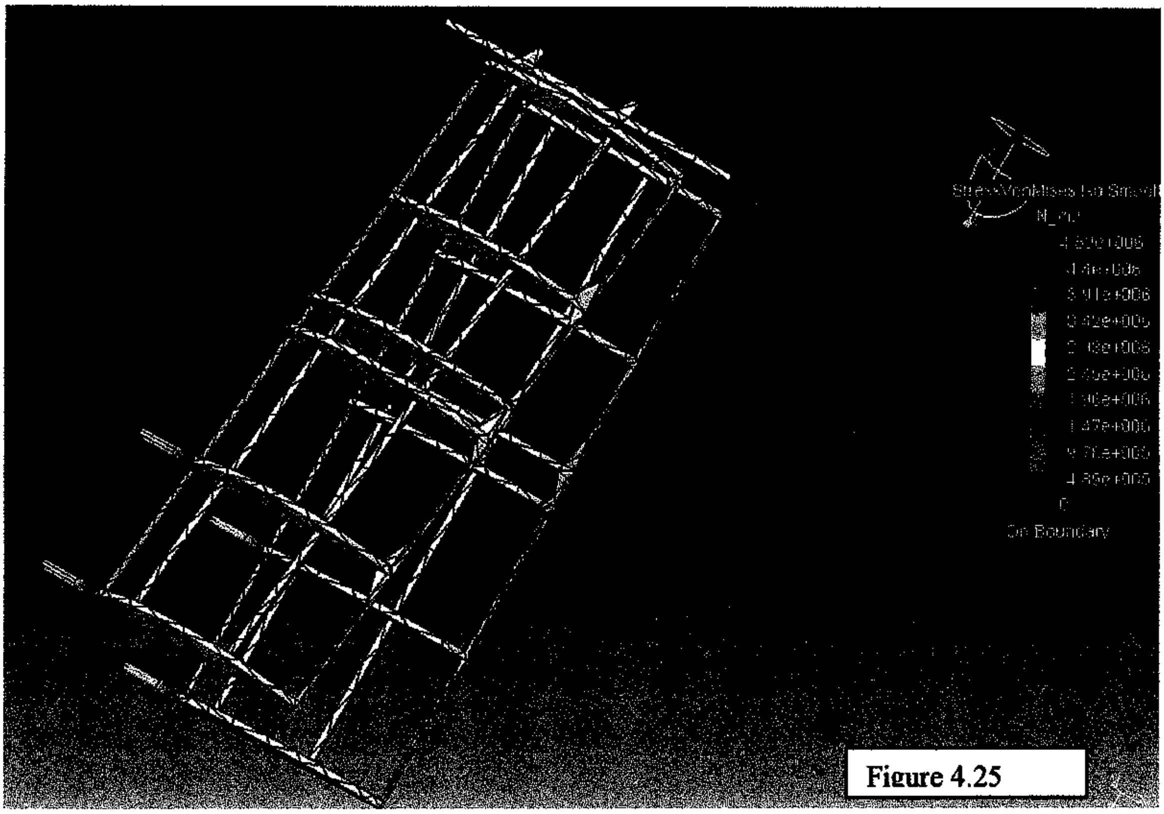


Figure 4.25

As before, the same design as previous analysis was used. However, the orientation of the force was changed. This time, the force was applied horizontally against the wing from the front, in other words parallel and opposite to the direction of flight. Again, this force is represented by the yellow lines in figure (4.25). 10N of force was used this time to simulate the event of a frontal crash of the aircraft, where the end of the wing hits the ground first.

The figure (4.26) shows that the deflection is most at the wing tip, and decreases as it gets nearer to the fuselage wall. The defelection is very minor, as the maximum deflection is only about 0.11mm. However, on the real aircraft, the wing can be deflected quite relatively easy as the quality of the build is not that perfect. The wings is not perfectly solidly held by the fuselage, as the wing can slide inward and outward slightly against the fuselage, allowing excess deflection to the wing.

Additionally, it can be observed (figure 4.26) that the lower wing experiences more deflection than the upper wing. This relates to the (figure 4.27) which shows that the lower wing experiences more stress (longer stress marks along the leading edge and spar) compared to the that of the upper wing.

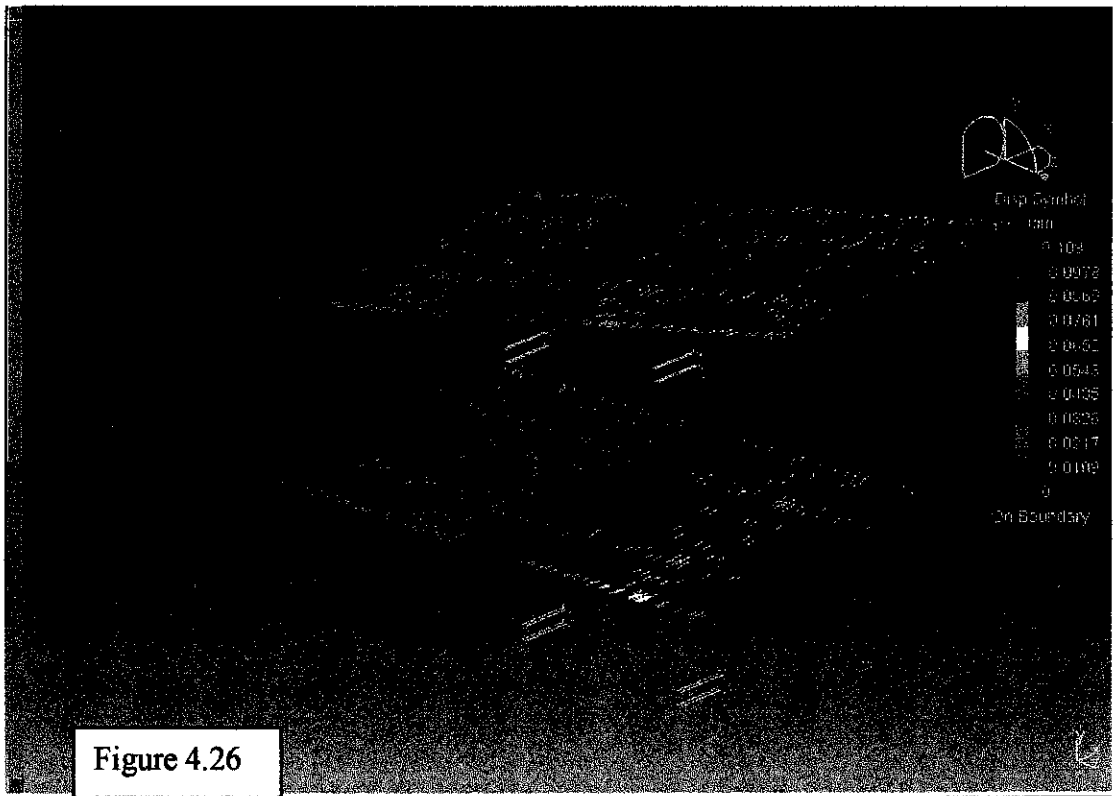


Figure 4.26

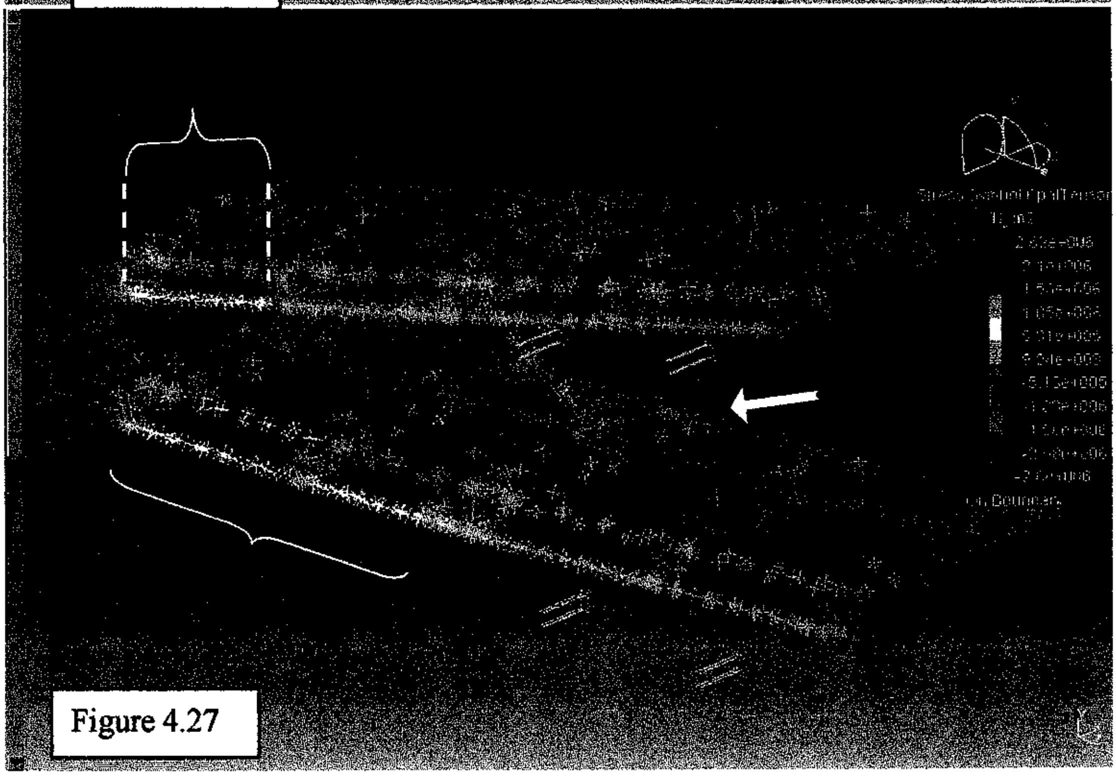


Figure 4.27

The figure (4.27) shows the maximum stress experienced by the wing structure uder horizontal loading at area where the big white arrow points at (center of lower wing at the trailing edge). Surprisingly, the area is the same as the area for the most stress experienced during a vertical loading as in the previous section. This shows that this area needs to be reinforced as in a normal crash or hard landing, the wing will be experiencing both vertical and horizontal stress, adding to the risk of the area to break.

From the deflection observed in this analysis, it can be concluded that the wing can survive crashes at normal speeds. This is evident as from both analysis, the wing only experience minor deflections. Furthermore, the wing is much stronger horizontally than vertically, mainly because the spar used is longer horizontally (7mm) compared to only 3mm vertically. This explains why the wing deflects much more vertically than horizontally.

4.5.2 Final Aircraft Design

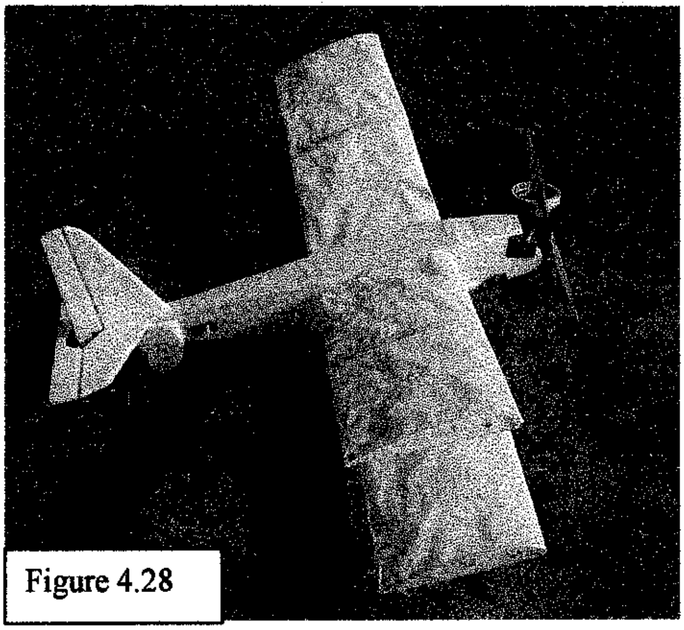


Figure 4.28

(refer to figures (4.28) for this section)

i) Specifications

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

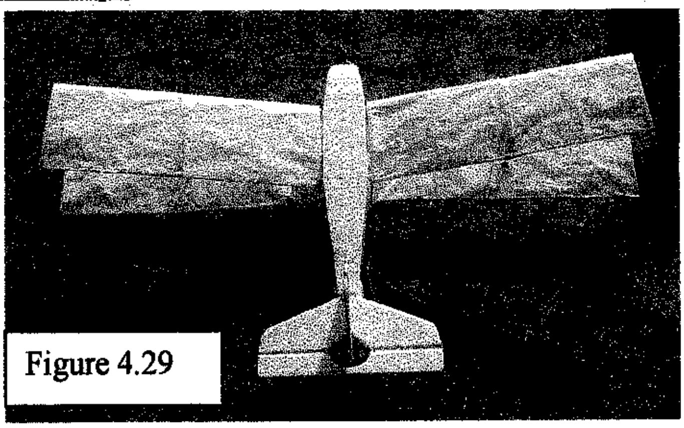


Figure 4.29

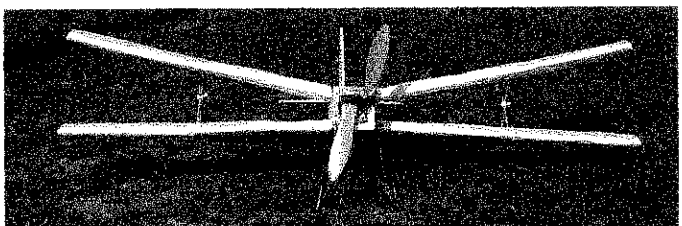


Figure 4.30

The aircraft failed to meet targeted weight of under 500g. Even though the weight of the wing section have been decreased a lot by the thinning of the bamboo spars used and the effective use of glue, the weight reduction was not enough. The weight reduction of the wing resulted in the drop of the total weight of the aircraft alone (excluding all components) to 356g, compared to the previous glider weight of 560g. (200g drop)

ii) Fuselage

The team had agreed that the fuselage was to be made using foam. The major cause of using foam is that foam is very light, but it has very good compresive strength. To compensate for its low shear strength, the design of the fuselage must be right so that each sides support each other well in case of an impact. One of the ways used were using ribs along the length of the fuselage. This way, the length of unsupported foam wall (between subsequent ribs) would be decreased, thus strengthening the build.

iii) Tail-end

There's no one responsible directly in designing the tail-wing setup. Thus, the author took the responsibility for this and decided to use available designs, such as for Bantam flyer and Fatty Sparrow design, which are quite similar to each other. However, to make things simpler for the fabrication process, the elevators on both sides are extended so that they can made into one piece, giving better strength & simplicity.

iii) Landing Protection

For the protection to the aircraft during landing, the team had installed landing gears and rear end sliders. The landing gears are self-made using a set of landing tyres bought of-the-shelf and a set of interconnecting wire gauge as the legs. At the rear, a slider was design so that during landings, the rear tail section would not hit the ground and get damaged. Its disadvantage is that for static take off on runways, the slider had to be modified to incorporate a wheel to allow it to roll on the runway. However, the team had decided that the slider would be efficient because the testflights would be conducted by throwing the aircraft into the air.

iv) Electonics and Electric Parts

The selection of all electronic and electric parts that was used were the responsibility of Mr. Izwan, the sole electrical student of the team. He had to decide which parts were suitable for the specification of the aircraft, and also according to the team's financial budget. Basically, all the components that are in the market have specification tables, specifying their capability ranges. From there, after knowing the specifications of the aircraft, the right components was chosen and bought for the final aircraft fabrication.

4.5.3 Test Flight Analysis

The test flight was done under low wind condition, on a hot sunny morning. The test flight was not successful as the aircraft failed to fly, but instead it just glided down and continues to lose altitude until it lands.

Figure 4.31

During the test flight, the aircraft crashed twice (figure 4.33). One of them was because of a sudden wind gush putting the aircraft unstable. Due to the aircraft not being able to pull up, it could not recover and thus crashed. The other crash was because the aircraft became unbalanced. It was because, during the previous landing, the battery went out of place, thus changing the aircrafts balancing point. Hence, during the following test flight, the aircraft was unbalanced thus causing the crash.

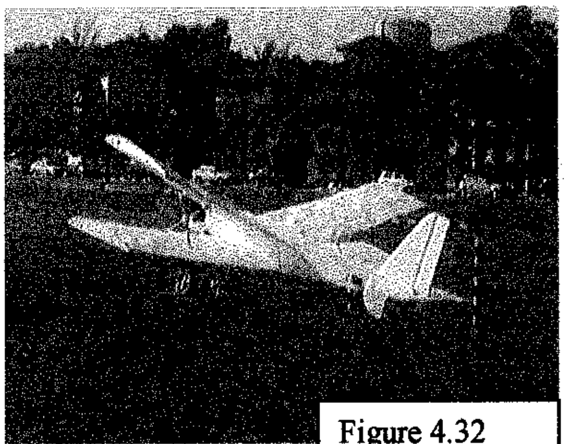


Figure 4.32

One more problem was that, the aircraft acts as if its tail heavy, eventhough modifications have been made to rectify the problem.

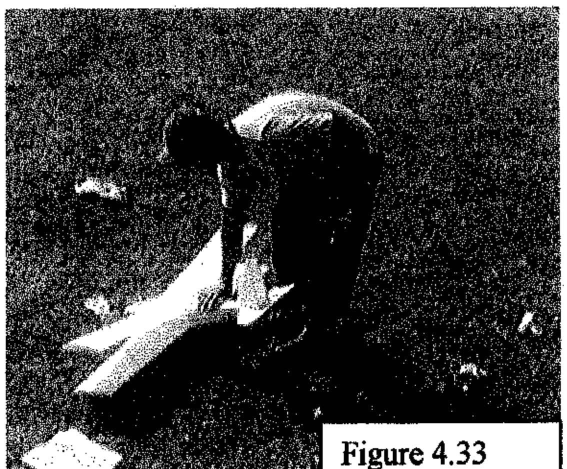


Figure 4.33

There are several possibilities for these problems to happen:-

i) The aircraft looked as if it did not have enough propulsion power to propel the aircraft into flight. One of the reason was that the target weight of the aircraft was below 500g. Unfortunately, the team managed to only trim down the weight to 650g. Therefor, the motor chosen according to the targetted load was underpowerred, thus incapable of providing sufficient lift for the aircraft.

ii) Referring to the design guide from http://users.mo_net.com/shirl/Design.htm quoted:

"If the tail hangs down, it means that there is not enough positive incidences in the wing. Thus, the leading edge needs to be raised a degree or so. (or lower the trailing edge). The behavior shows that the wing needs to attack the air at a higher angle, probably due to the overall wing loading of the model."

It is from this article that it was realized that the design was lacking the angle of incidence, or in other words the wing was attached to the fuselage with too small angle of attack. Subsequently, the aircraft acts as if its tail heavy even though modifications have been done to its center of gravity numerous times. However, even so if this is the case, the aircraft would have been able to fly (with the tail hanging down) if the aircraft were to have enough propulsion power, But it might be possible that with the current power system, the aircraft could have been able to at least maintain level flight if the angle of incidence of the wings were right. This is because, the tail hanging down during flight would create a lot of drag thus more power would be needed to maintain the aircraft airborne.

Unfortunately, time was running short, preventing the team from doing a second test flight of the aircraft. There was just enough time to only do analysis in finding what went wrong and completing the weekly and dissertation report.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

As a conclusion, the team had done its best to achieve the objective of the project, even though there are still many steps that have not been taken that can increase the quality of the outcome. The team had done what they could have done, with the limited time given, while carrying other subject loads upon their shoulders. Thus, these un-taken steps are left for future teams to take, to improve on the project and to insert more engineering into the project. It is hoped that in future, the next team would be able to continue from where the current team had stopped, to continue on and become successful. It is also hoped that one day, the achievement from such projects could help to raise the profile of Universiti Teknologi Petronas in its goal of becoming among the best academic engineering institution in the region, if not the whole world.

5.2 Recommendation

5.2.1 Future team should look into doing analysis using ANSYS or similar software's to determine the best airfoil that could be used. This is to ensure that the airfoil chosen would be the best lift provider among the list of the airfoils short-listed. This also help ensure that the wing can provide enough lift for the aircraft and its load, while showing proof that it mathematically can do it.

5.2.2 Future team undertaking this project should do more fabrication practices. After familiarizing with the terms and concepts involved, they should quickly start practicing fabrication. This is to give more understanding to the members of what each of their parts are all about. It will help them know what should be analyzed and calculated. This way, no important aspects would be left unaccounted for. Furthermore, fabrication also help team members to understand better about other team member's part, thus helping them to know the 'whole picture' of the project better. The frequent practice would also increase the team's ability to solve fabrications problem, thus help to smooth things out during the real fabrication process for the real product/aircraft.

5.2.3 For further improvements, as this project is more towards a manufacturing project, future team undertaking this project should show how effective the fabrication process is compared to the actual design. They should compare the actual dimensions of fabricated models to the actual designs and find ways on how to improve the fabrication process from one fabrication try to another.

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APPENDICES

Appendix 1

(http://users.mo-net.com/shirl/Design.html#top)

Here are some design thoughts

First let me say that I do not hold myself out as the ultimate authority. I do reserve the right to be smarter today, than yesterday. That way I get to change my mind. These notes are simply my understanding of how airplanes fly. There will be very little math and what math I will offer will be pretty basic. I have scratch built a lot of airplanes. Some flew, while one made a snappy looking race car (didn't get off the ground).

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General

Yes. If you have a better and simpler explanation of one of these items, I would appreciate your email. I don't want to get into physics or theoretical discussions or calculus or any other complication. In other words don't confuse me with facts. Here we talk simple logic. What works ,what doesn't, and why, told in an easy and understandable form.

If you haven't tried to design a model you are missing out on one of the greatest thrills in modeling. In addition you get to show off a brand new idea to everyone. Yes it takes time but once you do it, it gets easier. I hope to explain some terms in the process, just in case you are brand new to the hobby.

What you need handy

Chuck Cunningham wrote for Radio Control Modeler for a long time. About once a year he offered some basic criteria for designing your own model. I use his criteria as much as possible. Next, if you don't own a copy of Model Aircraft Aerodynamics by Martin Simmons, published by Argus Books then let me recommend it. Now all you need is a tablet, quad ruled with 4 blocks to the inch, a ruler, a pencil and a huge eraser. After you get the general airplane figured out & the side view drawn on the small pad, you then need a roll of meat wrapping paper to make your initial full scale drawing, and a 60 inch straight edge. That is about as basic as you can get. Yes, every one of my airplanes, from the Ligeti Stratos, the Mooney, the 1/2A Sky Pecker and even the 18 foot Sailplane were first drawn on a regular size notepad. After they looked right (subjective), the dimensions were transferred to the meat wrapping paper. Yes I know meat wrapping paper isn't dimensionally stable and that it isn't the best way. Like I said above .... let's keep it simple for now. I always try to be creative and try to make my craft look like an airplane ... and if not pretty, then something with character. Not look like a 5 gallon bucket of Monkey butts. (a phrase used by friend Jerry Shoemaker when describing another friend's 1996 Cadillac. (where the hell he came up with that one I'll never know-- and yes he has a very cruel sense of humor) Back To Top

Design Parameters

Here, the first thing you want to figure out is the wing span. Everything else keys from that. Next you need to get a handle on the power needed to fly whatever you come up with. If you scan a few catalogs, you can get some general ideas of what power plant goes with what wing span and model weight. After awhile you will soon realize the power parameter and just about everything else can be varied somewhat. For example you would initially think an old 60 four stroke would never fly an 18 foot, 19 pound airplane but it does on my Ultimate Solitude powered sailplane. Mainly because it has a lot of wing area. (the length of the wing times the width = the area). On the other hand my initial Mooney (the Blue one) has about a thousand square inches of wing area and weighs 14 pounds and is marginal on an O.S. 120 four stroke. Actually it fly's more scale, but you need some runway to get off.

So one of the first things you need to estimate is the wing loading, and how to figure it out. If for example your wing is going to be 80 inches long (SPAN) with a width (CHORD) of 13 inches, then your wing area will be 13x80= 1,040 square inches of wing area. Now that we have figured that out I will throw in another term called aspect ratio. Aspect Ratio is the width of the wing (chord) divided into the length (span). Generally a sailplane has a greater aspect ratio, maybe even 20 to one. The wing we just figured out has an aspect ratio of 80 divided by 13 which equals about 6 to one. Six to one is a good number for a basic airplane.

But back to calculating wing loading. First you take the area of the wing and divide it by 144 to get the actual square footage of the wing. In our case 1040/144= 7.22 sq. ft.. Next, if we have properly estimated the weight of our model..... for this example let's say it should weight about 14 lbs..... so we now need to convert pounds into ounces. Sixteen ounces to the pound x 14 pounds = 224 ounces. So to calculate wing loading you divide the weight in ounces by the square footage. i.e.- 224 divided by 7.22 = 31 ounce wing loading per square foot. At this point you pretty well know how the airplane is going to fly. It will fly a little faster than you might like and the landing speed too will be higher than you might like. For models of 80 inch span you generally want wing loading around 22-26 ounces per sq. foot. Keep in mind that the larger the model becomes, the higher wing loading you can handle without adverse effects and vica versa. A very small rubber powered model may come in around 3-6 ounce wing loading. Yes there are a lot of other factors that will affect how your model fly's but then we get into complications we don't want to cover here.

Next we will define other parameters such as determining the area of the horizontal stabilizer, the area of the vertical fin and rudder, the length of the fuselage, the nose and tail moments, & the area necessary for ailerons if you are going to use them.

The Horizontal Stab should equal about 12-15% of the wing area with about a 3 to 1 aspect ratio.
The Vertical Fin & Rudder should equal about 33% of the Horizontal Stab/Rudder with the Rudder itself consuming about 1/3 rd of that area.
The Length of the Fuselage should be about 75% of the length of the wing.
The Nose Moment (oh gawd another term) around 25-30% forward of the wing balance point.
The Tail Moment in the area of 65-70% of the fuse length (and aft of the balance point)
Fuselage height around 10-15% of the fuselage length.

(below I will define Nose and Tail Moment)

Aileron Area should be about 10% of the total wing area with the length of each about 8 times its width.
Landing gear placement should have the axle even with the leading edge of the wing on a tail dragger. On a tricycle gear you need the main gear slightly aft of the balance point. If you run a vertical line from the wheel touch point and then a line from there through the C.G. and note the angular difference, it should be between 15 and 25 degrees on a tail dragger.
Separation between wings if you decide to build a biplane. Vertically they must be separated by at least the Chord (width) of the largest wing.
Nose Moment - the distance from the balance point of the wing (approximate aerodynamic center of lift) forward to the prop. Most wings should be balanced initially 25% of the average chord back from the leading edge of the wing.
Tail Moment - the distance aft to the tail from the 25% average chord of the wing.

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The Wing

Let's talk some more about the wing. Most average airplanes fly because of the wing. Duuuahh!
Seems simple enough. Most average airplanes under average conditions land because the wing stops flying. Again ..... duuuaaah. The wing stops flying (stalls out) before landing.... or it loses lift or whatever you wish to call it. The reason I say this up front is because you and I have both seen flyers DRIVE their airplane to the ground rather than let them settle in for a nice smooth and cool landing. If it is windy, then you too need to DRIVE your model to the ground with more power than normal because it gives you better control. But generally you need to pull in some up elevator until the craft begins to lose altitude, then continue jockeying the flight controls slightly so that you can FLARE OUT (lose all lift) just before you land. That way your model won't just bounce up in the air again and start flying all over again.

Here again in generalities ... most models need to be balanced 25% or more back from the leading edge of the wing. If the wing is 13 inches wide, it needs to balance 3 1/4 inches back from the leading edge no matter what or how much is attached to the wing (--fuselage, tail feathers, landing gear, etc.). If you start your initial test flight with anything other than 25% aft, you are probably going to be surprised. You don't need these kind of surprises. To make your model less sensitive to flight control movements, you can balance at 2 1/2 inches for example. To make your model more sensitive to flight control movements, then move it back to 33% aft of the leading edge. The farther aft you move the balance point the touchier things get. I offer this very simple explanation at this point because it is something you really need to understand when you get into designing Canard's and/or tractor designs (engine up front) with lifting horizontal stabilizers. If you have ever flown a Carl Goldberg Sailplane (it was designed around the early 40's as a free flight) you quickly realized it thermaled & flew better with the balance point about 25% aft of the TRAILING edge. If you want to see what this old timer looks like then click here . I suspect the same could be true with the Hobby Lobby Telemaster ..... I mean the Telemaster probably will fly with a balance point way farther aft than 33% because it has a lifting horizontal stabilizer. Lifting ... meaning it too has an airfoil just like the wing rather than a flat plate stab.

Here is a simple way to figure out where to balance a tapered wing, assuming it is a straight taper. We will use an example of a 14 inch root chord and a 7 inch tip chord. Add the two together and divide by 2. 14+7 = 21/2 = 10 1/2. If half of your wing is 40 inches long, then measure out 20 inches and the chord at that point should be 10 1/2 inches. You need to balance 25% back from the leading edge of the AVERAGE chord of the wing. So 10 1/2 divided by 4 is 2 5/8 inches back. From that point, make a 90 degree line directly to the root of the wing and that is the balance point, even if the wing sweeps back.

Note: Sweep back normally helps stability whereas sweep forward is somewhat de-stabilizing. It is felt that the sweep back adds to the Dihedral of the wing. Oh lord ... another term. If you look at an airplane directly from the front or back you may see that the tips of the wing are physically higher than they are at the fuselage. This is dihedral. It adds to stability. Model sailplanes have about 6 degrees of this stuff, while low wing models may have up to 12 degrees. I usually just eye-ball it. What the heck. Slam the damn thing together and go fly it. Right?

Another thing you want to design into your craft are the stall characteristics. You want the inner portion of the wing to stall before the outer portion and you either want a sharp stall or a mild stall. The shape of the leading edge defines whether you have a sharp stall (a sharp leading edge) or a mild one (with a more rounded leading edge). Let me point out an observation. A rectangular wing needs no twist in it (wash) as the inner panel just naturally stalls before the outer panel. A tapered wing DOES need some WASH OUT (twist). Whereas an indoor models wing looks more like a propeller with the right panel trailing edge twisted up (WASH OUT) and the left panel trailing edge twisted down (WASH IN).
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The Airfoil

Now if you really want to learn about airfoils and how to plot them I may cover that later. For now I won't. Why? Mainly because about any ol shape you lay out will fly. Some better than others. You can get perfection later if you want. For sport flying and biplanes I like the NACA 2415. My friend George Sauer likes a NACA 23012. Both are basically a semi symmetrical airfoil. What is an airfoil. Well look at the end of any wing and you will see a shape. The top part is rounded and the bottom may or may not be rounded. The shape is what is called the airfoil. I like some of the Eppler airfoils. Haven't tried any of the Selig-Donavan airfoils but will someday. Another friend Dennis Reichenberger draws out, what he calls, a tear drop airfoil. Big ol round leading edge with the high point maybe 15% aft of the leading edge. It fly's very gentle. All of his 9 foot Quadra powered airplanes are made totally of cardboard and have unparalleled flight characteristics. Anyway .... just draw out something that looks like an airfoil and try to make the high point about 25% back from the leading edge. If you want a more aerobatic airplane then make the top and bottom of the airfoil curvature the same. If you want a trainer kinda airplane then make most of the bottom flat. About 35 years ago many people used a diamond shaped airfoil. They drew a round leading edge, then a straight line up to the high point on the top of the airfoil (about 25% back from the leading edge), and a straight line from that point to the trailing edge.

Next ... how thick do you need to make the airfoil? (from bottom to top). A good number is 12 to 15% of the chord. If your wing chord is 13 inches, then it should be about 1 3/4 inches thick including sheeting and covering. The thicker you make it, the more drag but probably more lift. The Ligeti model has an 18% thickness on the aft wing and about 13% thick on the front canard. Back To Top

Wash Out

If you want a tapered wing then just remember that the more you taper, the more WASH OUT you will need. The Mooney has a 50% taper as I recall. The ROOT (the middle of the wing) chord is about 14 inches and the Tip Chord is about 7 inches. This wing also has a symmetrical airfoil at the root and a flat bottom airfoil at the tip, just like the real one. It HAS to have about 3 degree's of WASH OUT. The trailing edge of the wing, out at the tip, has to be raised about 3 degrees and if you don't have it, it just fly's like crap. This twist needs to be linear in that it gradually twists from the root to the tip. If you don't have the proper twist (wash out - trailing edge higher than the leading edge) the tip of the wing stalls out before the middle of the wing. When that happens, the tip of the wing drops down violently when it loses lift and causes the airplane to try to flip on its back. Not good. A long slender wing (high aspect ratio) such as you will find with sailplanes need less twist. After you have drawn your airfoil, you need to approximate about where the middle of your leading edge circle is and make a mark there. Then plot a straight line from that mark to the trailing edge of your airfoil. We will call that a datum line. The datum line needs to be tweaked up at the trailing edge 3 degrees for a 50% tapered wing. Note: Sometimes a wing will do this kind of a flip anyway and this suggests that you may have your balance point too far aft. Back To Top

Wing Incidence

Above we talked about the datum line of the airfoil. You will probably need to draw this kind of a line for the fuselage. Pick out a place about midway (vertically) on your fuselage side and draw the line from the nose to the tail. Generally you will place your horizontal stabilizer flat in relation to this line. Your wing placement in relation to the fuselage datum line can vary some. Again, generally I want the wing to be zero degrees incidence from this line. Same for the horizontal stabilizer. The heavier wing loading your airplane has the more you want the wing to have positive incidence. This means that the leading edge of your wing, when viewed looking at the side of the fuselage drawing, needs to be up from 1 to 2 1/2 degrees. I do the same with biplanes. Zero degrees all the way. Some like the bottom wing to be more positive than the top wing, so that the bottom wing stalls first, letting the tail end come down first on landing and it also makes for better snap rolls. I understand that most real biplanes with positive stagger (top wing ahead of bottom wing) have more incidence in the top wing so that it will stall first, causing the nose to drop and stall recovery will be quicker. My der Jager was kitted that way and it originally didn't fly the way I wanted, so I changed it. Now it fly's better.

After you fly the model you will want to observe how it fly's. Is the tail end hanging down or is it way up? If it is hanging down that means you don't have enough positive incidence in the wing so you will need to raise the leading edge of the wing a degree or so. (or lower the trailing edge) The model has told you that the wing needs to attack the air at a higher angle, probably due to the overall wing loading of the model.

Now if you really want to impress someone, then talk about DECALAGE. Hey weird-o what's the decalage on your airplane? Weird-O answers ...... " I thought I got all that stuff off ... damned cat!" The word simply means the angular difference between the wing and horizontal tail surface. If the rear end is set at zero incidence and the wing at +2 degrees incidence then the DECALAGE is positive 2 degrees. Not only that but no one really cares unless they are working with Indoor Models or rubber powered outdoor ones. Still it really doesn't matter in my mind because you have set the incidence at both ends the way you wanted them so screw it.
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Thrust Line

If you look at the side of your engine it is pretty easy to imagine the line of the crankshaft from fore to aft. This is the thrust line of the engine. Unless your engine is a firewall mounted engine, the mounts will be horizontal to the thrust line. If it is firewall mounted, then the thrust line has to be imagined along the line of the crankshaft and exactly 90 degrees from the firewall vertical mount. When you mount your engine, make sure you have built in 2-3 degrees of right thrust (engine pointing to the right for a tractor set up (engine up front), and 2-3 degrees of down thrust. (crankshaft pointing down). This imaginary thrust line is in relation to the datum line you have drawn for your fuselage. Some plans show these datum lines for the wing and the engine but many of them don't and you can end up with a very pretty model that fly's like crap. Here is where purchase of a $20 incidence meter comes in very handy. Don't buy or use 2 of them as they usually don't match each other. (found that out the hard way too). After your first few flights you may need to adjust your engine thrust line. Get your model tracking straight and true at altitude, then chop the throttle. The nose should drop some. If the model's nose pops skyward then you have to much down thrust. If you have designed a tail dragger, it will be very easy to tell if you have enough right thrust, when you try to take off. Your model naturally tries to turn to the left. If you have set up the right thrust just right, your model will track straight ahead on take off. Back To Top

Balance

The balance point is not the Center of Gravity. Generally all we want to worry about is the balance point of the wing. As I said earlier, it needs to be about 25% of the chord back from the leading edge. If you have a biplane then draw a line connecting the leading edge of the wings and make a mark at the half way point, then from that point move aft 25%. For canard's see the information below as they are a little different.

In addition you should balance your model fore and aft. Put one finger on the end of the crankshaft and the other finger at the tail. If it continually flops to the same side, then that side is too heavy. Probably because you have the engine set sideways with the head of the engine on one side or the other. If not the engine then it is something else, like maybe you covered the cat inside the wing or more plausible, the cat took a dump in the wing. Just start adding lead to one wing tip or the other till it balances, then kill the damned cat.

If you want to get a rough estimate for the Neutral Point of your model (i.e.-where it will become unstable) then use this formula: The distance between the quarter chord point of the wing vs the horizontal stab times the area of the horizontal stab divided by the wing area times the wing chord.
example: Lets say the distance is 38 inches and the horiz. area is 410 square inches with a wing area of 3000 sq. inches and a wing chord of 14 inches. The formula would work out this way:
38 x 410 = 15580 divided by 14 x 3000 =42000. And 15732 / 42000 = .37 or 37% of the average chord. In this case .37 x 14' = 5.18 inches aft of the leading edge. To be safe you need to deduct from that measurement. Using a chord of 14' times a **minium** safety factor of 10% you would come up with 1.4". Just deduct the 1.4" from the N.P. measurement of 5.18 inches and you would initially balance at 3 3/4 inches aft of the leading edge or a balance point 26% aft of the leading edge. I wouldn't start out any farther aft than that.

Summary: I have found that anytime you balance beyond 33% you are getting into an unstable condition. For rough estimates I would use that normally and just make sure I was balancing ahead of that point.

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Appendix 2

(because this document is too lengthy, only the sections containing properties of bamboos were taken. For full report, including preservation techniqye, go to the URL below:-http://www.inbar.int/publication/txt/INBAR_Technical_Report_No03.htm)

BAMBOO PRESERVATION TECHNIQUES : A REVIEW

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BAMBOO PRESERVATION TECHNIQUES : A REVIEW

INTRODUCTION

Bamboos play a dominant role as woody raw material for a variety of products in the tropical regions. Almost all continents, except Europe, have indigenous bamboo species. Bamboos are, however, more abundant in the tropics, with over 75 genera and 1250 species, ranging from small grasses to giants of over 40 m in height and 0.3 m in diameter (Tewari, 1993).

India, with an annual production of about 3.2 million tones of bamboos, ranks second only to China in bamboo production (Pathak, 1989). Over 136 species in 30 genera occur in India (Suri and Chauhan, 1984). The two most widely distributed genera in India are Bambusa and Dendrocalamus. In South and Southeast Asia, the most economically important species for structural uses from the point of view of easy availability are Bambusa balcoa, *Bambusa* bambos, *Bambusa blumeana, Bambusa nutans, Bambusa polymorpha, Bambusa tulda, Barnbusa vulgaris, Dendrocalarmus hamiltonii, Dendrocalarnus strictus, Melocanna barnbusoides, Gigan tochloa spp., Ochlandra travanicorica and Oxytenathera nigroeiliata.* All these species are included in the INBAR priority list (Williams and Rao, 1994)

At least one third of the human race uses bamboo in one way or another. Bamboo is an integral part of the culture in several Asian countries. In India, over one million tonnes of bamboo are used as a long fibre source for the manufacture of pulp and paper. Its unique strength properties, coupled with innovative uses by people, have enabled its versatility to be exploited for many industrial and architectural uses. Bamboo is used for housing construction (as poles, purlins, rafters, trusses), mats (to substitute flat boards), ladders, floating fenders, furniture, handicraft articles, baskets, etc. Its versatile nature and innumerable uses have earned bamboo the name 'green gold of the forest'. Since bamboo is less expensive than construction materials like steel, cement and even wood, it is considered to be 'poor man's timber'.

Unfortunately, like most lignocellulosic materials, bamboo has very low resistance to biological degrading agents. Several techniques to enhance its durability have, therefore, been developed. This review on bamboo preservation has been compiled to consolidate all useful information and to provide helpful guidelines to users.

PROPERTIES OF BAMBOO

Anatomically, bamboo is quite different from wood coming from gynosperms and dicotyledonous angiosperms (Ghosh and Negi, 1959). All the growth in bamboo occurs longitudinally and there is no lateral or radial growth as in trees. Characteristically, bamboo has a hollow stem, or culm (solid in some species only), which is closed at frequent intervals called nodes. The bamboo culm comprises about 50% parenchyma, 40% fibres and 10% vessels and sieve tubes (Liese 1987). Fibre percentage is higher in the outer one- third of the wall and in the upper part of the culm, contributing to its superior slenderness (Grosser and Liese, 1971). Most fibres have a thick polylamellate secondary wall (Parameswaran and Liese, 1976). The typical tertiary wall present in most woody cells of gymnosperms and angiosperms is not present. Similarly, bamboos do not develop reaction wood, which is most common in tree species due to ageing.

Fibres in bamboos are grouped in bundles and sheaths around the vessels. The epidermal walls consist of an outer and inner layer; the latter is highly lignified. The outer layer contains cellulose and pectin with a wax coating. Silica particles also exist in the peripheral parts of the culm. These anatomical features are responsible for the poor penetration of preservatives into round culms during treatment. Although vessel elements in bamboo are easily permeable, lateral flow is restricted because of the absence of ray cells.

Physical and Mechanical Properties

The density of bamboo varies from 500 to 800 kg/m depending on the anatomical structure, such as the quantity and distribution of fibres around the vascular bundles. Accordingly, it increases from the central (innermost layers) to the peripheral parts of the culm. This variation could be 20-25 percent in thick-walled bamboos like Dendrocalamus strictus (Sharma and Mehra, 1970). In thin- walled bamboos, the differences in density are much less (Sekhar and Bhartari, 1960).

Bamboos possess a very high moisture content which is influenced by age, season of felling and species. Season has a greater influence than any other cause. Moisture is at its lowest in the dry season and reaches a maximum during the rainy season. Among the anatomical features, a higher amount of parenchyma increases the water holding capacity (Liese and Grover, 1961). Moisture also varies from the bottom to the top and from the innermost layers to the periphery. Green bamboo may have up to 150% moisture (oven-dry weight basis) and the variation reported is 155% for the innermost layers to 70% for the peripheral layers (Sharma and Mehra, 1970). The variation from the top (82%) to the bottom (110%) is comparatively low. Moisture content decreases with age while the increase in specific gravity is rather limited (Limaye, 1952).

The fibre saturation point (FSP) of bamboo is around 20-22 percent (Jai Kishen et *al.*, 1956; Sharma, 1988), while *Phyllostachys* pubescens has a lower FSP ~ 13% (Ota, 1955). The FSP is influenced by the chemical/anatomical nature of tissues (Mohmod and Jusuh, 1992). Parenchyma cells, being more hygroscopic, result in raising FSP.

Bamboo shrinks in diameter (10-16%) as well as in wall thickness (15-17%) (Rehman and Ishaq, 1947). Such shrinkage is appreciably higher than encountered in wood. In bamboo, shrinkage, which in fresh culms begins linearly, becomes negative or almost zero as MC falls between 100 and 70 per cent and this continues until fibre saturation point is reached. Below FSP, shrinkage again follows, a linear trend (Sharma *et al.*, 1987.) Tangential shrinkage (6.5-7.5s) in some species is reported to be lower than shrinkage across the wall thickness (1 \1- 13%) (Espiloy, 1985). Shrinkage has been related to culm diameter and wall thickness (Mohmod and Jusuh, 1992). Because of differences in anatomical structure and density, there is a large variation in tangential shrinkage from the interior (10%) to the outermost portion (15%) of the wall (Sharma and Mehra, 1970). Such behaviour in shrinkage and density leads to drying defects, such as collapse and cracking, and affects the behaviour of bamboo when pressure treatments are applied.

Bamboos possess excellent strength properties, especially tensile strength. Most properties depend upon the species and the climatic conditions under which they grow (Sekhar and Gulati, 1973). An increase in strength is reported to occur between 2.5 to 4 years. Thereafter, the strength values start falling (Sekhar et al, 1962; Sekhar and Bhartari, 1960,1961; Sattar et al, 1990; Espiloy, 1994; Kabir et al, 1991). To possess optimum strength, there is a 'maturity age'. Thus, only mature bamboos are harvested for structural or other uses.

There is a variation in strength along the culm height as well. Compressive strength tends to increase with height (Espiloy, 1985; Liese, 1986; Sattar et al, 1990; Kabir et al, 1991), while the bending strength shows a decrease (Espiloy, 1985; Janssen, 1985; Limaye, 1952; Kabir et al. The strength increases from the central to the outer part. According to Baumann (Narayanamurti and Bist, 1947), there is more than 100 percent variation in strength from the inner to the outer layers (Table 1).

Although several studies on strength properties have been conducted, the information on strength properties and its correlation with various factors such as moisture, anatomical structure, growth factors, drying and preservation are still lacking for most species. Furthermore, there are still no standard methods of evaluation (Liese, 1985). The earliest tests on strength were carried out in India on Dendrocalamus strictus (Limaye 1952). A need was felt to standardise the testing methodology (Sekhar and Rawat, 1956). An Indian standard for the same was formulated (Anon., 1973). Most of the reported strength data have, however, been obtained using different test methods with widely varying conditions. Such data on some of the species are reported in Table 2, which shows that bamboo is as strong as wood; some species even exceed the strength of the strongest timbers like sal (Shorea robusta).

Natural Durability of Bamboo

Bamboo consists of 50-70s hemicellulose, 30% pentosans, and 20-25% lignin (Tamolang et al, 1980; Chenef al, 1985). Ninety percent of the hemicellulose is xylan with a structure intermediate between hardwood and softwood xylans (Higuchi, 1980). The lignin present in bamboos is unique, and undergoes changes during the elongation of the culm (Itoh and Shimaji, 1981). Bamboo is known to be rich in silica (0.5 to 4%), but the entire silica is located in the epidermis layers, with hardly any silica in the rest of the wall. Bamboos also have minor amounts of resins, waxes and tannins. None of these, however, have enough toxicity to impart any natural durability. On the other hand, the presence of large amounts of starch makes bamboo highly susceptible to attack by staining fungi and powder-post beetles (Beeson, 1941; Gardener, 1945; Mathew and Nair, 1988; Gnanaharan *et* al, 1993). Laboratory tests have indicated that bamboo is more prone to both soft rot and white rot attack than to brown rot (Liese, 1959).

The natural durability of bamboo is very low and depends on species, climatic conditions and type of use. Early observations on durability of bamboo were based on the performance of full-sized structures. Under cover, the untreated bamboo may last 4-7 years. Under favourable circumstances, trusses and rafters may last l0-15 years. Systematic data on natural durability when there is ground contact and exposed conditions are very limited. Tests conducted in the Philippines indicated variation among species. Dendrocalamus *merillianus* was found perishable while *Schizostachyum* species were found quite resistant. Laboratory exposure to fungal attack showed that some species like Bambusa *blumeana* and *Gigantochloa* showed moderate resistance (Guzman, 1978). Graveyard tests (Fig. 1) completed recently on some important Indian species showed that the average life of untreated bamboos is less than two years (Table 3). This confirmed the earlier observations on natural durability of bamboo reported by Purushotham et al (1954). According to durability classification (Anon., 1982), bamboos thus fall in class III (non-durable category) with little variation in durability among different species.

Variation in durability has also been observed along the length of the culm and the thickness of the wall. The lower portion of the culm is considered more durable, while the inner part of the wall deteriorates faster than the outer harder portion. This is probably related to the anatomical and chemical nature of the woody cells.

Because of the lack of any toxic constituents, bamboos form a ready food source for a variety of organisms. The presence of considerable quantities of starch in green or dry bamboo makes it more attractive to such organisms, especially stain fungi and borer beetles. Some sap sucking insects have been reported to attack bamboo plantations as well (Chatterjee and Sebastian, 1964,1966; Singh, 1988). The most serious borers of felled bamboos are three species of Dinoderus (celluris, minutes, brevis) and Lyctus, which attack bamboo rich with starch (Casin and Mosteiro, 1970; Sandhu, 1975). They cause immense damage during drying, storage, and subsequent use. Carpenter bees and termites also attack bamboo (Beeson, 1938;Sensarma and Mathur, 1957). Bamboos are attacked by marine organisms as well (Anon, 1945).

It is reported that bamboos harvested during summer are more rapidly destroyed than those felled in the rainy season (Liese, 1980). Culms of bamboo plants which have flowered are more resistant to beetles because of starch depletion. Efforts have also been made to correlate the natural durability of bamboo with phases of the moon (Kirkpatrick and Simmonds, 1958), but it appears to be more of a myth than a scientific fact.

Biodegradation of Bamboo during Storage

Biodegradation is a serious problem in pulp bamboos but is seldom recognised by the pulp mills, as such mills store bamboos in forests/depots for over one year. In earlier investigations, various white rots and brown rots were found to attack the bamboo stacks. No appreciable differences in unbleached and bleached pulp yield were noticed between attacked and sound bamboos, owing to the proportional removal of both lignin and cellulose during fungal attack. (Yields were calculated on the basis of weights of material at the pulping stage, with no allowance made for the weight loss that occurred during storage.) Strength properties of paper from decayed material were, however, appreciably lower (Guha, et al., 1958; Bakshi, et al. 1960). The influence of decay on yield was very striking in studies on flowered bamboos (Bakshi et al, 1960). A 4% decrease in unbleached pulp yield was noticed in bamboos with early stages of white rot attack. Moderate and advanced white rot attack, however, showed an increase in pulp yield on the basis of weight of decayed material charged into digester, because of the simultaneous attack of such fungi on lignin. Advanced brown rot resulted in 25% loss in yield and produced unbleachable pulps.

Decay fungi seriously affect the pulp yield (up to 25% loss over one year storage) and pulp strength is reduced by 15 to 40% (Guha and Chandra, 1979; Bakshi et lal, 1960). In addition, loss of fibrous material due to fungal, borer or termite attack increases chipping losses and reduces digester capacity (Kumar et al, 1980). Fungal attack increases pulping costs, owing to increased alkali demands (because of acidic nature of fungi) and higher bleach consumption (Singh, 1977). While advanced fungal attack produces unbleachable pulps, borer attack in epidemic stages reduces the entire stack to powder, causing losses between 20-40% of volume. Termites also attack bamboo stacks, which in the absence of adequate protection, can suffer losses up to a level. of one metre from the ground during one year of storage (Kumar et al, 1990; Fig. 3a). Protected bamboos remain sound during storage

Any prophylactic treatment of bamboo for pulping should take into account the effect on water quality during processing. Research has shown such treatment is possible but rarely used due to costs.

(Refer website for full report)

Appendix 3

Covering Foam Wings With Ordinary Brown Paper

By Steve Kerrey
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The method is *roughly* as follows - there is still plenty of room for experimentation. Feel free to try any variations, and let everyone know what works and what doesn't work. Sharing information is what the Net is all about.

If you haven't tried this before, it might be worth practising on a spare wing core. Anyone who cuts their own wings will probably have several 'spare' cores lying around :-)

You will need:

- Brown paper, obviously. The most common paper is the brown stuff for wrapping parcels, you can find it at your local post office or newsagent. It usually has a shiny side and a matt side, the matt side should be the one in contact with the foam.

- A large bottle of glue (PVA, also known as white glue or Elmers), thinned down with water. 1 part glue to 1 part water is a good start, make it thinner if you live in a hot climate. It is very useful to add a splash of food colouring as well, to help show any bits you miss (ever tried to see white glue on white foam?) and to ensure an even coverage. Put it in a small bucket such as a margarine container.

- A brush for the glue, whether it is disposable or not is up to you. Use whatever size you feel comfortable with.

- A decent pair of scissors. Buy your own pair to avoid domestic arguments :-)

- A _sharp_ knife. This is important, fit a new blade in your scalpel.

- Lots of newspaper on the workbench and floor, it can get messy :-)

Add the LE and TE to the wing, but do not hang any ailerons yet. Make sure the wing is clean and smooth, and the paper free of wrinkles (iron it if necessary). Cut a piece of paper large enough to cover the wing, with an overlap all the way around. Give the wing a coat of the thinned glue mixture, and lay the paper on the wing (matt side down). Brush another coat of glue on to the paper, then trim around the edges. If you are covering the wing in two pieces, repeat for the other surface immediately. Covering the wing in one piece is preferable, although a little trickier when brushing glue on both sides. Rounded tips can be negotiated by cutting a series of slits into the paper with that nice new scalpel blade, when the whole thing is dry you can sand down any ridges caused by overlaps. Brown paper sands nicely if you keep the strokes smooth and even.

To save precious ounces, wait for five minutes (depending on the local temperature) then scrape 90% of the glue off again using your Amex Gold Card :-) This is very messy unless you can catch the excess glue in the bucket again (good luck) but will result in a light, strong airframe. If weight is not critical (sport slope soarer), you could probably skip this step. The glue adds both strength and weight, use your discretion.

PVA contracts as it dries, as does brown paper. The wing will almost certainly warp unless it is pinned down while drying. For a flat-bottom wing this is easy, don't forget to use a few strips of scrap balsa to elevate it from the building board so the air can get underneath. For symmetrical airfoils, put a length of timber (ie. broom handle) under the LE and another under the TE to keep them parallel. Put a strip of sticky tape on the timber first, otherwise you will glue the wing to it! A thin wedge under the TE will add washout if appropriate.

When dry, sand the wing smooth and check for warps. You can then cover it with film if you want, but a spray can of acrylic paint from the local hardware store is just as good and a lot cheaper. PSS models in particular benefit from this technique, as it is quick to build and cheap to repair.

Covering fuselages is pretty much the same, work with a series of panels rather than covering the entire fuz in one step (unless you are a six-armed paperhanger). To avoid warping the fuselage, work on both sides together.

Many other variations have been tried, including the use of scrap fan-feed computer paper instead of the brown stuff. It works fine, and most offices throw mountains of it away on a daily basis. In January, it is not uncommon to find brightly coloured models with Christmas wrapping paper on their wings!

One of the members of my former club (BATS) built a PSS Airacobra completely out of foam and scraps of plywood. The wings were covered with computer paper, and the fuz was covered with 2" wide strips of masking tape! Unless you stood right next to the model, you couldn't tell the difference. It flew well, looked good in the air, and was dirt cheap to build from the local DIY store.

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