DESIGN AND MANUFACTURING OF GENERIC UNMANNED AERIAL VEHICLE FUSELAGE ASSEMBLY (PAYLOAD BAY, EMPENNAGE, WHEEL ASSEMBLY AND WINGBOX) VIA LOW COST FIBER GLASS MOLDING PROCESS

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A project progress report submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering (Hons) Mechatronics Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2012

DECLARATION

I hereby declare that this project report is based on my original work except for the citations and quotation which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Design and Manufacturing of Generic Unmanned Aerial vehicle fuselage assembly (Payload bay, empennage, wheel assembly and wingbox) via low cost fiber glass molding process"** was prepared by **ANG ENG LING** has met the required standard for submission in partial fulfillment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering at Universiti Tunku Abdul Rahman.

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Supervisor : _______________________

Date : _______________________

Specially dedicated to

my lovely parents

who are so concerns of my health

ACKNOWLEDGEMENT

The successful of this project laid on the good guidance and instructions of both my supervisors, Mr. Chuah Yea Dat and Mr. Julian Tan Kok Ping. Their expertise in manufacturing and aeronautics assisted me in solving difficulties faced in the project. Besides their guidance, they sacrificed their precious time in exploring me to various fields of knowledge to enhance the quality of the project and prototype.

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ABSTRACT

The use of generic unmanned aerial vehicle (UAV) is getting common as its small size can easily replace bulky aerial vehicle such as helicopters and airplanes in performing surveillance missions. However, spacious room is need to store the UAV and the cost for a generic UAV is relatively high and seldom be owned by normal commercials and industries other than military forces. The purpose of this project is to produce a detachable, and yet low cost generic unmanned aerial vehicle (UAV). This aircraft should be light weight enough to be hand launched to the air. Hence a lot of conventional methods to produce an aircraft are not suitable in manufacturing this generic unmanned aerial vehicle. For example, the use of bulkhead will be reduced to minimum in order to decrease the weight of the generic UAV and increase the cargo space for the payload bay. In addition, the generic UAV has to be detachable. This enables the user to attach it when performing surveillance activity and detach it for easy storage so that the generic UAV could be packed in small space. The proposed method in this project to manufacture the generic UAV economically is by using low cost fiber glass to mold the fuselage of the place. A pair of male and female mold will be constructed and the shape of the fuselage will be imitated using flexible fiber glass in the molding part of the mold. Epoxy cohesive and hardener will be used to harden and sustain the shape of the fuselage during the molding process. Finishing touches will be applied to the new molded fuselage to refine the aerodynamics flow around the body.

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CHAPTER 1

INTRODUCTION

1.1 Background

Generic unmanned aerial vehicle (UAV) is undoubtedly the future equipment for scouting and surveillances. It is small in size, versatile, and low in fuel upkeep. However, the demand of generic UAV is low in commercial sector as its high initial cost. Besides that, maintenance cost could be fly high as generic UAV mostly land on uneven ground as there is always wear and tear due to fragile fuselage components. All generic UAV are not detachable and need a roomy space to store it when it is not in service. This could not be handy and it’s a waste of space as the storage compartments cannot be fully utilized.

There the purpose of this project is to design a durable fuselage assembly that can tolerate raft conditions. In the same, it has to light weight to be hand launched while supporting the structures and components firmly. Another important criteria in this project is to minimize its initial cost. Besides using low cost fiber glass as the material for the fuselage and components assembly, the manufacturing process and method are crucial for building a low cost generic UAV.

1.2 Objectives

- To study and learn about the current design and manufacturing techniques of generic unmanned aerial vehicle.

- To design and manufacture generic unmanned aerial vehicle fuselage assembly via low cost method.

- To apply the knowledge learnt by producing a generic unmanned aerial vehicle prototype.

- To learn practical experience through producing prototype of generic unmanned aerial vehicle.

- To perform test flight of the prototype of the generic unmanned aerial vehicle.

1.3 Chapter Outline

Chapter 1 introduced the reason for this title selection and the problems occur by most generic UAV. The objectives needed to be archived are also stated in this chapter.

Chapter 2 in the literature review done about the title selected. Related information is review for example the current development of UAV, deployment methods, manufacturing techniques, and low cost material selection.

Chapter 3 is the flowchart of the design and the manufacturing process that is planned in order to producing a successful generic unmanned aerial vehicle.

Chapter 4 is the design and fabrication of the UAV. The design of fuselage and empennage of the UAV is first discussed follow by the material selection and manufacturing method selection. Then the fabrication process of fuselage, empennage and landing gear are discussed in detail. Problems faced during the manufacturing process are also included.

Chapter 5 is assembling the UAV. The assemble steps of UAV empennage, wings, wiring and servo motors are discussed.

Chapter 6 is the UAV testing section. Fluttering test and test flight are done. Result is shown.

Chapter 7 is the conclusion and recommendation. What I had learnt throughout the process is jotted down. Recommendations are written for further improvement in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Recent UAV development

This section reviews the recent development of UAV that were designed to perform surveillance and monitoring for the US navy.

2.1.1 Silver Fox

The Silver Fox UAV was first designed and built in 2001 to meet a US Navy requirement to search for and monitor the movement of whales. It has the size and shape with a 5 inch fuselage and a 94 inch wingspan. The initial success of this UAV and the ease of launch and recovery gained support within the Navy with the goals of proving an organic intelligence capacity, in real time, to small contingents of forward deployed military personnel. The Silver Fox system can be fully employed by a team of two individuals, who if desired can fly multiple UAVs simultaneously. (Patterson & Brescia, 2007)

Figure 2.1.1: Silver Fox Block – B4 UAV (Patterson & Brescia, 2007)

2.1.2 Manta

Manta UAV was designed in 2002 with a purpose to provide larger payload than the Silver Fox for a wider range of missions. With the same wingspan as the Silver Fox UAV, the fuselage region is significantly larger and enabling to carry a standard payload of 6.81 to 8.17 kg compared with 2.27-3.63kg for the Silver Fox. It carries a hyperspectral imaging unit and other advanced cameras. A catapult system was developed for the maritime operations. (Patterson & Brescia, 2007)

Figure 2.1.2a: Manta UAV Block B
(Patterson & Brescia, 2007)

Figure 2.1.2b: Manta UAV Launched to Air by Catapult System from the Stiletto Experimental Hull Vessel
(Patterson & Brescia, 2007)

2.1.3 Coyote

The coyote was built to be stored and launched from a standard sonobuoy tube. It is to provide surveillance capability for aircraft. The defined mission would be preloaded into flight control software prior to launch and the Coyote would gather surveillance data of the defined target. It has a cruising airspeed of 50 knots and dash airspeed of 75 knots. It can operate up to 25,000ft. (Patterson & Brescia, 2007)

Figure 2.1.3: Coyote with Sonobuoy (Patterson & Brescia, 2007)

2.2 Design of Fuselage and Empennage of UAV

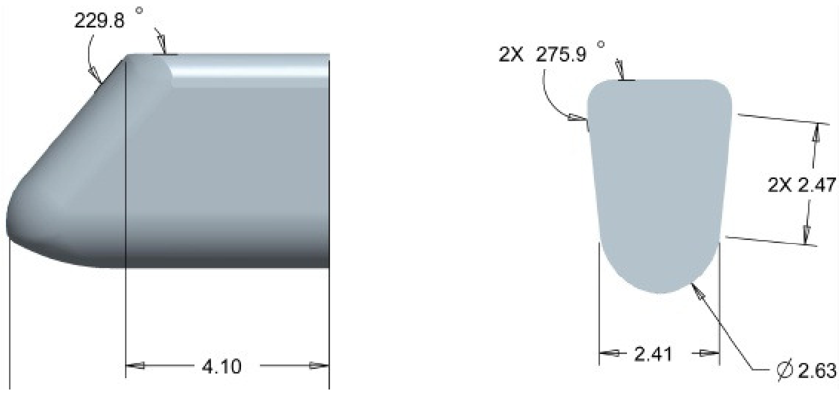

Figure 2.2a: Side View and Rear View of the Fuselage (All Dimensions in Inches) (Alioto et al., 2010)

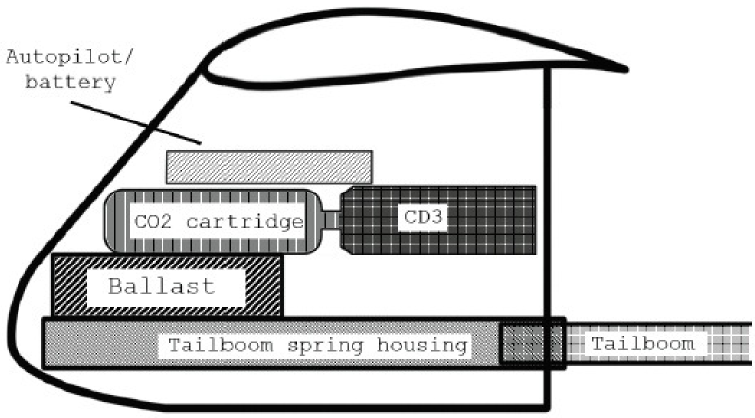

Figure 2.2b: Internal Layout of the Fuselage (Alioto et al., 2010)

Figure 2.2a above shows the fuselage exterior and figure 2.2b shows the internal layout of the fuselage. Alioto et al. (2010) realize that the main constraint for the fuselage is the overall size. The collapsed aircraft needs to fit in a standardized ARLISS deployment tube with an inside diameter of 5.5 inches and length of 10.5 inches. Empennage will be situated on a boom, which will be spring loaded to allow automatic deployment in midair. These parts will be made of rolled fiberglass and carbon fiber tubes in order to provide the tailboom, with a maximum amount of rigidity.

The tail volume coefficient method was used to size the empennage (Rockam. J, 2004).

$$S_h = \frac{V_h S c}{X_h} \qquad\qquad S_v = \frac{V_V S b}{X_v}$$

"S, S_h, and S_v are the wing, horizontal and vertical area. X_h and X_V are the distances of the horizontal and vertical aerodynamic centres from the wing leading edge; b is the wingspan and c is the wing chord; V_h and V_v are the volume coefficients for the horizontal and vertical stabilizers. The figure 2.2c below shows the aircraft dimension used in the sizing of the empennage." (Kovanis et al., 2011)

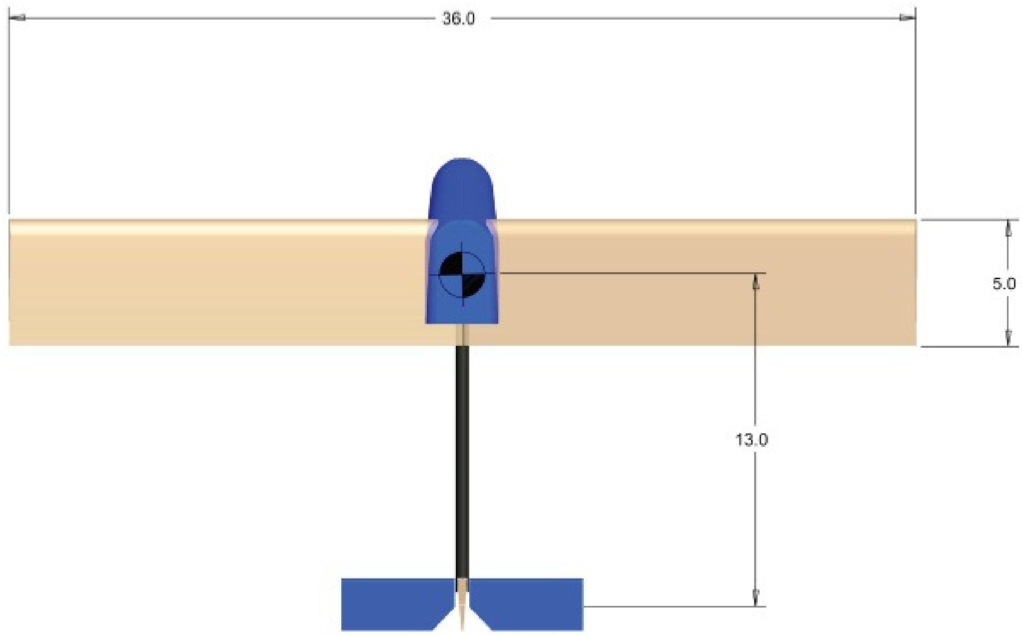

Figure 2.2c: Aircraft Dimension used to size the Empennage
(Alioto et al., 2010)

2.3 Ways of deployment of UAV

There are many ways to launch a generic UAV. Eight deployment options were considered and these options were divided into two groups. The first is aerial deployment and the second is surface deployment. Traditional take off method is not in consideration in order to minimize the cost of the UAV and to improve mission and location versatility. "The landing gear required for traditional take-off greatly increases the cost, weight, and complexity of the UAV design. In addition, a runway is needed in controlled location, greatly reducing the reconnaissance capabilities of the aircraft." (Team Lemming, 2003)

There are five options in the aerial development category. They are simple drop, parachute assisted drop, boom launch, hard point launch, and low tow line.

- Simple drop

  This method is to push the plane out of the rear cargo door of the transport aircraft and the UAV is expected to fall a predetermined distance and then pull out of the dice once it has gained control. The advantage of this method is low cost but will need minimal modifications to both UAV and the transport aircraft. The disadvantage is the UAV size restriction stemming from the internal storage and the stability and control issues associated with the dive recovery. (Team Lemming, 2003)

- Parachute-Assisted Drop

  This deploy method is like the simple drop, save for a parachute attached to the tail section of the UAV. After deployment, the engine will start up and the UAV will be released from the chute. The advantages of this option are its simplicity and inherent stability provided by the chute. "The disadvantages to this deployment options are the size restrictions imposed on the UAV and the discarding of the drag chute after launch." (Team Lemming, 2003)

- Boom Launch

  "Boom launch method involved the mounting of the UAV to a boom that extends from the transport aircraft." Its advantage is the simplicity in release due to the pre-launch positioning of the craft in its autonomous flight position. The disadvantages are the inherent cost of the boom design and the internal storage size restrictions imposed on the UAV. (Team Lemming, 2003)

- Hard point launch

  This option is to mount the UAV to a hard point on the transport aircraft and then releasing it. The released UAV will enter the sustain flight on its own. "The advantages to this option are the minimal modification required for the transport aircraft and the method's proven history." The drawback is that the external storage of the UAV would require a stronger structure to withstand the cruise speed of the UAV and the separation issues associated with a deployment so far forward on the transport craft. (Team Lemming, 2003)

- Tow Line

  The UAV is towed behind the helicopter to the deployment location and is released from the helicopter. The lack of UAV size restriction and the cruise speed of the helicopter that is near to the UAV are the advantages of this method. However, only one UAV launch is possible per transport. (Team Lemming, 2003)

The remaining three methods are surface deployment options. The ship rocket-assisted take-off (RATO) launch, the submarine launch, and the ship catapult launch.

- Ship RATO launch

  The UAV will be launched from the deck of the ship placing a small rocket on the underside of the UAV which is used to accelerate the UAV to its cruise speed and position. The advantages of this method are the multiple UAV launch capacity. The disadvantages to this option are the launch would be limited to coastal area and the increase of structure design cost due to high launch velocity. (Team Lemming, 2003)

- Catapult launch

  This launch option involves mounting a catapult to a ship and the UAV is launched with sufficient velocity for the aircraft to sustain flight autonomously. This launch option is a proven method. Besides, multiple UAV deployment capability and its cost effectiveness are advantages. However, this method is only limited to coastal regions and calm seas as for the requirement for a catapult launch. (Team Lemming, 2003)

- Submarine launch

  This launch option is similar to the RATO launch option. The difference is the UAV is first launched from the submarine in an ICBM tube before the rocket is fired above the surface of the water. "The primary advantage to this design is the stealth of the transport submarine." (Team Lemming, 2003)

The selection of deployment options will be determined by a decision based on six factors of merit (FOM). The factors of merit were quantified with on through five weighting scale, respectively low to high importance. (Team Lemming, 2003)

- The first factor is the UAV cost, weight five of the scale.
- The second factor is the deployment system cost, weight three.
- The third factor is the feasibility of deployment option, weight four.
- The fourth factor is the reliability of deployment option, weight two.
- The fifth FOM is the safety of deployment option, weight two
- The final FOM is the UAV launch capacity, weight one.

The table below shows the decision matrix for the UAV deployment options.

Table 2.3: Decision Matrix for UAV Deployment Options (Team Lemming, 2003)

	FOM	UAV Cost	System Cost	Feasability	Reliability	Safety	# Deployed	Totals
	Ranking	5	3	4	2	2	1	
Deployment Options								
Hard Mount - Helo		2	4	5	4	3	2	58
Hard Mount - A/C		1	4	5	4	2	3	52
Tow Line Helo		4	5	5	3	4	1	70
Internal - Boom Deploy		5	2	3	3	4	4	61
Internal - Parachute Deploy		5	4	5	4	4	5	78
Internal - Simple Drop		5	4	4	4	3	5	72
Ship Launch - RATO		1	2	4	3	2	5	42
Ship Launch - Catapult		2	2	4	4	3	5	51
Sub Launch - RATO		1	1	2	4	2	2	30

The decision matrix highlighted the highest scoring deployment options. The three options highlighted in yellow are the options selected. The simple drop method is highlighted in orange as the author is not sure whether will the UAV recover itself.

2.4 Breakthrough in Aerospace Composites Manufacturing

This paper (Strong, A. Brent, 2004) suggests that airplanes are to be manufactured by composites. The highly sophisticated developed and automated techniques for making aircraft using a unique patent pending winding process called *f*ibeX. This manufacturing system produces light weight and low cost aircraft components.

The Rocky Mountain Composites (RMC) technology is able to manufacture light weight, low cost aircraft parts represents serious potential for cost savings in aircraft manufacturing. Some important new innovations have been made principally involving integral stiffening. The inclusion of the integral stiffeners, material that is put into the components is made by *f*ibeX, is about one third to one half of material cost as compared to typical equivalent high performance competitive materials. RMC's technology avoided the use of autoclaves as it is believed to be impractical and will be costly in the long run and therefore relatively inexpensive pressure mold system are used. (Strong, A. Brent, 2004)

The technology is to reduce the three main features of an aircraft

- A one piece co-cured fuselage design with integrated structural elements
- The layup of fuselage skins using low cost materials with automated placement of skin plies.
- Co-cured frames from material generated by advanced winding techniques.

The structure below shows a typical structural configuration and the major elements for a fuselage for a small airplane fuselage. The selection of composite materials for aircraft structures has several advantages.

- The ease of obtaining the desired aerodynamics shape and surface smoothness of the fuselage.
- Provides the ability to highly integrate many structural requirements
- Creates the ability to mold large structures in one piece.

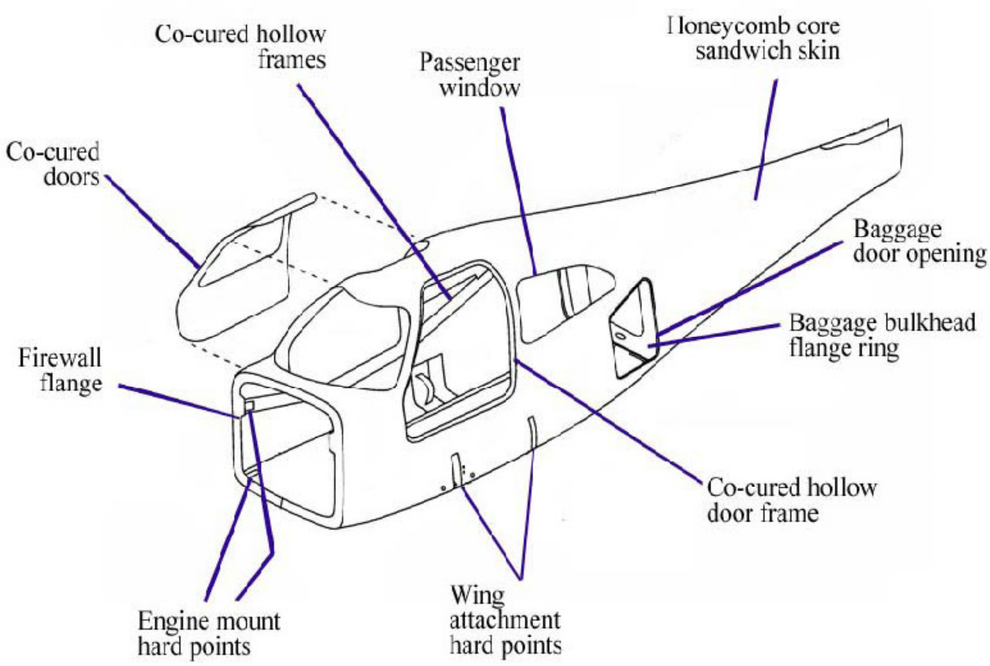

Figure 2.4:

Diagram of the Design of a Filament Wound Body for Small Propeller Driven Aircraft

(Strong, A. Brent, 2004)

2.5 Low Cost Composites Structures Manufacturing Techniques

The applications of advanced composite structure have seen tremendous growth across the spectrum of the aerospace industry over the past fifteen years. Composites structures offer reduced part-count, excellent mechanical properties, and significant weight savings as compared to the conventional metallic lightweight structures. Manufacturing aerospace grade required composite components by conventional prepregs manufacturing methods to reduce the cost in ongoing area of research at Carleton over the past three years. This research will directly benefit small aerospace companies as new low cost techniques, Vacuum Assisted Resin Transfer Molding (VARTM) method, is being investigated to produce composites aircraft. (Maley A.J., 2008)

Figure 2.5a: GeoSurv II Solid Model
(Maley A. J., 2008)

All major airframe components were manufactured using the conventional Vacuum Assisted Resin Transfer Molding (VARTM) Process. A typical VARTM processing cycle involves resin impregnation of fibrous perform under vacuum pressure. VARTM uses low cost, disposable materials, which makes this process economical for low parts counts. The figure below shows the schematic representation of VARTM process. (Maley A.J., 2008)

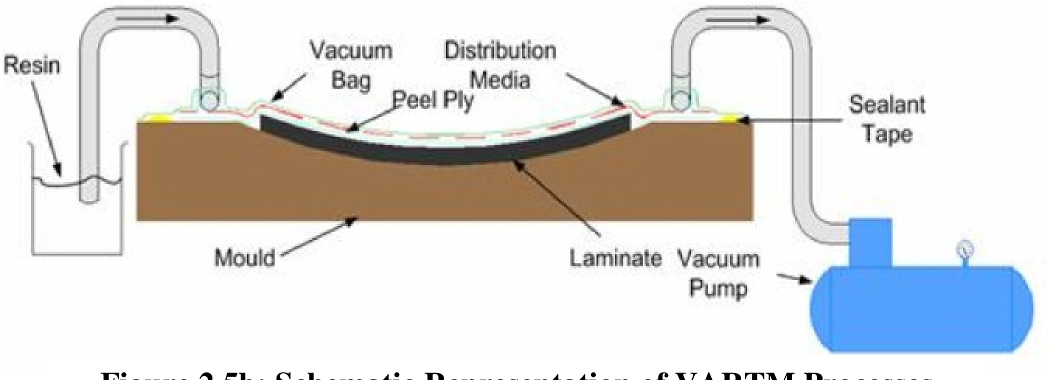

Figure 2.5b: Schematic Representation of VARTM Processes (Maley A.J., 2008)

An innovative moldless VARTM method was developed and implemented on the fuselage main frame. This process uses the core material as the mold to fabricate complex-geometry sandwich structured, eliminating the additional material and labour costs associated with mold preparation. In-house developed permeability evaluation techniques were used together with Liquid Injection Molding Simulation (LIMS) software to predict VARTM infusions. (Maley A.J., 2008)

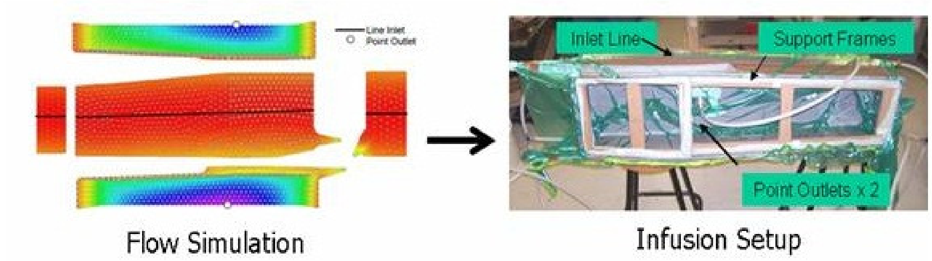

Figure 2.5c: Moldless VARTM Flow Simulation and Infusion Setup (Maley A.J., 2008)

This new type of VARTM method continues to be investigated by the author for improvement in the process robustness, repeatability, and part tolerances. The issues under further study include improved simulation of resin flow, variations to basic manufacturing processes for better performance and strength / damage tolerance evaluation of the resulting structures. (Maley A.J., 2008)

According Zhang X.T. (2010) in his project report of UAV Design and Manufacturing 2010, he manufactured the fuselage using vacuum forming technique. Vacuum forming is one of the methods using thermoforming treatment. This method is generally been promoted as a 'dark art' and best left to companies with sophisticated processing equipment that is able to supply the facility and service. The whole fuselage requires vacuuming forming as a tool to manufacture two parts: aircraft nose and the tail cone.

The process is by inserting a thermoplastic sheet in a cold state into forming clamp area and to heat it to desired temperature either with just a surface heater or with twin heaters. Then the mould is raised from below. The trapped air is evacuated with the assistance of a vacuum system and once cooled a reverse air supply is activated to release the plastic part from the mould. The heated sheet is placed over a cavity mold. Contact between the sheet and the mold are made by creating a seal. (Zhang X.T., 2010)

There are a few advantages of vacuum forming technique. The exact shape as the moulds can be made easily which is one of the key factors in the UAV design. It is relatively easy to use vacuum forming method for fabrication as the station is build by vacuum cleaner, vacuum table, oven and a frame. Besides that, it is not a very time-consuming process. The figure below shows the work station for the vacuum forming fuselage manufacturing technique. (Zhang X.T., 2010)

Figure 2.5d: Vacuum Forming Work Station

(Zhang X.T., 2010)

However, this method do process a few disadvantages. Solutions were being given in order to overcome these drawbacks. (Zhang X.T., 2010)

- Toxic gas will be release if the plastic is heated too much.
  - The temperature of the oven and the time is set to desired temperature according to different material. For example 0.5mm PVC, the oven is set to 240˚C and 1minute of heating time.
- Non-Uniform Wall Thickness will occur during the stretching process
  - There are many design rules as well as process variations to lessen the impact of 'stretching'. Drawing ratios include Aerial Draw Ratios, Linear Draw Ratios and Height-to-Dimension Ratios

2.6 Low Cost Expendable UAV

Analysis of material is very important before it is used to build an unmanned aerial vehicle. The author in this research paper decided to focus his material selection on aluminum and composites as both materials are extremely popular in aircraft industry due to their suitable qualities. (Team Lemming, 2003)

Aluminum is an abundant low cost material and it has perfect characteristic to construct UAV. It is a versatile material with super corrosion resistance, good formability, flexibility, and strength. Composites, with great fatigue resistance, good damping characteristics, and very light weight, cheap, are often the ideal selection when cost is an important consideration. (Team Lemming, 2003)

Table 2.6a: List of Material in Consideration (Team Lemming, 2003)

Composite	t	cost	cost	weight	?$_{yield}$	score
	(in)	($/yd^2)	($/yd^2/in)	(oz/yd^2)	(lb/in)	
Uni Carb Graphite	0.006	14.76	2.46	4.70	550	47.570
Bi Carb Graphite (Plain)	0.007	16.48	2.35	5.70	300	22.356
Bi Carb Graphite (8HS)	0.013	27.44	2.11	10.90	650	28.252
120 E Fiberglass	0.004	4.80	1.20	3.08	125	33.820
3733 E Fiberglass	0.010	5.40	0.54	5.85	250	79.139
7533 E Fiberglass	0.009	5.70	0.63	5.64	250	69.989
Bidirectional Kevlar	0.010	14.50	1.45	5.00	630	86.897
Aluminum Alloy						Al score
2024T3	0.040	33.93	0.85	5.184	1880	427.532
6061T6	0.040	15.234	0.38	5.130	1400	716.567
7075T6	0.040	39.17	0.98	5.238	2920	569.277

Table 2.3 tabulated the data for material selection. In order to compare the materials, the thickness (in), cost ($/yd^2), tensile strength (lb/in) and weights (lb/yd^2) were recorded. Dividing the given value by material thickness then normalized the cost. A final score (X) was obtained for each material using the following equation.

$$X = \frac{\text{Tensile Strength}}{\text{Cost} \cdot \text{Weight}}$$

After the analysis, the best material for the UAV was the use of aluminum 6061T6 and the composite material Bi-directional Kevlar. Since there was not a large discrepancy between the costs between both materials, the best choice was to use Bi-direction Kevlar composite. As presented in previous research from the author, the weight saving of up to 15% are possible with the use of composite construction. The weight difference will provide crucial savings in engine power and fuel consumption. Therefore, the determination was made that the UAV airframe will be constructed of a composite material. (Team Lemming, 2003)

Team Lemming (2003) revealed that bi-directional composite consists of high strength fibers embedded in an epoxy matrix. These composites provide for major weight savings, up to 20%, while maintaining similar characteristics as aluminum. Some advantages of the composites are listed below

- Low weight and low material: composite densities range from 0.045 lb/in^3 to 0.065 ib/in^3 as compared to 0.10 lb/in^3 for aluminum.
- Ability to tailor the fiber/ resin mix to meet stiffness and strength requirements
- Elimination of part interfaces via composites molding
- Low cost, high volume manufacturing methods
- Tapered sections and compound contours easily accomplished
- High resistance to corrosion
- Resistance to fatigue
- Low coefficient characteristics
- High damping characteristics

Composites possess inherent properties that provide performance benefits over metals. A wide range of fibers and resins are available for the selection of the optimal material combination. The high strength-to-weight and stiffness-to-weight ratios are the primary reasons composites are widely used. In addition, all metal castings contain notches that can catastrophically fracture under impact due to their respective stress concentrations. The fiber reinforcement of composites alters this failure sequence resulting in an increased resistance to impact. The impact toughness of composites can be maximized by fiber selection, length of fiber and use of tougher resin such as thermoplastics. (Team Lemming, 2003)

By using Bi directional Kevlar we will greatly reduce weight and advance in performance using a composite for our construction can also provide a consolidation of parts, thus improving the reliability of the structure and keeping the costs competitive with metallic structure. (Team Lemming, 2003)

In Zhang X.T. (2010) UAV project, he proposed that the choice of material emphasizes not only strength or weight ratio but also

- Nose transparency for camera function
- Comparable large strength allied to lightness
- Strong stiffness and toughness for the rear rod
- Low cost and weight for all parts
- Fracture toughness
- Crack propagation resistance
- Exfoliation corrosion resistance

The popular trend of manufacturing UAV is aluminum alloys, which pure aluminum is mixed with other metals to improve its strength. In real world aircraft, Cui Degang (2008) "conventional stiffed fuselages (skin/ frames/ stiffeners), sandwich fuselage, double walls (skin with an interior panel), insulation blankets in between the skin and the interior panels, application of damping improving viscoelastic layers, application of piezo electric elements for active noise control, are designed and launched to strength the fuselage." However UAV does not need too much strength, therefore only the skin with basic holding structure would do. (Zhang X.T., 2010)

Table 2.6b: Selection Material for UAV Fuselage (Zhang X.T., 2010)

Material	Density	Tensile Strength @73 °F	Stiffness (E)	Method of manufacture	Price
Aluminum sheet	2.7 g/cm3	30,000psi	70000MPa	Forging	Expensive
Wood	0.8 g/cm3	550psi	10000MPa	Adhesive Bonding	Cheap
Styrofoam	0.18 g/cm3	100psi	5000MPa	Hotwire Cut by CNC	Cheap
Plastics (PVC)	1.15 g/cm3	7,000psi	3000MPa	Vacuum Forming	Very cheap
Carbon fiber	1.78 g/cm3	100,000psi	50000MPa	Epoxy Resin	Very expensive

The materials selected for comparison are aluminum sheet, wood, Styrofoam, plastics (PVC), and carbon fiber. Considering the entire factor listed including stress factors, cost, manufacturability, weight-to-stress ration, and resistant to corrosion or stress concentration, plastics are the best choice and vacuum forming method is chosen for plastics’ manufacture. (Zhang X.T., 2010)

CHAPTER 3

METHODOLOGY

3.1 Project Design Overview

At the beginning, the title of project is selected and research is done to have adequate understanding on the project title. The mission that will be performed by the UAV is identified and the specification is determined accordingly to the type of mission performed. After that, the fuselage generic UAV is designed and its follow by fabrication of the UAV. The fuselage is fabricated by parts and therefore all parts have to be assembled together. With the wings and all other components mounted on the UAV, test flight will be performed to test the stability of the UAV.

The UAV will be sent back for troubleshooting is any problems occurred. This process will be repeated until no problem may arise during the test flight. The following in to determine whether is there any improvement shall be made on the generic UAV. If there is improvement needed on the UAV, the required parts will be fabricated again and then be assembled on the UAV fuselage. The process end if there is no further improvement required.

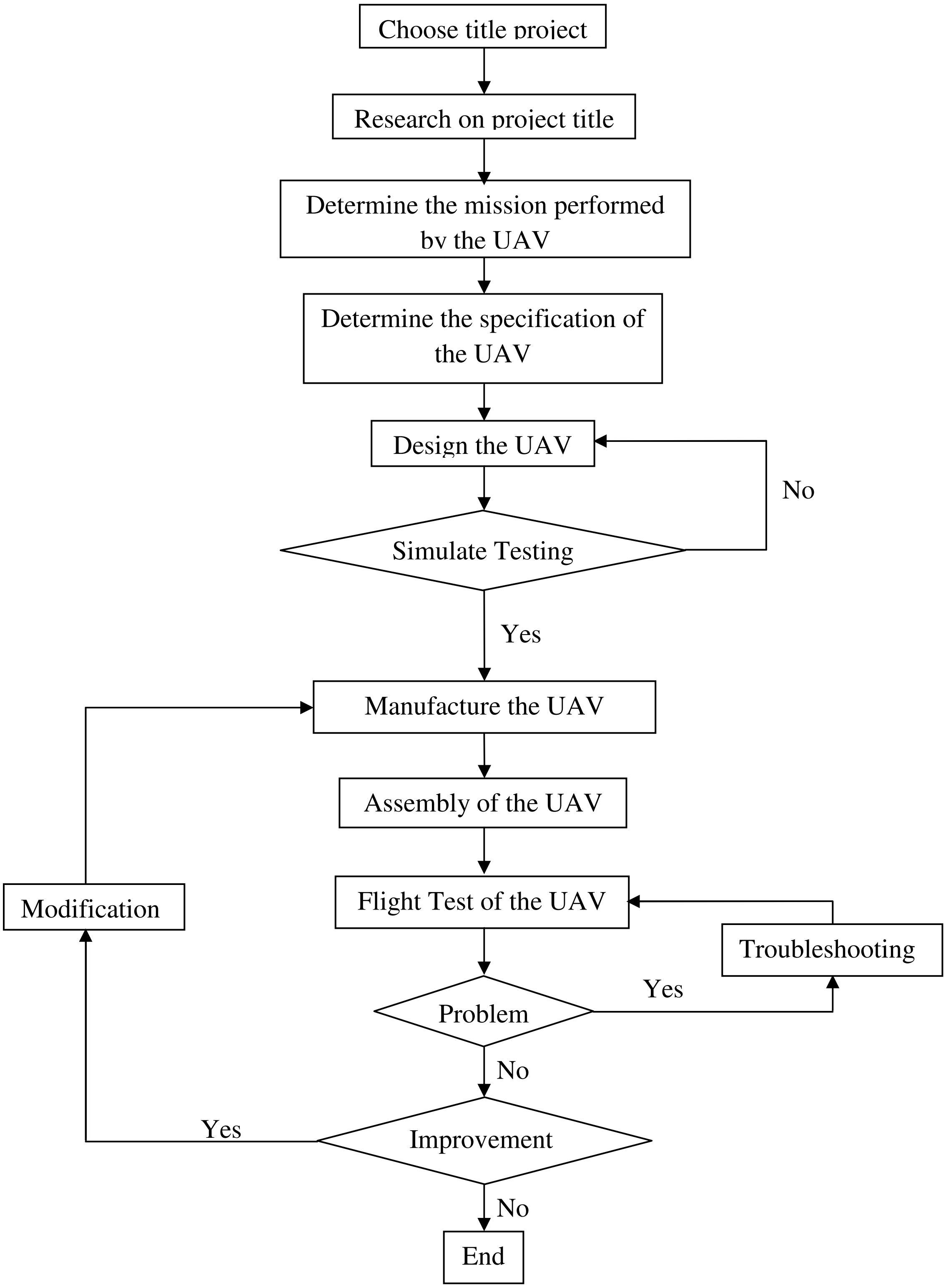

Figure 3.1: Project overview flowchart

3.2 Designing the UAV

There are a few stages in designing the UAV fuselage. Three conceptual designs will be made to accommodate more ideas. However the best designs will be selected. Simulation will be done using software to know the characteristics of the UAV. If improvement is needed, the design of the fuselage will be modified and be simulated again. At the end, the design is finalized and is ready for manufacturing.

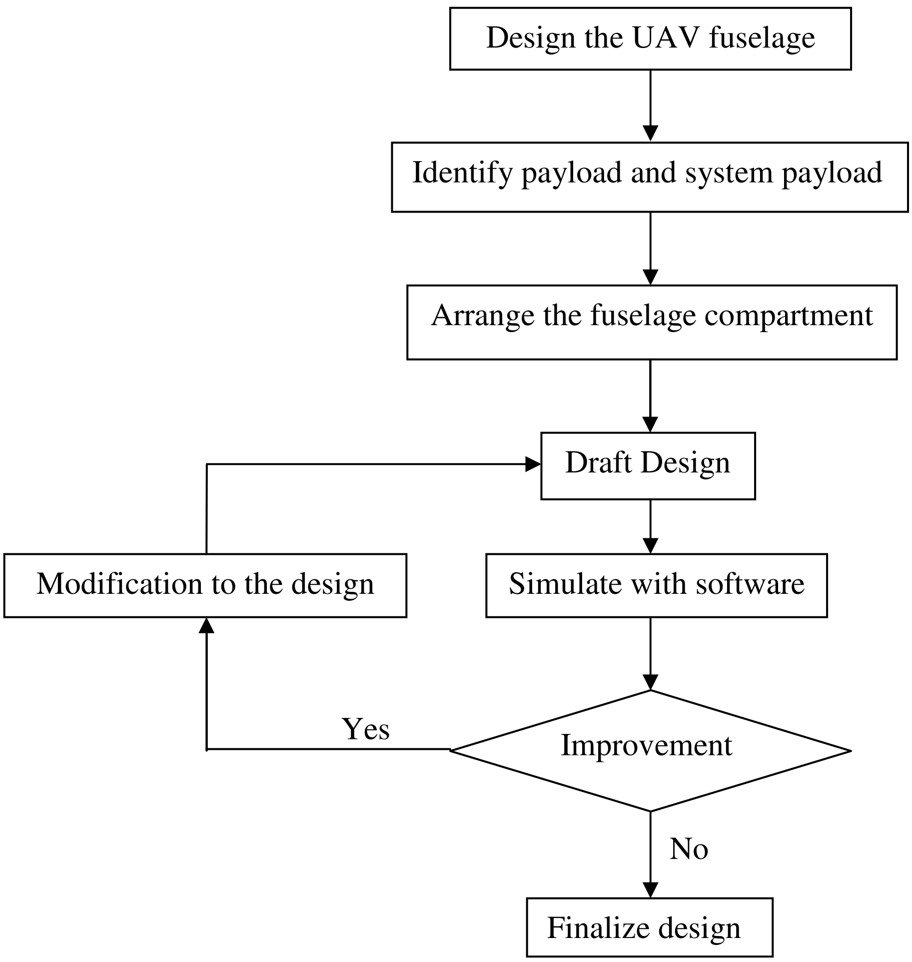

Figure 3.2: Designing flow chart of the UAV fuselage

3.3 Fabrication of UAV fuselage

In the manufacturing stage, it is important to determine the manufacturing method and the material being used to fabricate the UAV. After the selection is done, mould has to be produced in order to mold the shape of the UAV. The UAV will be fabricated by part and will be assembled in the next stage.

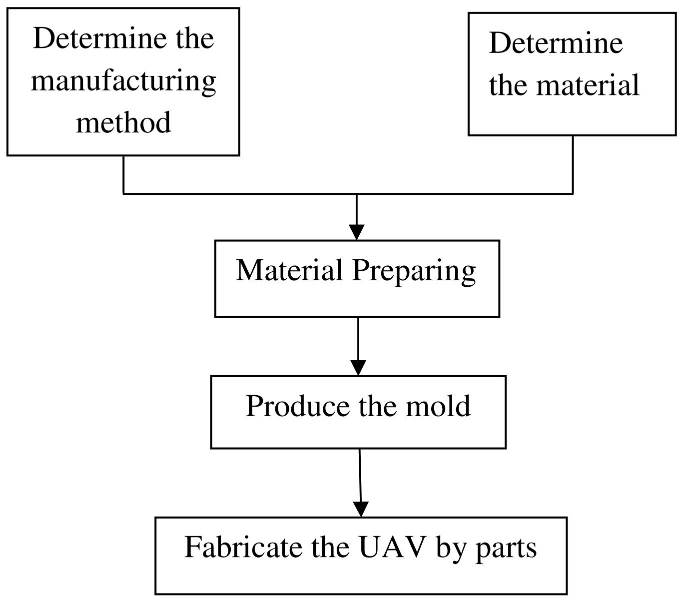

Figure 3.3: Manufacturing flow chart of the UAV

CHAPTER 4

DESIGNING AND MANUFACTURING THE UNMANNED AERIAL VEHICLE

4.1 Designing the UAV

4.1.1 Fuselage Design

The unmanned aerial vehicle (UAV) fuselage is to be designed into two main sections. The front section is the payload bay. This is the area for imaging device (e.g. high-end imaging camera, video recording with supporting equipments, supporting device for downlink with wiring and computer systems) to be mounted in the UAV.

The back section will be the wing box of the UAV. Wing box is a crucial for UAV fuselage as this is the part where the wings will be mounted on. The wing box must withstand the lift force of the wings and UAV during takeoff, descent, turning and even the side force during flight mission. Therefore, it must be constructed strong enough to ensure the fuselage and wings will firmly hold after assembled where no failure is allowed due to structure weakness.

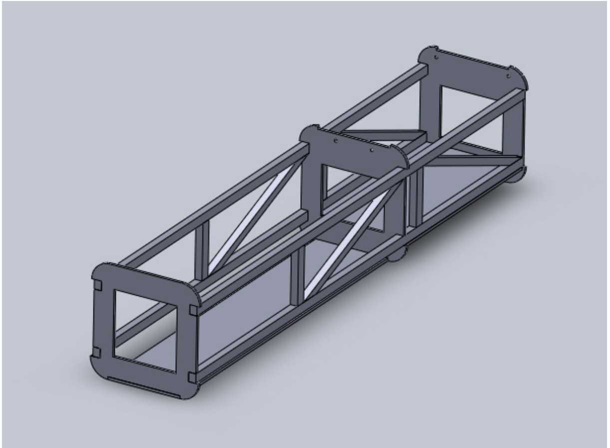

Figure 4.1.1: Fuselage Design

As shown in the figure above, this is the design of the fuselage frame.

Components

- Four primary long main frames – These four main frames will hold the fuselage in longitude shape.

- Bulkhead – Three bulkheads were customized for the UAV fuselage. The three bulkheads will be positioned differently in the front, middle and at the back. It gives the fuselage a near square shape with round corner filling. It also strengthens the structure to avoid the fuselage from breaking inward. The back bulkhead will serve as the assembly point for the UAV tail cone.

- Vertical and Diagonal Supportive – These supportive parts are added to reinforce the fuselage to enable the structure to withstand more force.

- Payload bay base structure - All payload devices will be stationed on this base structure.

- Wing box base structure – This strong base structure will be the assembly point of the rear landing gear. Besides that, the power source and autopilot system will be mounted on this base structure.

4.1.2 Empennage

The empennage of the UAV is also known as the tail or tail assembly. It gives the whole aircraft stability in a similar way such that feathers work on arrows. UAV empennage incorporating vertical and horizontal stabilizing surfaces which stabilizes the flight dynamics of pitch and yaw, as well as housing control surfaces.

4.1.2.1 Single Boom or Double Boom

In the design of the empennage, there are two selections that are being put into considerations. A single boom empennage and a twin boom empennage. Single boom is easy to be designed as it structure connected to the fuselage. The UAV with single boom is easy to be hand launched as the propeller has to be built very high since our UAV is using a ‘pusher’ propulsion system. However, single boom empennage is difficult to manufacture as the boom must be structure larger so that it has the strength to hold the assembly of the rudder, horizontal stabilizer and elevator. Besides that, very big elevator and rudder must be fabricated in order to provide sufficient control authority to the UAV during maneuvers. Tail ground strike is a common phenomenon for single boom therefore higher clearance of landing gear is needed which in turns complicated the manufacturing process of the airplane.

Double boom is however a preferable method of designing the empennage. Although the assembly step is a little more complicated to the single boom, it possesses the characteristic that we want to archive in the objectives of this project. Smaller elevator, rudder and boom are needed for this design. This eases the manufacturing process of the whole empennage. Since our UAV is a pusher type aircraft, we do not need to fabricate an additional structure to increase the height for the propeller assembly. The most important advantage is that twin boom design increase an aircraft structure’s rigidity, strength, and fuselage internal volume which provide rooms to carry more payloads that are much needed to the UAV.

Table 4.1.2.1: Advantages and Disadvantage of Single Boom and Double Boom

Single Boom Tail	Double Boom Tail
Disadvantages • Larger boom required and hard to be manufactured. • More material needed to fabricate bigger elevator, rudder and horizontal stabilizer. • Tail strike on ground. • Higher landing gear needed for higher ground clearance.	Disadvantages • More assembly steps
Advantages • Easily to be designed • Can be hand-launched	Advantages • Smaller boom structure, elevator and rudder. • Do not need additional structure to increase propeller height. • Increase aircraft's rigidity, strength. • Increase fuselage internal volume for more payloads space. • Meet this project objective – Easy to be manufactured.

4.1.2.2 Empennage Design

The empennage consists of the entire tail assembly including the fins, the rudder, the tailplane, the elevator and the twin boom where it is assembled to the wings of the UAV.

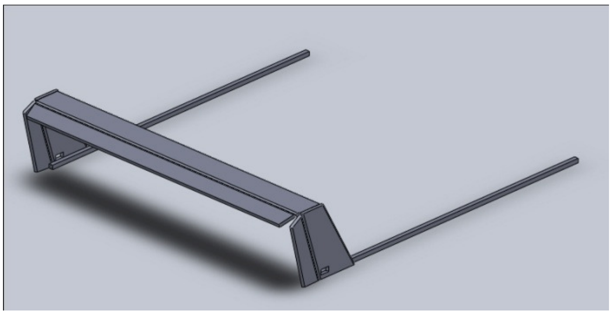

Figure 4.1.2.2: Empennage Design

Components

- Twin Boom – These two straight booms attached the whole empennage to the UAV by being assembled to the wings. It also shield all the wiring connected to control device of stabilizer.

- The Tail Plane – It is normally called the horizontal stabilizer. It is used to balance and share lifting loads of the main plane dependent on the centre of gravity.

- Elevator – Hinged to the horizontal stabilizer. It is a movable airfoil that controls changes in pitch, the up and down motion of the aircraft's nose.

- The Fins – It is a fixed structure which normally called the vertical stabilizer. It is used to restrict yawing (side-to-side) motion of the aircraft.

- Rudder – Rudder is a vertical movable airfoil that is used to turn the aircraft in combination with the ailerons.

4.2 Material Selection

The material selected to fabricate the UAV is essential as this will determine the success or failure of the whole project. This is as the structure UAV must be built lightly but with enough strength to withstand all forces acting on it. Besides that, the overall structure has to be strong to withstand all odd events that may happen during flight mission. Material selected for the UAV must be light, strong and cost reasonable and therefore material selection for the UAV is one of the hardest parts in the whole project.

4.2.1 Fuselage Material

The fuselage consists of a few parts which are the frame, bulkhead and the skin of the aircraft. Each of these section required different material for fabrication. Material of each section is considered with great meticulous.

4.2.1.1 Fuselage Frame

The fuselage frame consists of four main longeron, two vertical supportive structures, and four diagonal supportive structures. Although bulkheads are one of the part of the frame, its prominent contribution in supporting the frame while maintaining the shape of the fuselage make its have to be considered differently.

The material selected for the fuselage will be considered with few aspects as stated, manufacturability, cost, strength, weight, and manufacturing cost, easy available. These aspects will be rated from 5 (the worst) to 1 (the best). Materials that are taken into consideration are aluminum, balsa wood, stainless steel, carbon rod, and iron.

Table 4.2.1.1: Material Selection for Fuselage Frame

[Rated from 1 (the best) to 5(the worst)]

	Aluminum	Balsa Wood	Stainless steel	Carbon Rod	Iron
Manufacturability	3	1	5	5	5
Cost	4	1	5	5	3
Strength	2	5	1	3	1
Weight	2	1	5	5	5
Manufacturing Cost	4	1	5	5	5
Easy Available	2	1	5	5	4
Total score	17	10	26	28	23

Based on the table above, balsa wood is the ideal material to construct the fuselage frame. The only drawback of balsa wood is that the strength of balsa wood is not strong compared to metal form materials. However, in terms of manufacturability, balsa wood rated one which is the best among all compared material. Balsa wood is cheap compared to aluminum, stainless steel, carbon rod, and iron. The lightest weight among all materials is balsa wood. The cost for manufacturing of balsa is low as it is soft and can be crafted manually without any machine. Besides that, it is easily available throughout any hardware shop. Therefore, balsa wood is selected to construct the fuselage frame.

4.2.1.2 Bulkhead

As mentioned in the previous section, bulkheads are very important to the fuselage and therefore the material to construct bulkhead in considerate differently from the fuselage frame.

Bulkheads are important as its give the fuselage a near square shape with round corner filling. It also strengthens the structure to avoid the fuselage from breaking inward. The back bulkhead will serve as the assembly point for the UAV tail cone.

Therefore more criteria are considered during selecting the material for bulkheads. These criteria are cost, manufacturability, strength, weight, hardness, toughness, and manufacturing cost. These aspects will be rated from 5 (the worst) to 1(the best). Materials that will be compared are iron, 3-ply hardened plywood, and hardened aluminum.

Table 4.2.1.2: Material Selection for Bulkhead
[Rated from 1 (the best) to 5(the worst)]

	Iron	3-ply hardened plywood	Hardened aluminum
Cost	3	1	5
Manufacturability	5	1	5
Strength	1	1	1
Weight	5	1	5
Hardness	1	1	1
Toughness	1	2	1
Manufacturing Cost	5	1	5
Total Score	21	8	23

3-ply hardened plywood outstand iron and hardened aluminum. It scores the highest in cost, manufacturability, weight and manufacturing cost. 3-ply hardened plywood has the same score with iron and hardened aluminum on hardness. However, the score of toughness for the 3-ply hardened plywood lag behind by one compared to the other two materials. In overall, 3-ply hardened plywood still score greatly beyond iron and hardened aluminum and therefore be selected for the material to construct bulkheads.

4.2.1.3 Fuselage Skin

After the completion of fuselage and bulkhead being assembly, a covering is required to cover up the fuselage frame and bulkheads. The fuselage of aircraft is covered by what is referred to as the skin.

The skin for the UAV must be weight saving yet hard enough to protect the fuselage frame, for example belly landing. The maintenance cost for the skin has to be low and therefore the skin must have no corrosion and fatigue cracking. It must also be easily manufactured for time saving during mass production.

With all the selection criteria stated above, fabric covering for the skin of fuselage is definitely out of the choice. This is because, fabric is very soft and can endure tear easily. This will not serve the purpose for protecting the fuselage. In order to fulfill all the criteria above, composites material will be the best choice. With all consideration, glass fiber, carbon fiber and spectra fiber will be looked in detail.

The elements that will be taken into considerations are cost, manufacturability, strength and manufacturing cost. These elements will be rated from 1(the best) to 3(the worst).

Table 4.2.1.3: Material Selection for Fuselage Skin

[Rated from 1 (the best) to 3(the worst)]

	Fiber Glass Reinforced Plastic	Carbon Fiber Reinforced Polymer	Spectra Fiber
Cost	1	2	3
Manufacturability	1	3	3
Strength	3	2	1
Manufacturing Cost	1	2	3
Total Score	6	9	10

The highest among these three composites is spectra fiber. Spectra fiber, the high-strength fiber developed by Honeywell, is the base material for special storm-resistant curtains. Storm-A-Rest curtains manufactured by spectra fiber can protects windows and doors during hurricanes as they can withstand 155mph winds and impact from large wind-borne projectiles. “Pound for pound, Spectra fibre is 15 times stronger than steel.” (Honeywell, 2011) However, the purchasing cost for spectra fiber is too great which cause spectra fiber being ousted. This is because the lowest price range varies from USD25 to USD50 per kilograms with a minimum order of 300kg.

Carbon fiber reinforced polymer has stronger strength then fiber glass and the price compared to spectra fiber is definitely lower. It should be the best choice after spectra fiber. However carbon fiber reinforced polymer is best to be cured with resin matrix under heated condition to bring out its maximum hardness and strength after curing. This increases the complexity of the manufacturing method and time consuming. Therefore carbon fiber reinforced polymer is not a suitable material to fabricate the skin.

Fiberglass is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive.

Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes.

Fiberglass reinforced polymer out score carbon fiber and spectra fiber in terms of cost, manufacturability and manufacturing cost. Although the strength of fiberglass is not as strong compared to carbon fiber and spectra fiber, its strength is sufficient to provide the protection and support to the fuselage frame and bulkheads. The table below shows the general values strength of fiberglass.

Table 4.2.1.3: Tensile Strength and Compressive Strength for Fiberglass (East Coast Fiberglass Supplies, 2012)

Material	Tensile Strength MPa	Compressive strength MPa
Polyester resin (Unreinforced)	55	140
Polyester and Chopped Strand Mat laminate 30% E-glass	100	150
Polyester and Woven Rovings Laminate 45% E-glass	250	150
Polyester and Satin Weave Cloth Laminate 55% E-glass	300	250
Polyester and Continuous Rovings Laminate 70% E-glass[	800	350

The fiberglass that is chosen to fabricate the skin of the UAV is woven fiberglass. This is because the strength is higher than chopped fiber. Based on the table, Polyester and Woven Rovings Laminate 45% E-Glass has tensile strength of 250MPa and Compressive Strength of 150MPa which is sufficient to create a hard skin for the fuselage.

4.2.2 Summary of Material Selected

This section is the summary of material selected for fabrication of UAV.

Table 4.2.2a: Material Selected for Fuselage Frame

Fuselage Frame	
Material Compared • Aluminum • Balsa Wood • Stainless Steel • Carbon Rod • Iron	Material Selected ✓ Balsa Wood

Table 4.2.2b: Material Selected for Bulkhead

Bulkheads	
Material Compared • Iron • 3-ply hardened plywood • Hardened aluminum	Material Selected ✓ 3-ply hardened plywood

Table 4.2.2c: Material Selected for Fuselage Skin

Fuselage Skin	
Material Compared • Fiber Glass reinforced plastic • Carbon Fiber reinforced plastic • Spectra Fiber	Material Selected ✓ Fiber Glass reinforced plastic

The material selected will be used to fabricate all the parts of the UAV.

4.3 Manufacturing Method Selection

CNC machining is preferred for the fabricated process of the UAV. This is because CNC machining has high accuracy in every aspect of cutting, milling and drilling. However, the cost of CNC machining is very high that cannot be affordable due to budget constrain. This is because aluminum blocks for the female mold in order to fabricate the fuselage.

Since the material that are going to be used in the fabrication process are EPS foam, balsa wood, 3-ply hardened plywood and other non metallic material, it is decided that manual handwork will be used to fabricate UAV. Therefore no fabrication cost will be included expect material costing.

4.4 UAV Fabrication

Since all the materials and methods have been determined, the fabrication process of the UAV can now be started. The UAV is fabricated by few major parts. The first major part is the fuselage frame which consists of bulkheads, lengerons, payload bay base, wing box base and supportive structures. The second major part is the skin of the UAV which will be made by fiberglass. The third major is the tail of the UAV which is the empennage.

4.4.1 Fuselage Frame

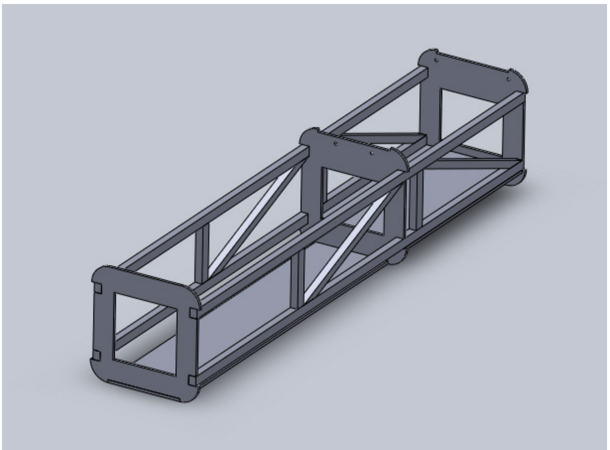

Figure 4.4.1: Fuselage Frame Design

The figure above shows the design of the fuselage. Let us refresh that there are four main longerons, three bulkheads, vertical and diagonal supportive structures, payload bay base structure, and wing box base structure.

4.4.1.1 Longerons

The four main longerons are the first to be fabricated. As we know balsa woods are selected to construct the main frame. Balsa wood strips with dimension of 10 mm × 100 mm × 1000mm were bought. Four main longerons will be cut out from the balsa strips. The longerons will be cut from the balsa strips using a balsa wood stripper.

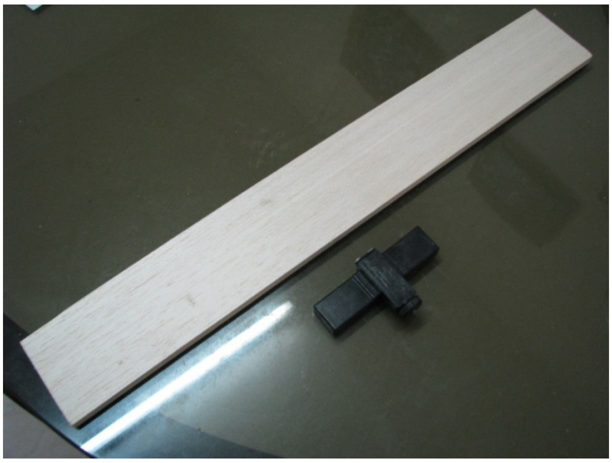

Figure 4.4.1.1a: Balsa Wood and Balsa Stripper

Each longeron with a dimension of 1 cm × 1 cm × 65cm is cut out from the balsa strips.

Figure 4.4.1.1b: Me Cutting the Balsa Strips

The excessive of the balsa strips was cut away so that it will only be 65 cm.

Figure 4.4.1.1c: Cutting Away the Excessive Balsa Wood

4.4.1.2 Bulkheads

The three bulkheads for the fuselage frame will be fabricated from 3-ply hardened plywood. Real scale dimension of the bulkhead was printed on a print of A4 paper. The bulkhead outline on the paper was then cut out to be pasted on the 3-ply hardened plywood.

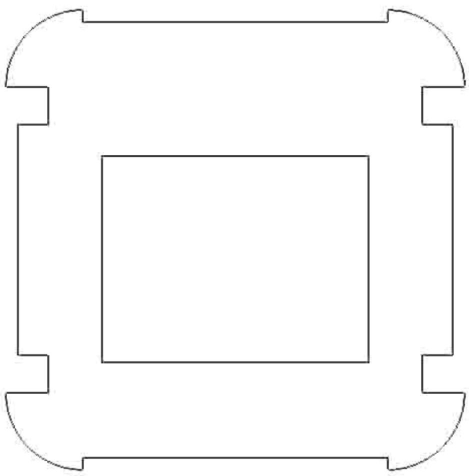

Figure 4.4.1.2a: Bulkhead Outline

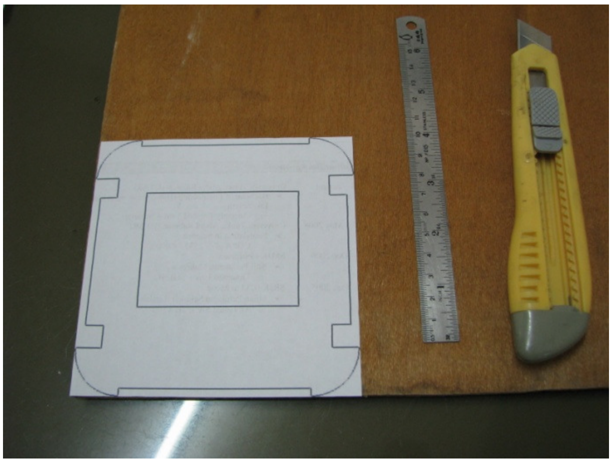

Figure 4.4.1.2b: Cut Paper Bulkhead Outline pasted on the 3-ply Hardened Plywood

The real bulkhead will be cut out from the plywood based on the actual dimension outline pasted on the plywood. However, a square shape bulkhead is cut out rather than the actually shape of the bulkhead. This is because the plywood is very hard and the round cornering is hard to manually cut by hand.

Figure 4.4.1.2c: Square Bulkhead with Pasted Outline

Therefore, the square unfinished bulkhead is taken to the lab to sand of the remaining unnecessary part.

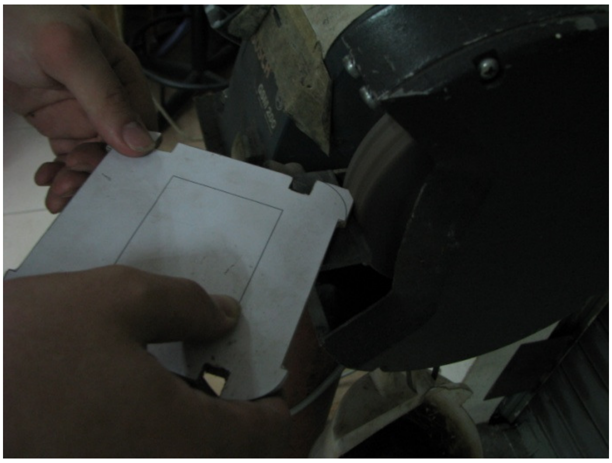

Figure 4.4.1.2d: Me Sanding the Bulkhead

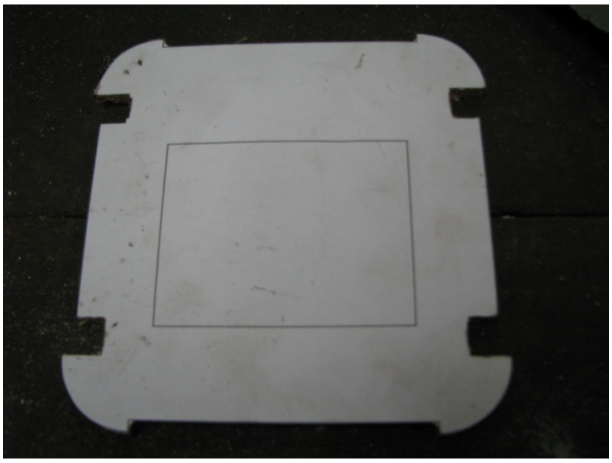

Figure 4.4.1.2e: Finished Bulkhead

The steps are repeated for the next two bulkheads.

4.4.1.3 Vertical and Diagonal Supportive Structures

The vertical and diagonal structures were cut out from balsa strips too.

The required dimension of the vertical supportive structure is determined and cut out from the balsa wood. The fabrication diagonal supportive structures are somehow more challenging then the vertical supportive structure. Ordinary measurements and cutting methods is not accurate as the margin of error is so small that even a degree of miss fabrication will cause the diagonal supportive structure out of service thus wasting the materials.

The real scale dimensions of the diagonal supportive structures were printed on A4 size paper. The outline of the diagonal supportive structures was then but from the paper to be pasted on the cut balsa wood strips.

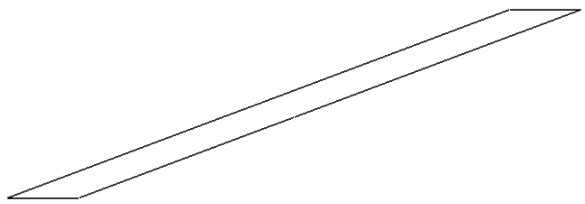

Figure 4.4.1.3a: Diagonal Supportive Structure Outline

Figure 4.4.1.3b: Paper Outline Pasted on the Balsa Wood Strip

The balsa wood is the cut off according to the outline of the paper outline.

Figure 4.4.1.3c: Finish Diagonal Supportive Structure with Pasted Actual Dimension Paper Outline

The supportive structures were finish fabricated and the next step is to connect the entire jigsaw to form the fuselage frame.

4.4.1.4 Connecting the Jigsaws

With all the components ready, the fuselage can now be connected together.

The bulkheads are connected with the four main longerons. The front bulkhead was first set in place. The middle bulkhead was then adjusted to the required distance away from the front bulkhead. The four main longerons were then fitted into the side jigsaw cutting of the bulkhead. After that the back bulkhead was fitted in place.

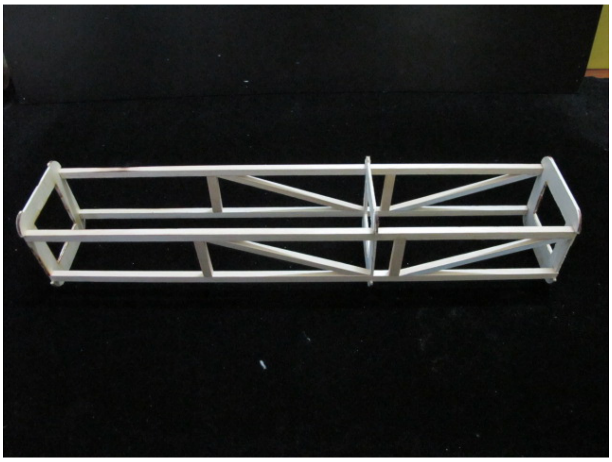

Figure 4.4.1.4: Fuselage Frame

The joints of all fitted fuselage frame were being adhered by fast drying cyanoacrylate. This step consolidates the fuselage frame firmly.

4.4.2 UAV Skin

The process of creating the skin started after the fuselage frame is ready. All the tools required like EPS foam, 5 hours epoxy resin and hardener, fiberglass, Meguair's mold release wax and cutter blades are prepared. Everything must be planned and prepared ready as the molding steps are very important. The whole molding process will be ruined by only one wrong fabrication process.

4.4.2.1 Preparing the Mold

The mold of the UAV fuselage will be made by high density EPS foam. High density EPS foam is selected as it will not crumble easily and it can withstand higher temperature occur during the chemical reaction of epoxy adhesive during the laying of fiberglass.

Firstly, two mock up bulkheads were fabricated. These mock up bulkheads have the same dimension with the actual bulkhead on the fuselage frame. Then these mock-up bulkheads will be strong consolidated at each end of the EPS foam where the core will be cut out by tracing the outline of the mock-up bulkheads and our fuselage female mold is ready.

Figure 4.4.2.1: Fuselage Female Mold

4.4.2.2 Molding the Skin

The skin of the fuselage frame will be mold using this female mold. The female mold will first be wax to ensure clean surface for the molding process. The mold will be waxed using the Meguair's Mold release wax with soft sponge so that no scratches will be made on the mold.

Figure 4.4.2.2a: Applying Wax on the Fuselage Female Mold

Now it is ready to proceed to the next step of molding the fiberglass skin. 5 hours slow cure epoxy resin and hardener was mixed thoroughly to create a perfect adhesive for the molding process. The mixed epoxy adhesive was spread evenly in every corner of the mold carefully. Then the first layer of fiberglass was laid into the mold.

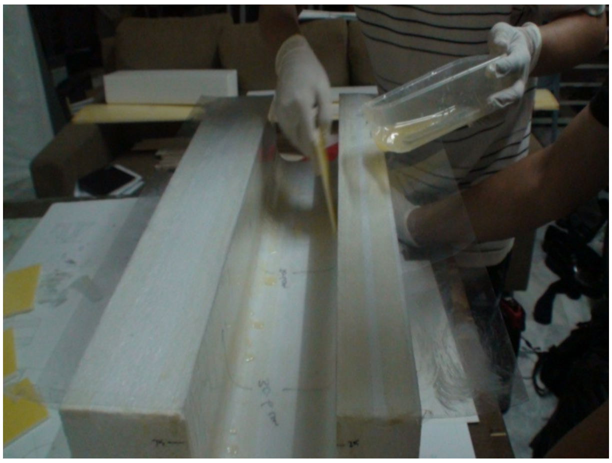

Figure 4.4.2.2b: Spreading the Epoxy Evenly

Figure 4.4.2.2c: Laying the Fiberglass

The first fiberglass layer laid was left overnight with the mold so that it will be harden. This formed a hard surface skin for the fuselage frame. In the next day, the same steps were redone to lay the second layer of the fiberglass in the mole where the first layer of fiberglass was hardened. The second layer of fiberglass was laid then the fuselage frame was inserted into the mold. The mold was left overnight again so that the skin and the fuselage frame will bond together into a strong single part.

4.4.4 Problems Encounter during Fabrication Process

The shown steps of fabricating the UAV fuselage seems to be easy but there are a lot of problems faced throughout the process.

4.4.4.1 Balsa Woods

Cutting the balsa wood is quite challenging although it seems easy. Razor sharp blades were needed in order to cut the balsa strips well. If a slightly blunt blade was used, the cutting process will be miserable. The balsa wood would be tore apart instead of being slice and cut properly. Internal tear with uneven surface makes the balsa wood to be structurally weak and hence the cut balsa strip is not usable anymore. The bad balsa woods were rejected and new balsa woods have to be cut.

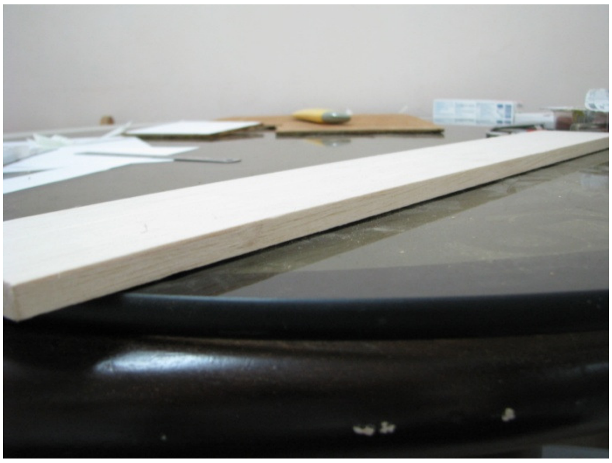

Figure 4.4.4.1a: Figure of Good Cut Balsa Wood

Figure 4.4.4.1b: Figure of Bad Cut Balsa Wood

4.4.4.2 Fuselage Frame Warping

The fuselage frame actually had a little bend or what we normally warping when all the jigsaws were consolidated properly. This was because all the balsa wood strips which were our four main longerons, vertical and diagonal structures were not perfectly straight. Therefore this reason caused the fuselage to warp.

The whole fuselage frame was slightly heated and small forces were applied to the warp area so that a fine tune was made. This step unwarps the fuselage frame so that it fit into the mold for skin molding process.

4.4.4.3 Mixing the Right Ratio and Amount of Epoxy Adhesive

Mixing epoxy is a very easy task but mixing the right amount of epoxy with right ratio proved a difficult skill.

The normal epoxy mixing ratio of resin and hardener is one to one. We are normally advised to mix the same amount of resin with same amount of hardener into to create a good epoxy adhesive. Everything seems to work well in routine usage as the amount of epoxy adhesive we use is very little. However problems surface out when large amount of epoxy were used.

During the initial process of laying fiberglass, a ratio of one to one 5 hours epoxy slow cure resin and hardener were mixed and spread evenly on the mold. The chemical reactance produced so much heat and it ended up destroyed the mold. The EPS foam mold had suffered burn where the foam melted.

The mold was discarded and new ratio of epoxy resin and hardener were experimented. The best ratio obtained is five to one of epoxy resin and hardener. The new mix ratio of epoxy was mixed and the laying process was then started all over again by producing the mold again. Precious time was wasted.

4.4.4.4 Spreading Right Amount of Epoxy Adhesive

Besides mixing the right ratio of epoxy, the amount that was being spread on the mold during laying fiberglass layer was also very important. This was because if too few epoxies were applied the fiberglass could not be hardened well and therefore the fiberglass layer will peel off after the epoxy cured.

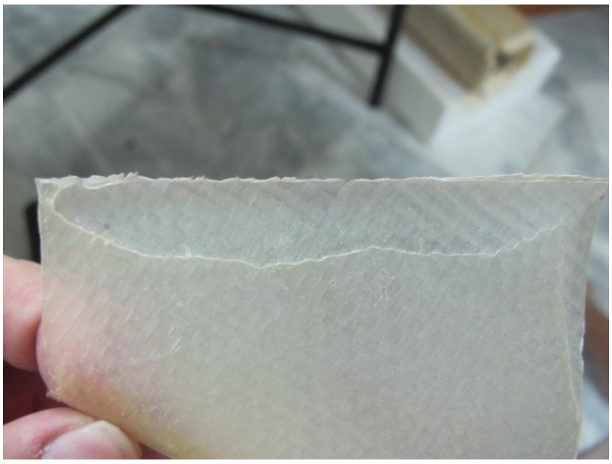

Figure 4.4.4.4: Fiberglass Peeled Off

If too many epoxies were applied during the laying process, many uneven surfaces will emerge after the epoxy cured. This will affect the straightness of the fuselage skin.

As a conclusion, the right amount of epoxy has to be applied during the laying process depending on the type fiberglass used and the viscosity of the epoxy mixture solution.

4.4.4.5 Laying the Fiberglass and Health Issues

Laying fiberglass on the mold required good techniques to ensure that the hardened fiberglass will be smooth. The hardened fiberglass will crease if the fiberglass layer was not laid properly during the molding process. The crease fiberglass will not be accepted.

In addition, precautions were taken during the handling of fiberglass. This is because fiberglass will irritate the eyes, skin and the respiratory system. Gloves were worn as itchiness occurred or even worse that skin may have ration. Mask and safety glasses were worn throughout the handling process.

4.4.5 Completed Fuselage Frame with Skin Molded

The figure below shows the completed UAV fuselage.

Figure 4.4.5: Completed Fuselage Frame with Skin

4.5 Fabricating the Empennage

The figure below shows the design of the UAV empennage and let refresh the required parts of the empennage.

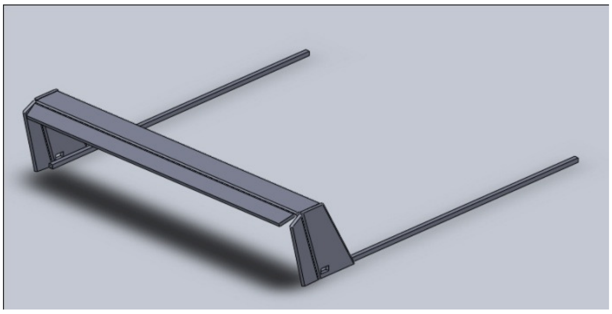

Figure 4.5a: Empennage Design

The main parts are

- Twin Booms
- The tailplane
- Elevator
- The fins
- Rudders

An actual size mock up empennage was being produced before the real empennage was fabricated. This was to ensure that the design worked well and to eliminate unforeseen error of the design.

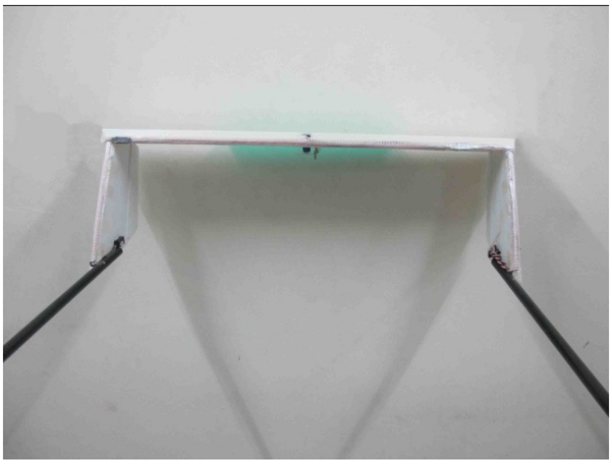

Figure 4.5b: Actual Size Mock Up Empennage

4.5.1 Fabricating the Tailplane and Elevator

The tailplane which is the horizontal stabilizer was fabricated by using of the shelf material. The balsa wood plate was used. The dimension of the real horizontal stabilizer was the same with the mock up horizontal stabilizer. Therefore the outline of the mock up tailplane was traced on the balsa wood plate. Then the tailplane was cut out from the balsa plate.

The cut tailplane has a square corner. The corner of the tailplane was sand to the desired curve edges.

Figure 4.5.1a: Me Sanding the Horizontal Stabilizer

The elevator is a smaller compared to the tailplane. The steps to produce the elevator were the same as to produce the tailplane.

Figure 4.5.1b: Tailplane Sanded to Desired Curve Edges

Figure 4.5.1c: Completed Tailplane and Elevator

4.5.2 The Fins and Rudder

The fin or the vertical stabilizer was fabricated by using a smaller size of balsa wood. Small balsa wood was cut to the same size of the mock up fin with desired diagonal angle. Then it square corner was sand to the desired curve edges. The steps were the same as to produce the rudder. After a set of fin and rudder was completed, all the steps were repeated to fabricate another identical set of fin and rudder.

Figure 4.5.2: Completed Fin and Rudder

4.5.3 Filming all Empennage Components

All the components were covered with ToughLon protection film after being fabricated with balsa wood. The white ToughLon film was ironed on all the components.

Figure 4.5.3: Figure of me Covering the Empennage with White Film

4.5.3.1 Ironing the ToughLon

The ToughLon film had to be iron in suitable temperature. Suitable temperature could iron the ToughLon nicely with clearing all the shrinkage occurred. Low temperature means ToughLon film will not adhere properly on the structures. If high temperature was applied, the ToughLon film will shrink so fast and it hardened immediately and no recover works could be done. The damaged film had to be peeled off and new films were applied.

Figure 4.5.3.1: Damaged ToughLon Film

4.6 Landing Gear

Landing gear of the UAV was fabricated from the design drawn.

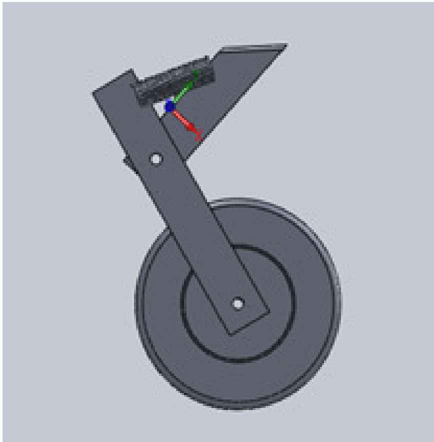

Figure 4.6a: Landing Gear Design

The required pieces of aluminum structured which were downlock struck and shock struck were cut for an aluminum plate. Then the downlock struck was bended by 90 °. The figure below showing bending of the downlock struck.

Figure 4.6b: Bending the Downlock Struck

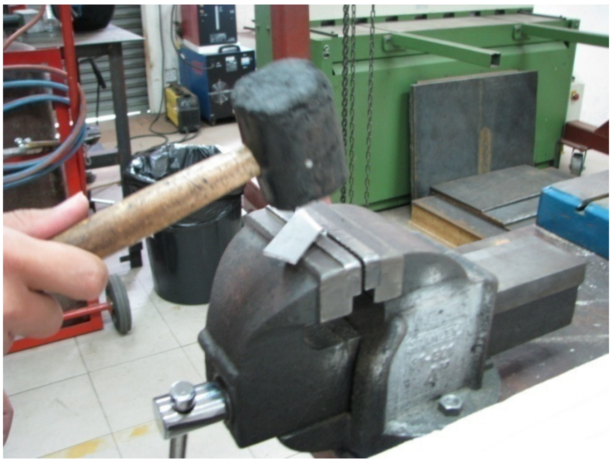

Figure 4.6c: Hammering the Downlock Struck

Then the excessive part of the Downlock Struck was cut away. The figure below show the cutting of excessive part of Downlock Struck using vertical bed saw.

Figure 4.6d: Cutting the Excessive Part Away

Then holes were drilled on the downlock struck and shock struck to assemble the pivoting screw and damping spring. The figure below shows the completed landing gear.

Figure 4.7e: Complete Landing Gear

Figure 4.7f: Landing Gear Fully Compressed

CHAPTER 5

Assembling the UAV Fuselage, Wings and Empennage

5.1 Assembling the UAV

All finish fabricated parts were now ready for assembly. The fuselage will be assembled with the wings and empennage to form a real UAV. Only crucial assembly parts are discussed in this chapter. This is because the assembly works of other parts of the UAV are just simply repetitive screwing and adjusting.

All the components that were assembled were the

- Wings
- Empennage
- Servo motors
- Wiring

5.1.1 Assembling the UAV Empennage

The finished fabricated horizontal stabilizer was connected with the elevator with hinges. The figure below shows the hinges used to hinge the horizontal stabilizer and elevator together.

Figure 5.1.1a: Tailplane and Elevator Fiberglass Hinges

After the horizontal stabilizer and elevator were hinged together, these connections were adhered with 5 minutes Quik-Cure Epoxy Adhesive. The figure below shows the horizontal stabilizer with hinged elevator.

Figure 5.1.1b: Hinged Taiplane and Elevator

The same steps were repeated for hinging the fins and rudder together. The figure below shows the hinged fin and rudder. Two sets of identical fin and rudder were assembled.

Figure 5.1.1c: Hinged Fin and Rudder

After the fin and the rudder was strong consolidated. The fins were adhered strong the square carbon rods which are the twin booms of the UAV. The figure below shows the process of adhering the boom to a set of fin and rudder.

Figure 5.1.1d: Adhering the Boom to the Fin

The boom was firmly adhered to the fin using 5 minutes Quik-Cure Epoxy Adhesive. Two identical sets were produced.

Figure 5.1.1e: Adhered Boom to the Fin

Figure 5.1.1f: Two Identical Set Fabricated

The horizontal stabilizer was then connected tightly with the fin with screws and Plastic L bars. Therefore the whole empennage is fully assembled.

Figure 5.1.1g: Completed Empennage

5.1.2 Wiring and Servo Motors

Notice that there is a square hole cut on the fin or vertical stabilizer. Let us see the photo of the finish fabricated fin again.

Figure 5.1.2a: Fin with Hole

Servo motor will be installed in this hole. A digital servo motor will be installed to control the rudder. The digital servo motor will control the rudder for yawing the UAV left and right. It was adhered strong to the hole prepared previous. The figure below shows a digital servo motor adhered on the fin.

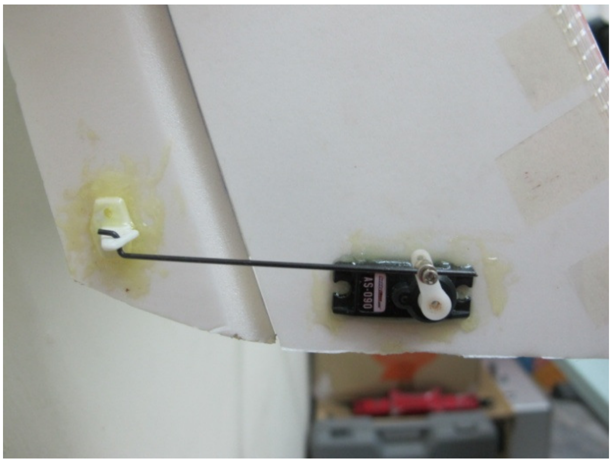

Figure 5.1.2b: Servo Motor Installed

A pusher rod was tighten with the digital servo motor and bend section was hook with the plastic loop which was adhered to the rudder. Then the wiring for the servo motor was installed to the UAV. The beginning of the wiring which is a female head is being led by aluminum bar. The figure below shows that the female being led closely by the aluminum bar.

Figure 5.1.2c: Installing Wiring (1)

Then the aluminum bar was being pulled out from the other end of the carbon rod. The figure below shows the wire being pulled slowly and the female head entered the carbon rod.

Figure 5.1.2d: Installing Wiring (2)

The two figures below show that the wire was completely pulled out. The wired being pulled out near the fin will be connected to the servo motors. The wired being pulled at the front of the fuselage will be connected to electronic control board in the fuselage

Figure 5.1.2d: Installing Wiring (3)

Figure 5.1.2e: Wiring Installed Complete

5.1.2.1 Problems of Wiring Installation

Many wires were installed to cater the control of empennage and rudders. However the centre hole of the square carbon rod was so small that it could hardly spare any extra space for the wirings. The aluminum bar must be pulled very slow to ensure that the wire slide very smoothly through the hole. If strong force was applied while pulling the wiring where there was a clinging effect, the result was the wiring will snap. In the end, all the wiring works have to be redone while replacing new wires. Tedious works were required.

5.1.3 Wings

The finish assembled empennage will be mounted on the wing of the UAV. The wing undergone few steps or furnishing and machining before the assembled empennage could be mounted on the wing.

The wings consist of three parts which are the middle wing, the left wing and the right wing. Each part of the wings will first be trimmed to remove unwanted molded material. The figure shows that the unwanted molded material cut from the wings.

Figure 5.1.3a: Trimming the Wings

All the three parts of the wings will be trimmed. Middle wing will undergo further holes drilling process before the empennage could be mounted on the wings. The figure below showing the middle wing is in the midst of drilling hole in the workshop.

Figure 5.1.3b: Drilling Holes on the Mid Wing

Four holes will be drilled on each side of the middle wing. This is because each boom will be mounted on the middle wing with two screws and surf locking nuts each. The boom will be hold firmly with the wings as the surf locking nut will locks its position on the screw tightly.

Two of the square booms are also required to be drilled as these holes will serve the position for screw being assembled to hold the wings and empennage together. The figure below shows drilling process of the square carbon rod in the workshop.

Figure 5.1.3c: Drilling Holes in Carbon Rod

Screws and surf locking nuts were assembled and hence the middle wing and the whole empennage are now firm attached. The figure below shows the firmly attached empennage and middle wing.

Figure 5.1.3d: Empennage Mounted on the Mid Wing

The left wing and right wing are then being assembled to the middle the wing and hence the wings and empennage assembly process is now completed. The figure below shows me exhibiting the wings and the empennage.

Figure 5.1.3e: Whole Wing and Empennage

5.2 Completed UAV

After all parts were assembled, the UAV was finally ready for its maiden test flight. The figure below shows the complete UAV.

Figure 5.2: Completed UAV

CHAPTER 6

TESTING THE UNMANNED GENERIC VEHICLE

6.1 Test Flight

The generic unmanned aerial vehicle is now ready for flight test. The UAV was successfully flown up to the sky thanks to the good design and strict manufacturing process to ensure the high quality of UAV prototype produced.

The test flight will perform the mission objective of the UAV that is to provide ground survey through aerial photograph. The test flight ground chosen is a field at Putra Heights. The UAV was successfully flown up high in the sky and photos were taken.

The few figures below show photos taken during aerial survey. The estimated height of the UAV flown was about eight hundred to one thousand feet high.

Figure 6.1a: Screen Shot of Video

Figure 6.1b: One of the Photos Showing a Ground Survey on the Field

Figure 6.1c: A Photo Shows Housing Layout

Figure 6.1d: A Photo Showing the Middle of the Field with Us Standing on It

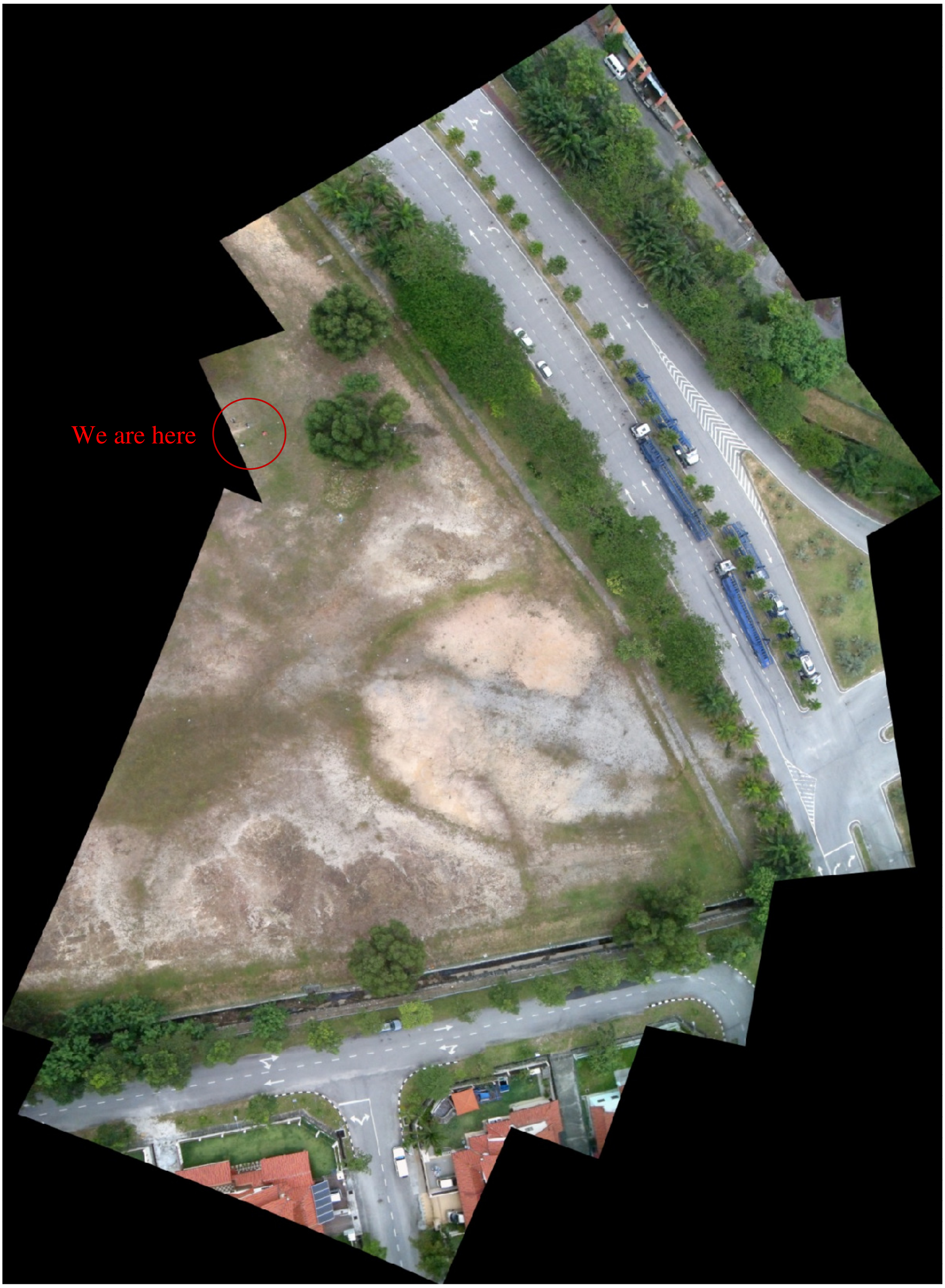

Figure 6.1e: Photos were Stitched to Show Aerial Survey

6.2 Flutter Test

Flutter is a dangerous phenomenon encountered in flexible structures subjected to aerodynamics forces. This includes aircraft, buildings telegraph, wires, stop signs, and bridges. Flutter occurs as a result of interactions between aerodynamics, stiffness, and inertial forces on a structure.

In an aircraft, as the speed of the wind increases, there may be a point at which the structural damping is insufficient to damp out the motions which are increasing due to aerodynamic energy being added to the structure. The vibration can cause structural failure and lead to the destruction of the aircraft.

Figure 6.2: Fluttering Test Video

The UAV was tightened on top of a four wheel drive vehicle and the vehicle was cruising about 60 kilometers per hour. The wing of the UAV did not flutter. This showed that the UAV produced if same to fly as 60 kilometers per hour as this is the maximum speed of the UAV.

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

In this project, I have learnt about the current design of generic unmanned aerial vehicle. Each part of UAV is designed for its own mission profile. Its wingspan and payload are all customizable to suite the mission needs.

I have learned the manufacturing techniques of generic unmanned aerial vehicle and apply the knowledge by producing a generic unmanned aerial vehicle prototype in this project. During the manufacturing process, I have learnt a lot of practical experiences such as the skill of weighing the essentialness of material during the selection. Off the shelf components are used rather self customize part to ensure future maintenance will be quick and easy. The use of general values for design the aircraft was learnt which proved very useful to solve problems.

7.2 Recommendation

EPS foam mold was used die to the budget limitation if possible aluminum mold should be used rather EPS foam mold as aluminum mold is sustainable compared to EPS foam mold. This is because aluminum mold can withstand higher temperature and hence more powerful epoxy matrix can be applied during the molding process. Powerful epoxy matrix means stronger structures produced. Carbon fiber can be applied as its tensile and compression strength are higher compared to fiberglass. These recommendation should be applied if the UAV if modified to cater higher class mission profile.

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APPENDICES

APPENDIX I – THE PROGRESS

May 2011

This is how it begins.

- Approached Mr. Julian Tan Kok Ping and Mr. Chuah Yea Dat for FYP title proposal.
- Both agreed to be my supervisors and FYP title was registered.
- First consultation session began to determine objectives and scope for the project.
- Basic guild lines given to learn the knowledge of aeronautics.
- Endless consultations with Mr. Julian Tan Kok Ping to determine mission profile and basic design of the UAV
- Frequent consultations with Mr. Chuah Yea Dat to assure the direction and progress on track.
- Basic design of the UAV determined and focused on final semester exam.

October 2011

The heat getting up

- Private class session given by Mr. Julian. 4 hours per session and twice a week on Friday and Sunday. Normally at night in Mr. Julian's house and occasionally at UTAR.
- Books given by Mr. Julian for reference.
- Material being proposed and determined.
- Basic rules of flying aircraft taught by Mr. Julian.
- Regular meet up with Mr. Chuah to report progress.
- Focus on short semester study and exam.

January 2012

Go on hell!!!

- Detail design determined for fuselage frame, empennage, landing wheel and others.
- Materials prepared and purchased.
- Manufacturing method confirmed.
- Fabricating and assembling the UAV started.
- Went to Mr. Julian's house every Friday after class until dawn of Saturday.
- Went to Mr. Julian's house every Sunday and Monday in the morning till midnight.
- Did refined jobs and figuring solution during weekdays.
- Did fabrication works in workshop every Thursday.
- Preparation for test flight after UAV completed.
- Hectic test flight schedules.
- Test flight successful.
- Report writing.
- Preparing for presentation.
- Work completed. Salute final year project.