Fabrication of Micro Unmanned Aerial Vehicle Using

Rapid Prototyping and Rapid Tooling

By

Nurul Syafiqa Binti Misran

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

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2009

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.

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NURUL SYAFIQA BINTI MISRAN

ABSTRACT

This project is about choosing the best manufacturing process in order to fabricate the body structure design of the Micro Unmanned Aerial Vehicle (MUAV) previous designed by Mohd Anuar bin Sulaiman(2009). The size of the model is 3" X 5" and the proposed material is Acrylonitrile Butadiene Styrene (ABS) which is Amorphous Thermoplastic Blend. There are several types of fabrication processes were studied such as Rapid Prototyping, Rapid Tooling, Conventional Lathe Machining, and Fiber Glass Layout. Based on the selected techniques the prototype was developed. The casing material was changed from ABS to fiber glass with epoxy layer due to availability problem. The model was fabricated and tested in the wind tunnel to study its aerodynamic characteristics in term of the drag force, lift, and also pitch. Based on the experimental data, the drag coefficient determined. Based on calculation, the drag coefficient of the MUAV is 0.1567.

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the support in completing this thesis. First and foremost, I would like to say a big thanks to my Final Year Project supervisor, Ir. Idris bin Ibrahim. Throughout this project, Ir Idris has contributed so much effort in guiding and supervising me until the project finished. Without any doubt, his knowledge and experience helped me a lot. He also supervise me the aspects needed to be put more concern in completing this project and the methods which are suitable to be used in analyzing the project. Thus the needed result can be obtained. Again, thanks a lot to Ir. Idris bin Ibrahim.

Then, I would like to thanks to all the other students those who involved especially Mohd Syahmi Hassan, Izyan Mohd Jaafar, Nik Farhana Nik Ahmad, and Nadhrah Mohd Jamaludin. Thank you for their cooperation and kindness to share the ideas and opinions to develop the MUAV indirectly help me completing my project. Thousands of appreciation to all the technicians involved especially Mr. Zamil, Mr. Faisal, and Mr. Jani.

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CHAPTER 1
INTRODUCTION

1.1 Project Background

Unmanned Aerial Vehicle (UAV) is an autopilot aircraft which uses remote control or fly autonomously based on pre-programmed flight plans or more complex dynamic automation. Micro Unmanned Aerial Vehicle is basically from the expansion of technologies of UAV. It is also known as Remotely Piloted Vehicle (RPV). Its first invention is to give benefits in military and wars. However, this expansion makes it useful to even other background and become one of the advanced technologies widely used.

This project is carried out to produce the MUAV prototype. The structural design project was done by Mohd Anuar bin Sulaiman, a final year student of 2009. In order to bring this project into real, a prototype needs to be produced. Thus, the very best manufacturing processes need to be found to produce all those parts consists on the model. After producing the prototype, it needs to be tested using some relevant testing processes which to make sure it can fulfil the requirements.

The work includes selecting the best processes, developing the complete manufacturing procedure, producing and testing the prototype. The output produced would be manufacturing techniques, processes and the MUAV prototype. Plus, it is planned to utilize the manufacturing equipment that is available at UTP.

1.2 Problem Statement

The structure of the Micro Unmanned Aerial Vehicle (MUAV) was designed by the previous FYP student. The proposed 3” X 5” MUAV structural material was proposed to be Acrylonitrile Butadiene Styrene (ABS) which is an amorphous thermoplastic blend. The designed detailed was published in the reference [1]. Nevertheless, the prototype has not been manufactured and hence, the physical testing could not be carried out.

The proposed design which is 3” X 5” is too small to be manufactured. This will invite other problem in the manufacturing process if the process chosen is not suitable. Besides, the material proposed, which is ABS is a material which is a bit hard to find in the market. Thus, a suitable material which can replace ABS should also be put under considerations.

Therefore, this FYP is conducted to study the best/optimum manufacturing process and hence produce the MUAV prototype. The scope of the project includes determine the manufacturing processes and related analysis, fabricate the MUAV, and perform testing. The MUAV structural design is limited to the pre-designed MUAV model, hence no new design will be developed.

1.3 Objectives And Scope Of Studies

1.3.1 Study the best manufacturing processes to produce MUAV

1.3.2 Develop detail processes of the selected techniques and manufacturing process

1.3.3 Produce and test the prototype

CHAPTER 2
LITERATURE REVIEW

2.1 Structural Design of Micro Unmanned Aerial Vehicle (UAV) by Mohd Anuar bin Sulaiman(2009)

Basically, the design proposed consists of (3) choices which are vary in sizes, weights, provisions, materials, and designs. The (3) different designs are as follows:

1. Flapping Mechanism (**Design A**)

   The concept of this design based upon nature and simulates the motions of the wings of flying creatures. The wings will simply flap in a vertical plane to produce thrust and lift.

2. Propeller (**Design B**)

   Designed as ducted fan air vehicle, and flies like helicopter. By using the propeller that draws in air through a duct to provide lift.

3. Counter-rotating Rotors (**Design C**)

   There would be an equal and opposite torque which applied to each of the rotor to lift the vehicle. Those rotors are used and functioning against each other to avoid vehicle to turn around and around.

However, after doing the design selection based on criterion such cost, manufacturability, weight/size, appearance, and arrangement of compartment, the chosen design would be design B.

Thus, the design of the MUAV is as shown in the sketch followed by the detail drawing of the design.

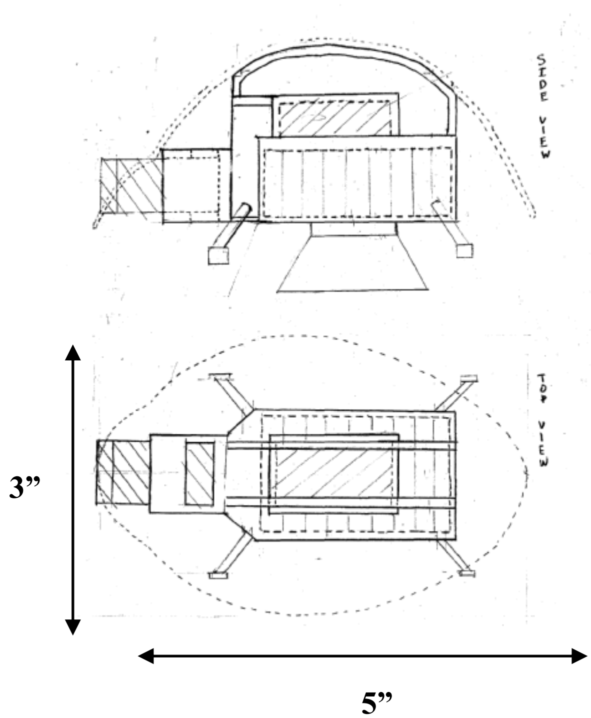


Figure 1: Sketch of propeller design concept

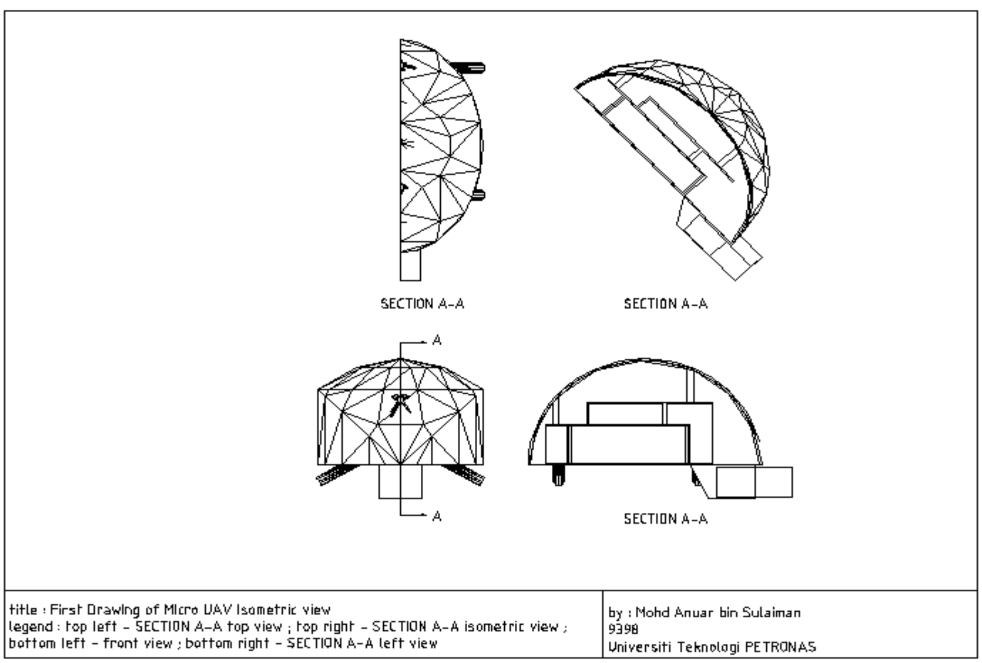


Figure 2: Isometric, top, side and front views of the updated design

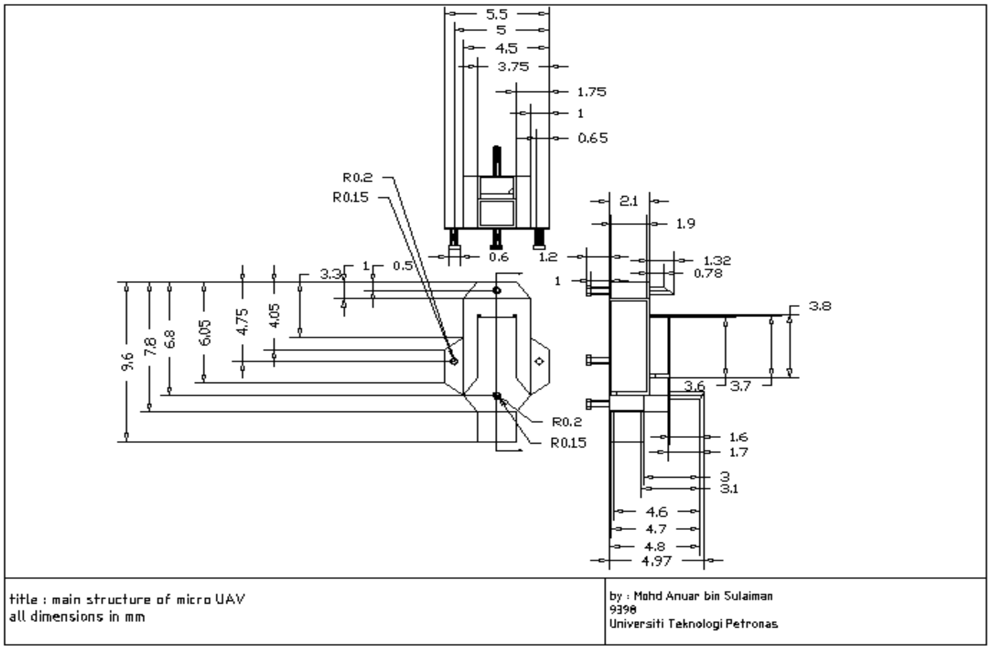


Figure 3: Structure with Dimension

When doing the material selections analysis, two materials are put under considerations which are Acrylonitrile Butadiene Styrene (ABS), and polycarbonate (PC). ABS is the amorphous thermoplastic blend which can be produced based on the different properties. Generally, it has good impact strength at low temperature. Other than having a glossy surface it's also easy to machine. Besides, polycarbonates are a group of thermoplastic polymers. They can be shaped, molded and transformed easily. This polycarbonate is very durable, has high impact resistance, low-scratch resistance and strong.

2.2 Structural design, fabrication, and testing of mini aerial vehicle by K.Kotwani, J Karnawat, and S Kamle(2003)

There are two main fabrication processes that were successfully done in order to produce the Mini Aerial Vehicle (MAV). The processes are Hand Lay-Up Techniques and Lathe Machining Process. The Hand Lay-Up technique was done on glass fiber/epoxy resin composites. Besides, the lathe process was done to fabricate the undercarriage of the MAV. There are three parts of the MAV that needs to fabricate which are the wings, the fuselage, and the undercarriage.

The fabrication of the wings was done using ribs, spar, and stringers. As the skin covering process was completed by doped cotton cloth. To make things easier, the exact full scale drawings was prepared on AutoCAD and was traced on composite sheet. Besides, a band saw machine was used to cut out the composite according to the airfoil shapes.

Other than that, fuselage is one of the compartments that are used to store components like servos, fuel tank, receiver, control rods, engine, and batteries. This is the critical part that should keep an eye while fabrication as it required many components to be stored and contains some critical parts of the MAV. Besides, fabricating the undercarriage part also an important process. The undercarriage was fabricated on lathe using SS rod. The wheels of the MAV also mounted using wheels collars.

Moreover, the doped cotton cloth was used as skin and was wrapped tightly around fuselage and wings structure. Then, they were stitched at some places. Finally, the finishing process of fabrication was done by covering the whole MAV with sign board film for better surface finish.

2.3 Micro Fabrication Process

According to Fransilla(2004), there are some processes of micro fabrication which will be put under considerations. The process includes etching. Basically, etching is a process which divided into two classes of wet etching and plasma etching.

However, before etching process, there are three steps which need to be done:

1. Transport of etchants to surface
2. Surface reaction
3. Removal of product species

If the etching process could not happen, failure of those three steps must be one of the causes. Thus, transport problems could be prevented or reduced by putting a thick boundary layer, where a native oxides or residues from previous step could retard or prevent the etching process from happening. Besides, the products also must not be volatile or soluble as they can be redeposited on the water. Thus, gas bubbles will form according to the reaction above and protect the surface from further etching.

There are some materials which can only be used for plasma etched instead of wet etching. The materials are including SiC, GaN, TiC and diamond. However, there are also some materials which cannot be etched by plasma etching. This is because of no suitable source gas/volatile product combination exists.

2.4 Injection Moulding

Booker(2003) believes that moulding is an old technique which has been given new twist by micro technologies. It can be said that all classes of materials can be used as moulds. It is said that injection moulding is basically applied for micrometer dimensions in mass manufacturing. The process includes injecting the molten plastic into a mould insert in order to fabricate compact discs (CDs). However, CD is an easy application as the pattern density is quite uniform and the pattern sizes are same.

Basically, injection moulding is a process of where granules of polymer material are heated. Then, it will be forced under pressure using a screw into the die cavity.

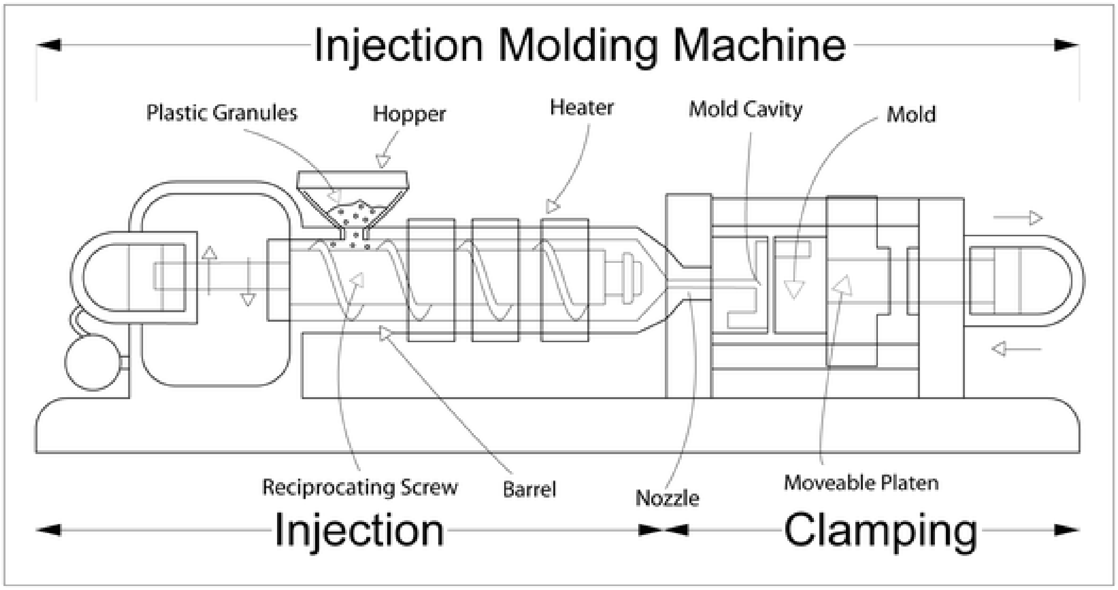


Figure 4: Injection Moulding Process

The materials that can go through this process mostly consists of thermoplastics which basically a thermosets. Other than that, composites and elastomers also can be processed. There are two variation processes that can be done through injection moulding. The processes are Injection blow molding and co-injection. In the parts of Injection blow molding, it allows small hollow parts with intricate neck detail to be produced. In the other hand, Co-Injection is done for products with rigid cores pre-places in the die before injection or simultaneous injection of different materials into same die.

Moreover, there are typical applications that can be done using injection moulding. Those are usually for products which are high precision, complex components, automotive components, electrical parts, fittings, containers, cups, bottle tops, housings, and tool handles. However, the quality problem that should take into considerations is when it is dealing with thick sections. It will be a bit problematic to produce those parts.

2.5 Forming Process of Powder Metallurgy

According to Booker and Swift(2003), powder metallurgy is basically a process of die compaction of a blended powdered material into a “green” compact which is then sintered with heat to increase the bond strength. However, for most cases, the secondary operations are performed to improve dimensional accuracy, surface roughness, strength and porosity.

Basically, the materials can be used using this process includes all materials which are typically metals and ceramics. The most common materials used are iron, copper alloys and refractory metals. Besides, powder metallurgy also can process materials which are not formable by other methods. Powder production processes are usually done through atomization, electrolysis and chemical reduction methods.

Moreover, there are nine processes which can be done through powder metallurgy. The processes such cold die compaction, hot forging, continuous compaction, isostatic compaction, extrusion, injection molding, spark sintering, pressure less compaction, and secondary operations. The, cold die compaction will be performed at room temperature which gives high porosity and low strength. However, in hot forging process, it is a deformation of reheated sintered compact to final density and shape.

Basically, continuous compaction is done for strip or ship product. This is slower than conventional rolling. The Isostatic compaction is a compaction of powder in a membrane using pressurized fluid or gas. Isostatic process permits more uniform compaction and near-net shapes. The extrusion is done at a high pressure ram forces through an orifice determining the section profile.

On the other hand, injection molding is also part of the process of powder metallurgy. In this process, fine powder coated with thermoplastic is injected into dies. The advantage of this process is the capability to produce relatively complex shapes with thin walls. The spark sintering process will give magnetic and pressure less compaction is done for porous components. Finally, the secondary operations will be done that includes repressing, sizing and machining the work piece.

Usually, this machining process is used to produce cutting tools, small arms part, bearings, filters, lock components, and machine parts such ratchets, pawls, cams, and gears.

2.6 Machining Process of Milling

Milling is a process of removing the material by chip processes using multiple-point cutting tools of various shapes. This is important to generate flat surfaces or profiles on a workpiece of regular or irregular sections. The materials that can be machined using milling process are basically all kind of metals which are mostly free for machining, some plastics, and ceramics.

According to Booker(2003), typically, milling machining is applicable to produce any standards or non-standards shapes requiring secondary operations, aircraft wing spars, engine blocks, pump components, machine components and gears. However, the costs are moderate to high and the direct labour costs are moderate to high as the process will require skilled labour. There are three major types of milling, which are peripheral milling, face milling, and end milling.

1. *Peripheral Milling (plain milling)*
    - The axis of cutter rotation is parallel to the workpiece surface
    - The cutter body is generally made of high-speed steel
    - The cutters might have straight or helical teeth
2. *Face Milling*
    - The axis of cutter rotation is perpendicular to the workpiece surface
    - The cutting teeth is basically made form carbide inserts
    - There are climb milling and conventional milling

3. *End Milling*

- There are two types of cutter, which are straight shank or tapered shank
- The cutter are mounted at the spindle of the milling machine
- Basically, end mills are made of high-speed steel or with carbide inserts

Basically, there is one important methods of milling machine that require some programming in order to give order to perform the machining process. It is called CNC machine. CNC machine is when the movement and control of tool, headstock and bed are performed by a computer program via stepper motors. There are some code that will be programmed and save in the machine. Thus, it will performed by itself.

However, there is also milling machines that require human skills to perform the operation which we called conventional milling machines. The required person will have to know how to perform the operations and understand the needed product design that will be produced. Thus, the required person will have to move the workpiece or cutter coordinates at the required positions before performed the machining process.

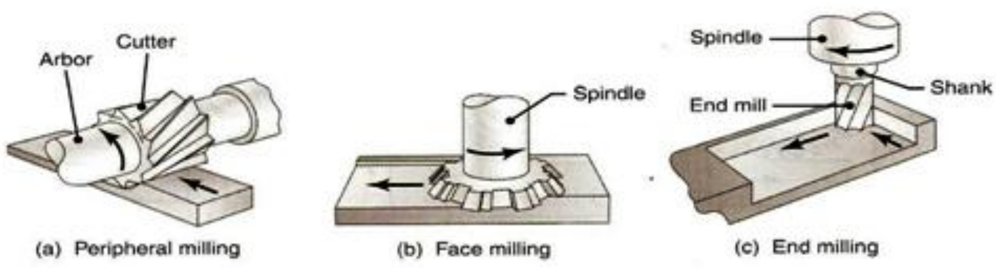


Figure 5: The three types of milling process

2.7 Joining Process of Thermoplastic Welding

Other than those machining process, the MUAV also can be produced just by doing some joining process. After find those suitable parts in the form of plates, they can be separated using some cutting process and joined using thermoplastics welding process. According to Booker and Swift(2003), Thermoplastic welding is a process of joining the edges which are heated using hot gas from a hand held torch. This has causing the thermoplastic material to soften. Thus, a consumable thermoplastic filler rod of the same composition as the base material is used to fill the joint and create the bond with additional pressure from the filler rod at the joint area.

This process can be put under considerations as the only materials can be used to perform this process is thermoplastics. This is because ABS is some form of thermoplastics. As stated above, it uses hot gas which can be either nitrogen or air which depending on thermoplastics that needed to be joined. This is because nitrogen minimizes oxidation of some thermoplastics materials. However, Kalpakjian convinced that various nozzles are used for different types of welding process such normal welding, speed welding, and tacking.

The other thermoplastics welding techniques available are such spin welding, ultrasonic welding and hot plate welding.

There are some factors that should be taken into considerations as the productions rates are very low. The tooling and equipments costs are generally low. Besides, some skills by operators are needed.

Moreover, the important thing that must be taken into attentions is the filler rods must be the same thermoplastic as base material. The force from the filler rod is applied to encourage mixing of softened material and must be consistent through the operation. And the hot gas also need excess moisture and contaminants removed using a scraper. The fabrication tolerances are typically ±0.5mm.

2.8 Rapid Prototyping and Rapid Tooling

As stated in the research of rapid prototyping of manufacture of scale model aircraft components that was done by Mr. Graham Bennett, rapid prototyping generates an image of graphic solid modeling system linked to sophisticated stereo lithography machines producing three dimensional objects using exotic technology. Basically, rapid-prototyping processes can basically classified into three major groups which are subtractive, additive, and virtual.

Almost all materials can be used through one or more rapid-prototyping operations. According to Kalpakjian, the properties that are suitable for these operations are polymer, followed by ceramics and metals.

Rapid prototyping is basically starts from the detail drawing of the products that will be produced. The drawings must be saved in solid or .stl file. Then, the product produced will be in form of wax having 5mm supports. Thus, this wax is produced just to take the shape that will be used to produce the mold using silicon.

The, rapid tooling is a further process of rapid prototyping. In rapid tooling, it starts with producing the mold using silicon. Once the parts form of wax is produced from rapid prototyping, it will further use in rapid tooling. The rapid tooling process is to produce the silicon rubber mold. The part will be hung in a vacuum chamber which is put in a container containing silicon rubber. After certain amount of time, as the silicon become hard, it will now be cut with some kind of shape just to differ its top and bottom view. Thus, the wax part is removed.

Next, as the mold is ready, we will fill the mold with a mixture of raisin and hardener. In UTP, the materials used as hardener and raisin are Isocyanate and Polyol. The mixing of Isocyanate and Plyol will produce thermoplastic of polyurethane. Thus, in order to put this process into considerations, the polyurethane properties are identified and compared to the ABS properties.

Polyurethane properties

Table 1: Polyurethane Properties

General Properties		
Density	1200	kg/m^3
Price	4	USD/kg
Mechanical Properties		
Young's modulus	0.025	GPa
Shear modulus	0.0086	Gpa
Poisson's ratio	0.50	
Yield strength (elastic limit)	30	Mpa
Tensile strength	30	Mpa
Elongation	75	%
Fracture toughness	0.30	MP a.m^1/2

Thus, a comparison can be done between ABS and polyurethane. This is done just to make sure if this thermoplastic can really place ABS.

ABS properties

Table 2: ABS Properties

GENERAL PROPERTIES				
Density	1010	-	1210	kg/m^3
Price	2.511	-	2.952	USD/kg
MECHANICAL PROPERTIES				
Young's modulus	1.1	-	2.9	GPa
Shear modulus	0.3189	-	1.032	Gpa
Poisson's ratio	0.3908	-	0.422	
Yield strength (elastic limit)	18.5	-	51	Mpa
Tensile strength	27.6	-	55.2	Mpa
Elongation	1.5	-	100	%
Fracture toughness	1.186	-	4.289	MP a.m^1/2

2.9 Testing

There are two types of testing that will be put under considerations, which are Non-Destructive Testing and Load Testing. Non-Destructive Testing (NDT) is basically a group of analysis techniques to evaluate the properties of a material, component or system without causing damage. Usually, common NDT testing methods includes ultrasonic, magnetic-particle, liquid penetrant, radiographic and eddy current testing [9]. One of the methods will be done according to the availability of the apparatus in UTP laboratory.

However, load testing is the testing of putting demand on a system or device and measuring it response. This is done by applying certain amount of load on the system and is raised beyond normal usage patterns. Thus, in order to test the system's response at unusually high or peak loads, it is known as stress testing [10]. Besides, when the prototype is produced and the load test is performed, the output result gain should match with the result gain by Mohd Anuar bin Sulaiman.

Figure 7 is the expected distributed load diagram that will be gained.

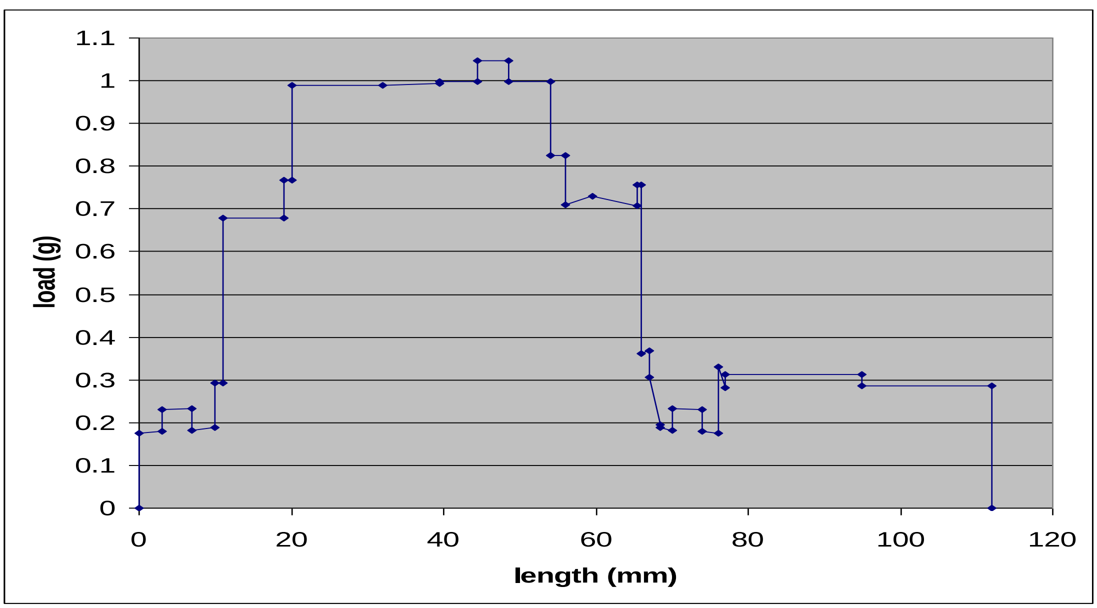


Figure 6: Distributed Load Diagram

2.10 General Machining Processes using Conventional Lathe

Lathes are known as the oldest machines tools. Basically, it was powered with the overhead pulleys and belts which best known as engine lathe. Lathe machine basic components would usually be the bed, carriage, headstock, tailstock, feed rod, and lead screw. However, lathe machines are capable of performing multiple cutting operations such as turning, boring, drilling, thread cutting, and facing.

Figure 7: The illustration of Conventional Lathe Machine

The most common process being used are facing, turning, boring, drilling, shaping, broaching and sawing. The characteristics of the process are described in the table 6 below.

Table 3: General characteristic of Machining Processes

Process	Characteristic	Typical dimensional tolerances, ± mm
Turning	Turning and facing operates on all types of materials, uses singe point or form tools.	Fine: 0.025-0.14 Rough: 0.13
Boring	Internal surfaces or profiles with characteristics similar to turning process	0.025
Drilling	Round holes on various sizes and depths	0.075
Shaping	Flat surfaces and straight contour profiles on relatively small work pieces	0.05-0.08

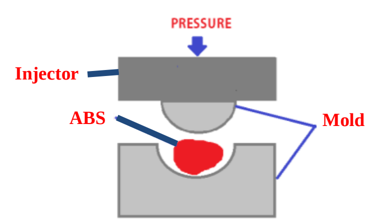
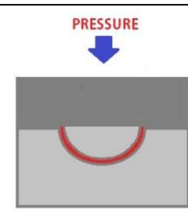
2.11 Casing Fabrication Methods

The casing of the MUAV is the most difficult part to fabricate as it is a hemispherical shape. There are a few processes which were being considered in order to fabricate the shape. There are 3 processes being investigated in order to choose the best process. The methods includes using compression molding machine, vacuum former followed with Mazak and lastly would be fiber glass layout.

2.11.1 Compression Molding Machine

Compression molding is the process of producing a final product using a mold which is preheated at certain level of temperature with a constant pressure. In order to apply this method, first thing that need to be prepared is the mold. The process can be seen in the illustration below.

Table 4: Compression Molding Process

Step 1	A piece of uncured ABS is put in the mold	
Step 2	The mold is closed up and held under hydraulic pressure while the ABS cures	

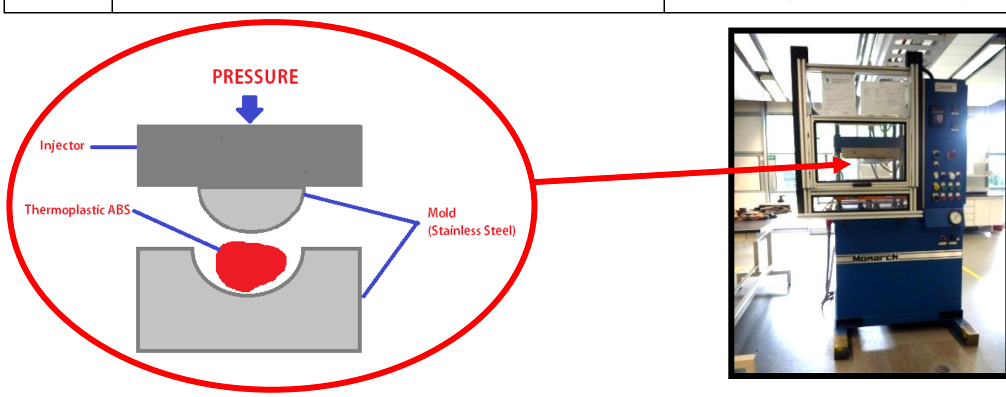


Figure 8: Compression Molding Machine

The figure above shows the injector and mold position in the compression molding machine. The process must be done under high temperature as to make sure that the ABS will be heated and formed the mold perfectly. The pressure ranges from about 10 to 150MPa. However, this method requires the mold to be produced before proceeding with the compression molding.

2.11.2 Vacuum Former with MAZAK

Thus, the second option being considered as vacuum former is available in the lab. Vacuum Former is a process of producing a finishing product where a sheet of plastic is heated to a forming temperature. Then it will be stretched into a single-surface mold, and held against the mold by applying vacuum between the mold surface and the sheet. These can be shown through the illustration below.

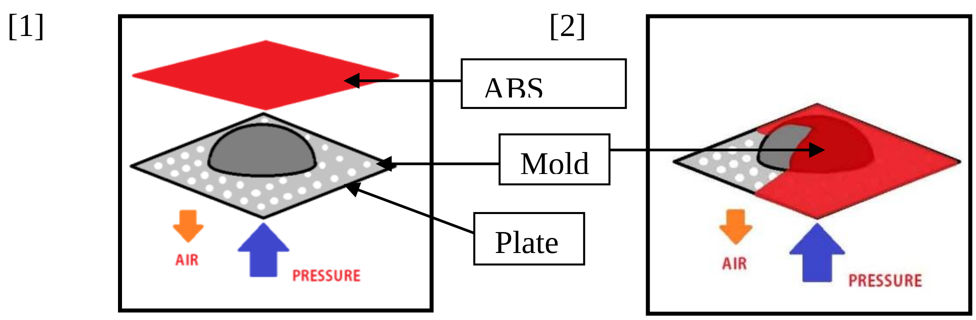


Figure 9: Vacuum Forming Process

Figure 10: Vacuum Former Machine and MAZAK

Before proceeding with vacuum forming, the mold need to produce using MAZAK which requires a block of aluminum and the drawings for the mold.

2.11.3 Fiber Glass layout

Fiber glass layout is a process of putting the fiber layer by layer according to sequence using the raisin and hardener. For this case, we will be using epoxy as it's already available in the lab. The process is a handmade process which requires skills and tidiness. Basically, fiber glass layout is done to coat a plywood boat using Poxy-shield epoxy resin.

According to Glen-L.com,

> "cleanliness is the most important factor for successful results. The application and all coatings should occur over a clean, dry, bare wood surface free from dirt, dust, oil, grease, wax, paint or other contaminants".

Besides, when the resin and hardener are mixing, the heat-producing reactions (exotherm) begin. However, the reactions are not noticeable for about 30 minutes at room temperature, but then the mixture will start to thicken and become solid material.

In the process of handling this process, safety cautions on epoxy resins need to give serious attention. As epoxy is considered as industrial chemical that should not be handled with less care. Always need to wear the gloves, eye protections, non-permeable protective clothing and dust mask.

2.12 The Basic Aerodynamic Principal and Wind Tunnel Analysis

According to R/C Airplane World, basically, there are 4 aerodynamic forces that act on an airplane in flight which are lift, drag, thrust and gravity. In simpler recognition, drag is the resistance of air that acted as a backward force on the light body. Besides, thrust is the forward force which actually the power to the engine. Thus, Lift is the upward force and gravity is the downward force. The gravity force is also known as the weight of the flight. Thus, in order for the airplane to fly, the thrust must be greater than the drag and the lift must be greater than the gravity. This can be illustrated according to the picture below.

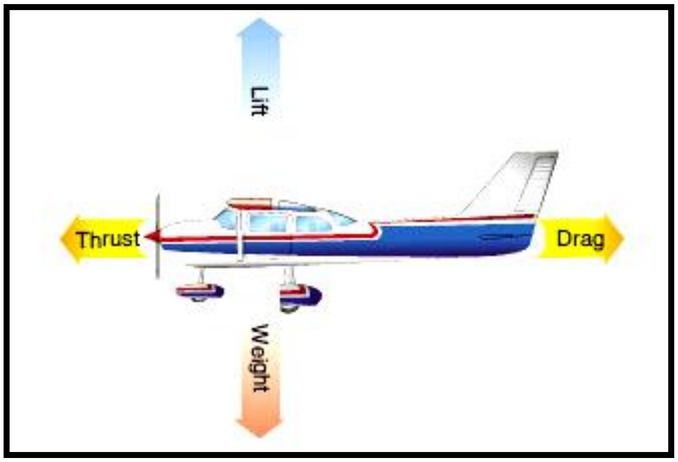


Figure 11: Aerodynamic Forces illustration on an Airplane

A wind tunnel is a tool used in aerodynamics to study the effects of air moving through a solid object. Other than measuring the drag and lift force experienced by the model, the wind tunnel is also equipped with a smoke machine. The smoke machine releases smoke fume that will give a clear indication of the aerodynamics profile of the model as well as the real object.

CHAPTER 3

METHODOLOGY

3.1 Work Flow

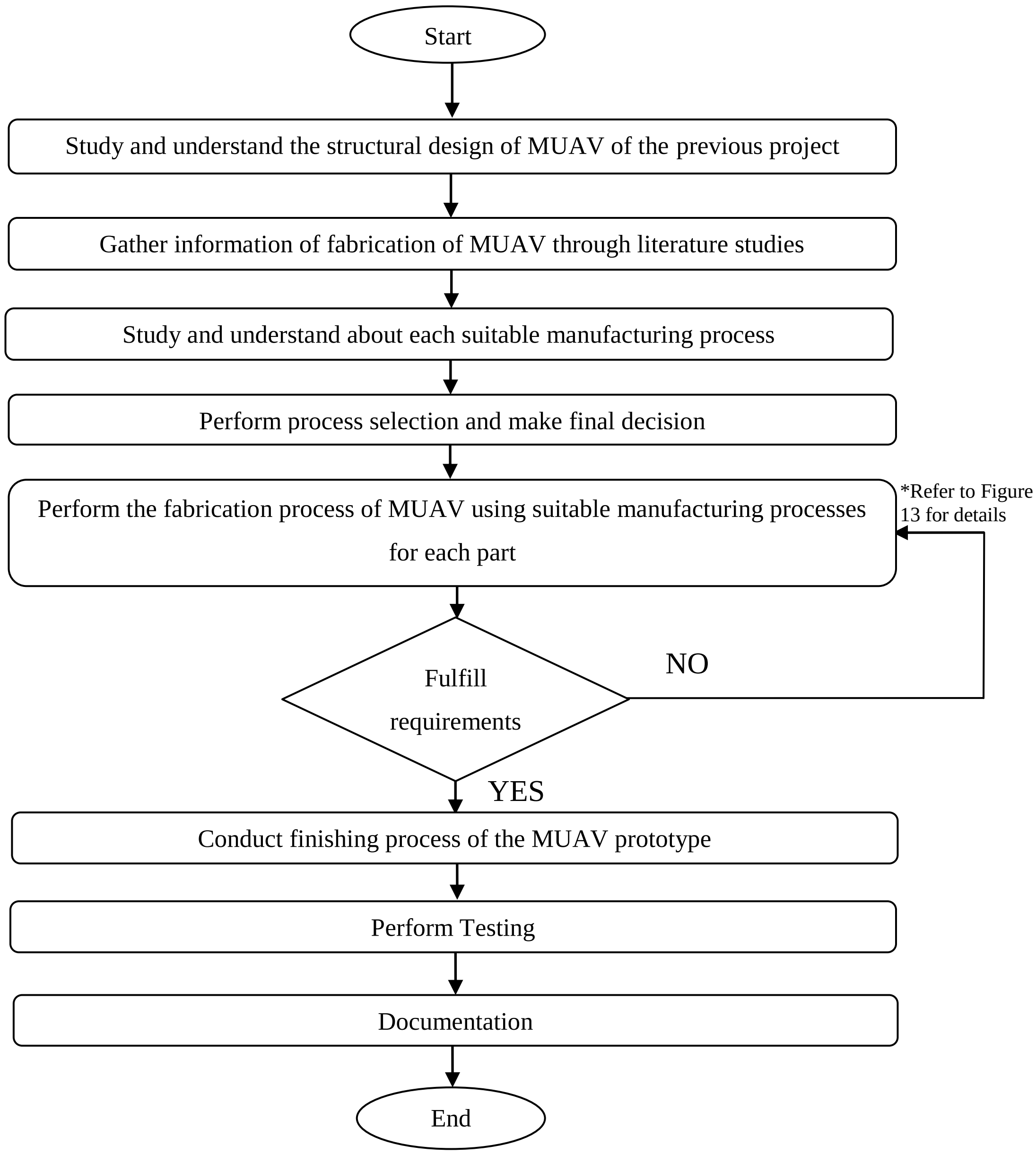


Figure 12: The Flow Chart of Work Flow

3.1.1 Methodology Sequences

There are some methodologies to be followed in order to carry out and implement the project:

1. *Study and understand the structural design of MUAV of the previous project*

   To produce a tough prototype of the MUAV structural design proposed by Mohd Anuar bin Sulaiman, the studies and understanding of related specification and criteria of the models need to be identified first.

2. *Gather information of fabrication of MUAV through literature studies*

   To find the best and optimum manufacturing process, some research and study on those fabrication processes need to be done. The research should be done through web hosting, books, thesis and other related materials input such a person who is experienced and lab technician.

3. *Study and understand about each suitable manufacturing process*

   After gathering the related information, there must be some process which will be short listed. Thus, further studies and understanding on that particular process will be done as to make sure the processes are really suitable to produce the prototype of the MUAV model.

4. *Perform process selection and make final decision*

   Process selection must be done before making a final decision of the best manufacturing process. Process selection is the process where we list down the possible process that will be put under considerations. Then, put some criteria which should take note in order to perform the process. Give some weight for those factors and calculate which the most reliable process is.

5. *Perform the fabrication process of MUAV using suitable manufacturing processes for each part*

   It comes to the part where the fabrication process is done. After perform the process selection and confirm with the selected process, the fabrication process will be done to each parts of the model. It will be produced exactly the same as the proposed model according to the detailed drawings done by Mohd Anuar bin Sulaiman.

6. *Perform Testing*

   The prototype is tested in the wind tunnel chamber. Wind tunnel analysis is to study the aerodynamic design of the MUAV. The analysis includes the study of the forces acted on the prototype. The forces are drag, lift and pitch. Refer to Appendix 7.

7. *Conduct finishing process of the MUAV prototype*

   After testing, the finishing process is conducted to make sure the prototype looks good before it is introduced.

3.1.2 Performing Manufacturing Process

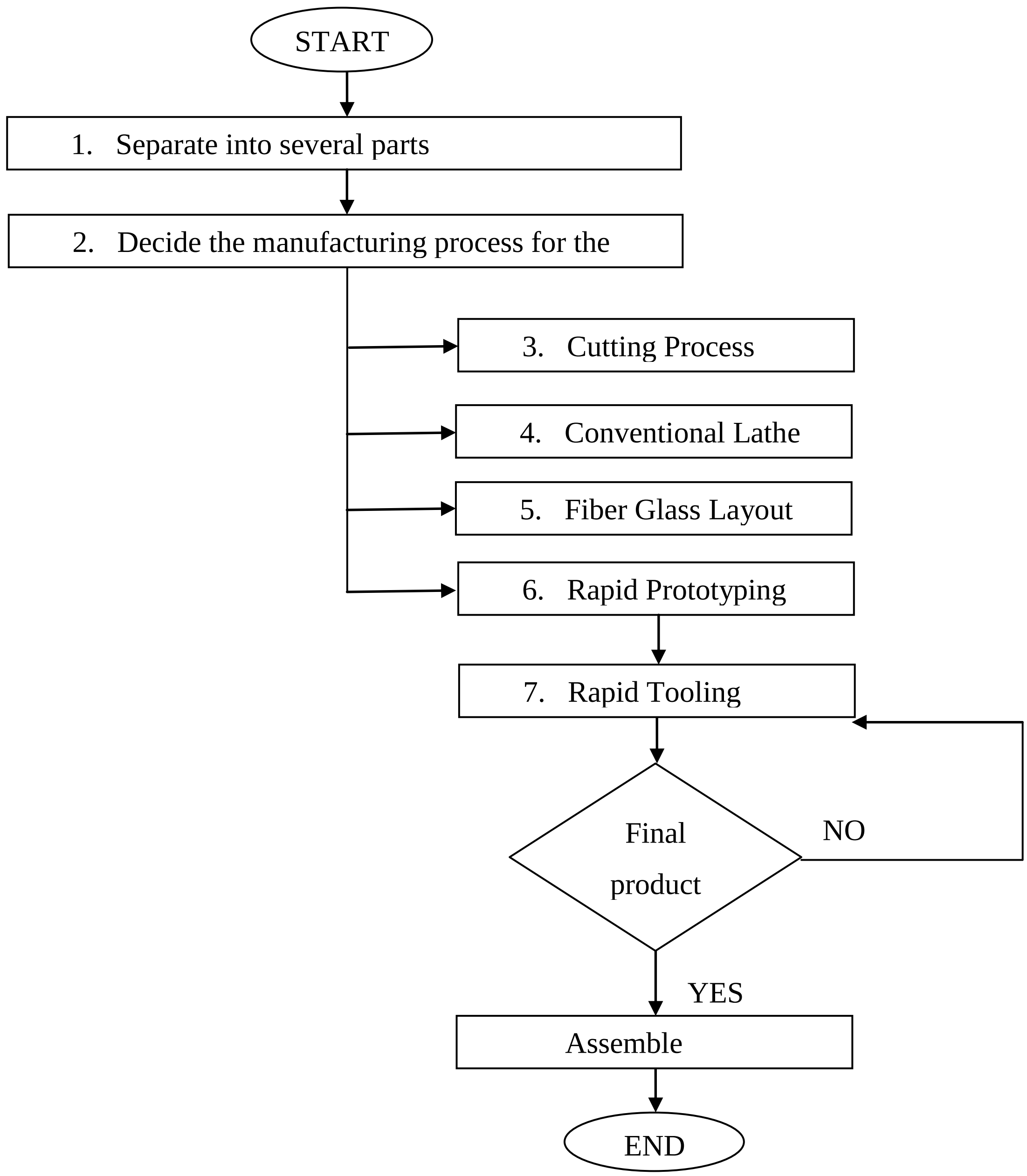


Figure 13: Flow Chart of Fabrication Processes

As there are some difficulties in fabricating this prototype and after study those manufacturing processes, I have come to the stage of redrawing the model. The model consists of some parts that can be fabricated straight away using Conventional Lathe Machine, and Conventional Milling Machine. However, there are some difficult parts that need to use Google Sketch Up Pro before proceeds to the Rapid Prototyping and Rapid Tooling Process.

1. *Separate into several parts*

    This is the process where I have divided those parts into several major components which then the suitable manufacturing process that will be decided.

2. *Decide the manufacturing process for the parts*

    After coming out with the components list and manufacturing process available, I will categorize the components according to the suitable process. For the parts that are a bit difficult will be fabricated using Rapid Prototyping and Rapid Tooling. However, the components that less difficult can be just performed using Conventional Lathe and Conventional Milling.

3. *Cutting Process*

    Cutting process is one way of dividing a sheet of ABS into the parts of body structure of the MUAV. After the parts are ready, then it will be assembled. Refer to Appendix 1.

4. *Conventional Lathe*

    The less difficult part will be machined using conventional lathe machine. The work piece would be a rod form of ABS or Polyurethane. Refer to Appendix 2.

5. *Fiber Glass Layout*

The other option to fabricate the casing for MUAV besides rapid prototyping and rapid tooling is fiber glass layout. The casing is the most difficult part to produce, thus this method is put under considerations as the tools are available in the lab. Refer to Appendix 3.

6. *Rapid Prototyping*

Rapid Prototyping is the process of printing a 3D model of components which form of wax. The process would start from designing, which then convert the design into stl format before printing. Refer to Appendix 4.

7. *Rapid Tooling*

Rapid tooling consist of two processes which the first stage is the process of producing the silicon rubber mold and the second stage is the process of mixing of resin and hardener in order to produce the final product which is polyurethane. Refer to Appendix 5.

8. *Final product*

The final product of Rapid Tooling is Polyurethane. Polyurethane comes from the mixing between resin and hardener. The resin is Isocyanate and the hardener is Polyol. Refer to Appendix 6.

9. *Assemble*

If the final product produced without any problem and fulfil the requirements, thus, they can be assembled.

3.2 Gantt Chart

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	FYP 2														
1	**Project work - Perform the fabrication process & Assemble**														
2	Submission of progress report 1														
3	**Project work - Perform Wind Tunnel Analysis**														
4	Submission of progress report 2														
5	Seminar (Compulsory)														
6	**Project work - Finishing process**														
7	Poster Exhibition														
8	Submission of dissertation of final draft														
9	Oral presentation														
10	Submission of dissertation (hard bound)														

3.3 Tools, Machine, Hardware and Software Required

Table 5: Apparatus needed in performing the fabrication process

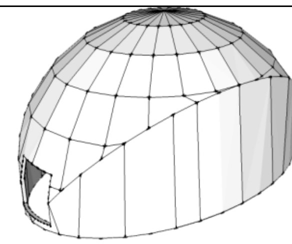
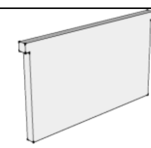
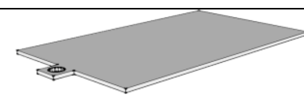
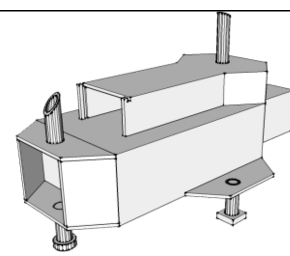
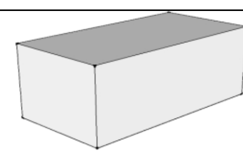
	Name	Description
3.3.1 Software	AutoCAD	The previous design model was design using AutoCAD and the file is in .dwg format The model was design in 2D view
	SketchUp Pro	Rework on the design to change the view into 3D before converting it into .stl format
	Stl Viewer	To view the .stl format files
	ThermoJet Printer Software v1.01	To preview and arrange the components before printing Print the components using ThermoJet 3D printer
3.3.2 Machine	ThermoJet 3D printer	To print the wax model of the components in order to proceed with Rapid Tooling.
	Conventional Lathe Machine	To machine the components that require rod by using facing and turning techniques
	Computer	To collect wind tunnel testing data
3.3.3 Tools	Pail Perspex Drill Scalpel Holder Insulation Tape Cone Container Vernier Caliper	To perform Rapid Tooling process.
	Brush Container Roller Knife Gloves	To perform Fiber Glass Layout process.
	Mounting Rod Wind Tunnel Screw driver	To perform Wind Tunnel Testing
	File Sand Paper	To perform filing process.
	Electrical Saw Electrical Hand Drill	To perform final preparations on the casing part.
3.3.4 Hardware	Vacuum Chamber	To degas the mixing materials during Rapid Tooling process
	Oven	To heat the Silicon Rubber Mold

CHAPTER 4

RESULT

The MUAV parts that have been divided into some major components consist of:

Table 6: Five Major Parts of MUAV

Parts	View
1. Casing	
2. Closing controller	
3. Closing Power pack	
4. Body Structure	
5. Box 1 (Camera)	

Rapid Prototyping and Rapid Tooling process is a process which require certain designs that can be comply with the tools and process. As for rapid prototyping, the design should not be complicated enough that will create so much support. After printing the 3D parts, the support will be removed. Thus, in order to avoid so much waste, the design should be designed and arranged in a correct way.

Besides, in continuing the process with Rapid Tooling, the parts also need to be taken into consideration as creating the mold using silicon rubber would be one of the challenging processes. In Rapid Tooling process, the wax printed part should not be complicated enough as to avoid the parts from broken off during pouring the silicon rubber. In the other hand, it also must create a mold which can be fully filled with the compound of isocyantate and polyol for the final product.

According to the constraint with Rapid Prototyping and Rapid Tooling, the parts are decided to be fabricated using different kind of process. The body structure of MUAV has been divided into other simpler parts so that it can be proceeded using Rapid Tooling and Rapid Prototyping process without wasting so must material that act as the support. Thus, the table below shows the body structure part that has been divided into several components.

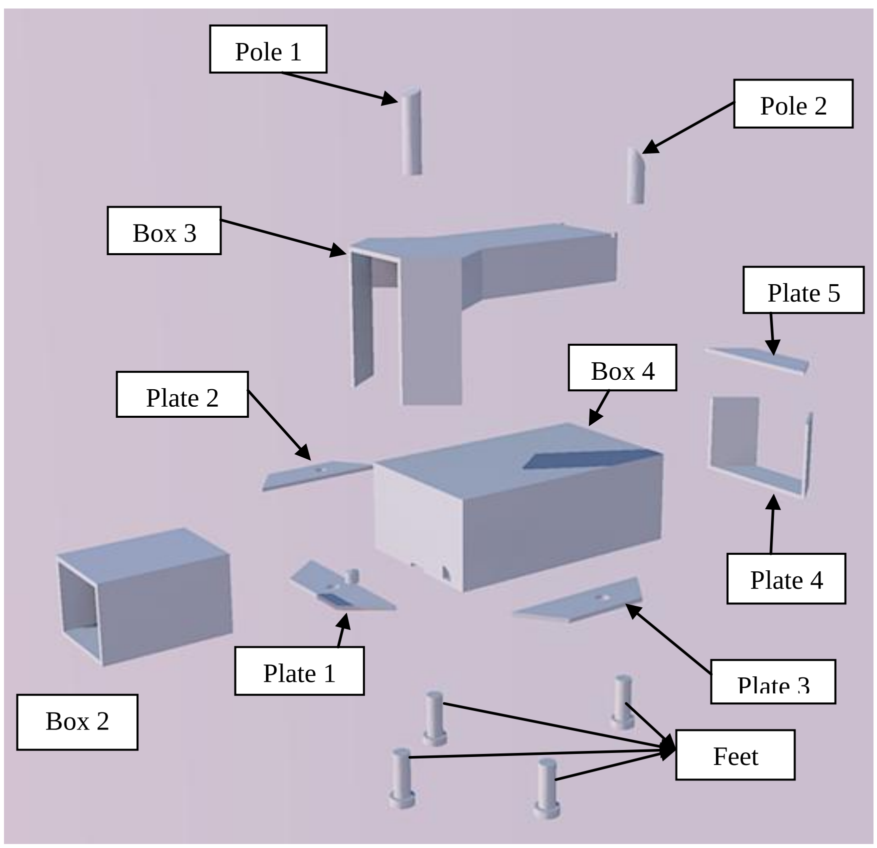


Figure 14: The Exploded View of Body Structure Part

After dividing those parts into several components, the suitable manufacturing process then decided. Table below shows the suitable manufacturing process for each parts and the progress.

Table 7: MUAV Parts with Suitable Manufacturing Process

No.	**Part Name**	**Process**	**Start**	**Finish**	**Remarks**
1	Casing	RP & RT	17/04/2010	Pending	Done
2	Closing Controller	Cutter	17/06/2010	18/06/2010	Done
3	Closing Power pack		17/06/2010	18/06/2010	
4	Box 1	Cutter	17/06/2010	18/06/2010	
5	Foot 1	Lathe	21/06/2010	22/06/2010	
6	Foot 2		21/06/2010	22/06/2010	
7	Foot 3		21/06/2010	22/06/2010	
8	Foot 4		21/06/2010	22/06/2010	
9	Plate 1	Cutter	17/06/2010	18/06/2010	
10	Plate 2	Cutter	17/06/2010	18/06/2010	
11	Plate 3		17/06/2010	18/06/2010	
12	Plate 5		17/06/2010	18/06/2010	
13	Plate 4	Cutter	17/06/2010	18/06/2010	
14	Pole 1	Lathe	21/06/2010	22/06/2010	
15	Pole 2		21/06/2010	22/06/2010	
16	Box 2	Cutter	17/06/2010	18/06/2010	
17	Box 3		17/06/2010	18/06/2010	
18	Box 4		17/06/2010	18/06/2010	

For those parts that need to be done using milling process, they will be cut using a plate that will be produced using Rapid Tooling first. The plate should be the same material with other parts. That is why the plate will be produced using rapid tooling first thus the plate will be in form of Polyurethane.

4.1 Rapid Prototyping and Rapid Tooling Product

The wax parts were produce by ThermoJet 3D printer during Rapid Prototyping Process. Besides, the Silicon Rubber Mold was produced during Rapid Tooling Process. All the procedure already elaborated in the methodology part.

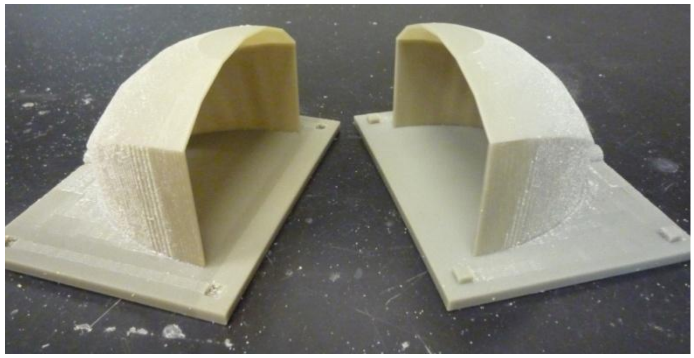


Figure 15: The Male and Female Wax Part of the Casing

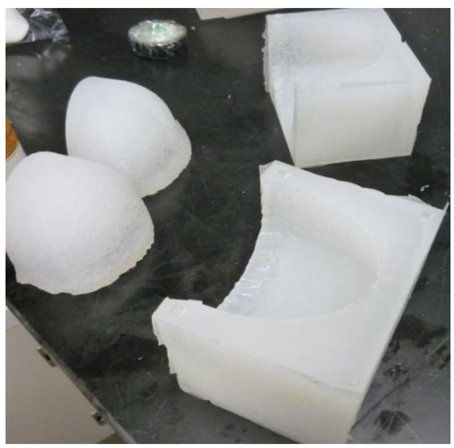


Figure 16: The Male and Female Silicon Rubber Mold Part of the Casing

4.2 Results for Final Product

4.2.1 Casing

The first approach was using the Silicon Rubber Mold that was produce in the Rapid Tooling. The process was done for several times because the first attempt was not successful. The final product gain was not solid polyurethane but it was brittle. Thus, it was done repeatedly.

Table 8: The Result for Final Product Using Different Ratio of Resin and Hardener

Attempt	Ratio (Hardener:Resin)	Result
First	1:2	Not Fully Filled
Second	1:3	Broken off
Third	2:3	Brittle
Fourth	1:5	Brittle

The second approached was using the Fiber Glass Layout method. The final product gain is shown below.

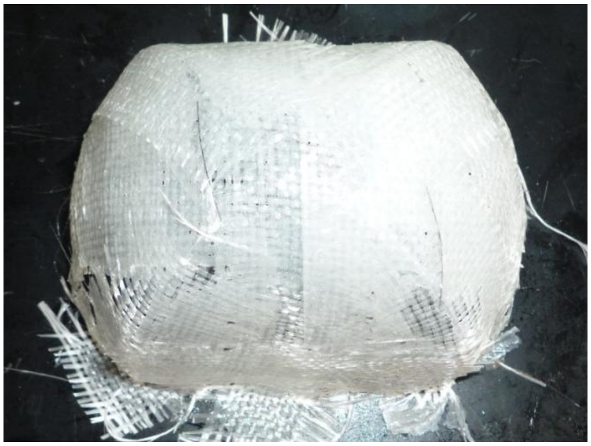


Figure 17: The Cured Casing Fiber Glass Layout

4.2.2 Body Structure

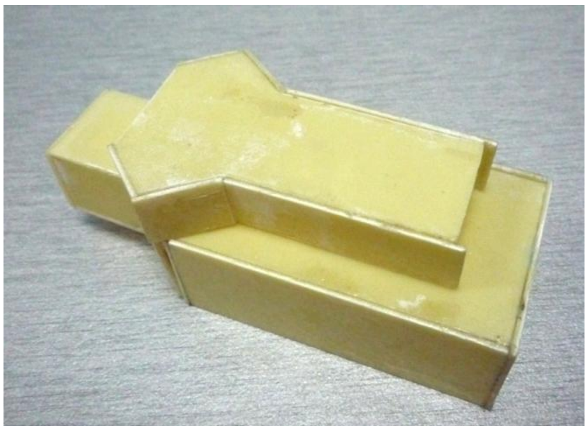


Figure 18: The Body Structure of MUAV

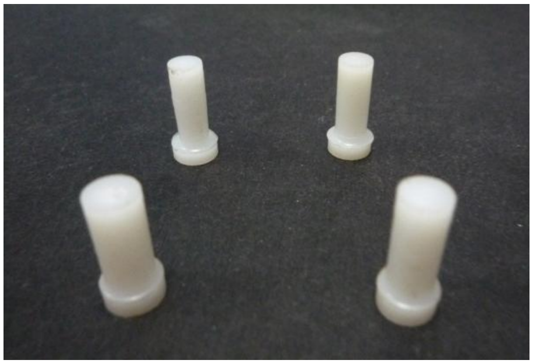


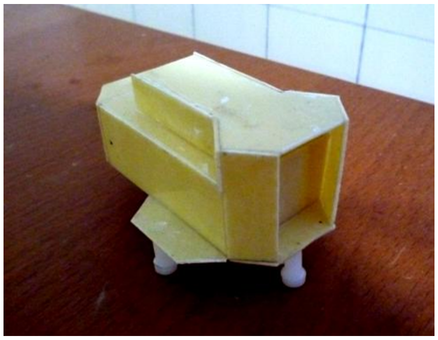
Figure 19: Two Pairs of Feet of MUAV

4.3 Final Product after Final Preparations

4.3.1 Casing

Figure 20: Before and After Final Preparations on the Casing

4.3.2 Body Structure



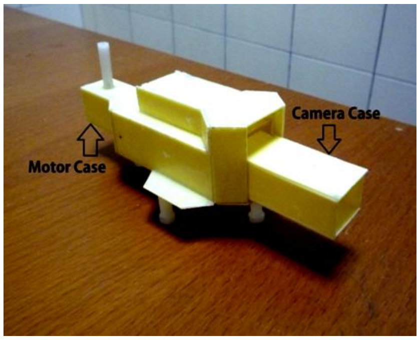


Figure 21: Before and After Final Preparations on Body Structure

4.3.3 Parts Combination

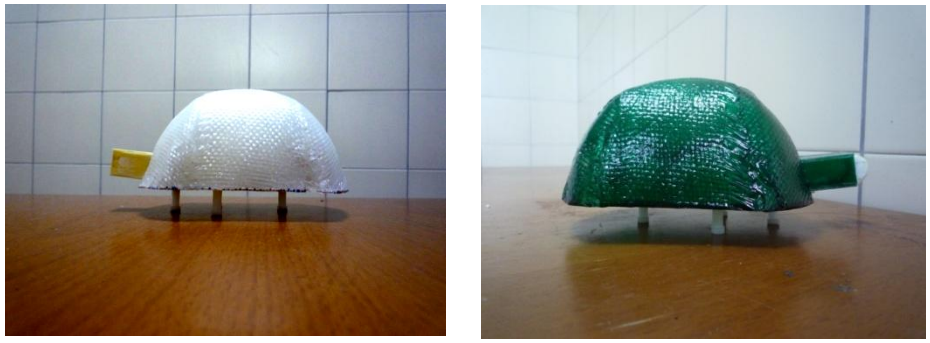


Figure 22: The Combination of Casing and Body Structure

4.4 Wind Tunnel Result Analysis

Besides, from the wind tunnel testing, the value of drag, lift, and pitch were obtained varies with the air stream velocity. From the data, the drag coefficient then can be obtained using the formula of;

$$F_{drag} = C_d \cdot A \cdot \frac{\rho_L}{2} \cdot v_\infty^2$$

Thus, $C_d = \frac{F_d}{\frac{1}{2} \cdot A \cdot \rho_L \cdot v_\infty^2}$

Where; A= cross sectional area exposed to flow

ρ_L= fluid density (density of air 1.2 kgm^3)

Example of Cd calculation (refer to the table 16)

V = 2m/s,

Drag = 0.02N

A = 44899.1mm^2 @ 0.0448991m^2

$$C_d = \frac{F_d}{\frac{1}{2} \cdot A \cdot \rho_L \cdot v_\infty^2} = \frac{0.02N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2 \text{ kgm}^3 \cdot (\frac{2m}{s})^2} = 0.185$$

The table below shows the data gained varies with the air stream velocity from 2m.suntil 20m/s with the increment of 2m/s.

Table 9: The Drag, Lift, Pitch and Cd of the MUAV

v (m/s)	Drag (N)	Lift (N)	Pitch (N)	Cd
2	0.02	-0.10	-0.01	0.1856
4	0.08	-0.31	0.00	0.1856
6	0.14	-1.51	-0.03	0.1444
8	0.23	-0.78	-0.09	0.1334
10	0.49	-0.21	-0.18	0.1819
12	0.70	-1.20	-0.17	0.1804
14	0.79	0.16	-0.24	0.1496
16	1.06	-0.63	-0.24	0.1537
18	1.15	0.00	-0.22	0.1318
20	1.30	0.57	-0.13	0.1206
			Average	0.1567

Thus, the calculated drag coefficient, Cd gained was 0.1567.

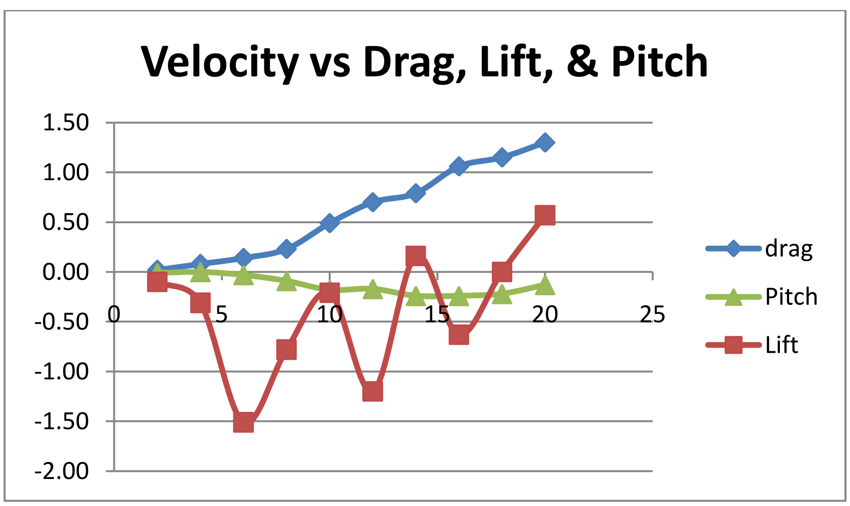


Figure 23: The graph of velocity versus drag, lift, and pitch

The graph above shows the trend of drag force that acted on the MUAV. As the air stream velocity increase, the drag force then increase and the lift force acted on the MUAV were fluctuating. However, the lift force supposedly to be zero as the MUAV is not flying and there is no angle of climbing. So, the lift should be zero as the angle is zero. The data were fluctuating because of the turbulence air that were trapped inside the casing of the MUAV and make it unstable.

The figure below shows the air stream around the MUAV when it was tested in the wind tunnel.

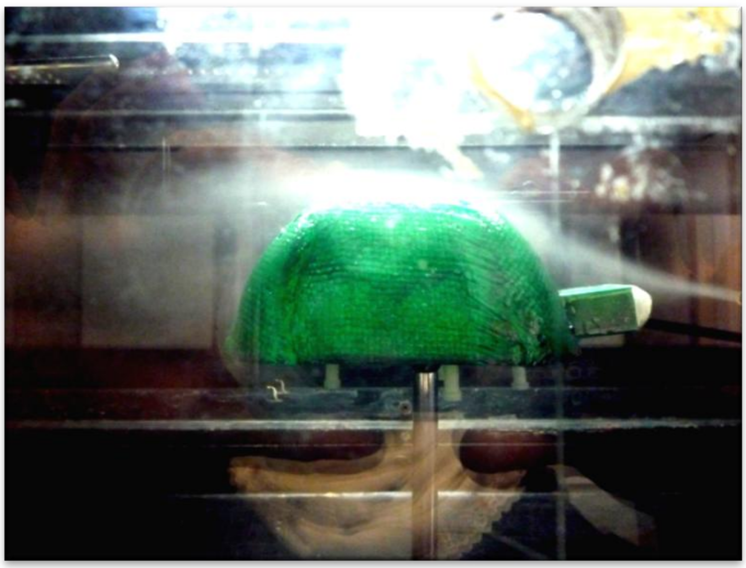


Figure 24: The MUAV in the wind tunnel camber

CHAPTER 5

DISCUSSION

The process need to be done repeatedly because the attempts were failed. The first attempt failed because there was trapped air in the mold during the pouring process. The compound did not fully fill the mold and get hardened. In order to solve the problems, I have discussed with the lab technician before proceeds to the next attempt. Thus, for the second attempt, I have made some holes through the mold so that there will be no more trapped air inside the mold.

However, the second attempt also failed. I tried to figure it out and realize that the possible problem would be because of the ratio of the Isocyante and Polyol. Thus, I increase the ratio of the hardener which is 2:3. But, it also failed because it broken off when I tried to remove the mold. Then, to figure out the cause I thought it would be the high ratio of the hardener would be the problem. This is because, when I discussed with my colleague that the other function of the hardener is it will make the compound more brittle. So, I tried to reduce the ratio of the hardener which is 1:5 but the result still the same.Those attempts prove that there must be something wrong with something else. Thus, I figured out that it would be some problem with the core materials which are isocyanate and polyol. Maybe, there are other substances that already mixed up with both materials. The lab technician also agreed with this opinion.

Besides, safety cautious on the operated machines must be taken care properly. The tools used must be very sharp and needed to use proper handling. As an example, operating the conventional lathe machine requires proper handling procedure in order to produce smooth surface of workpiece and avoiding them from broken.

Moreover, performing the final product preparations bring more challenges as the fiber glass layout process must be done very neatly in order to gain a smooth surface of casing. Besides, the hands should know how to maintain the choices of thickness. This same goes to the body structure, a very handle care of the material should be taken care off in order to maintain the structure and avoid the parts attached from tearing apart.

Besides, during the wind tunnel testing, the smoke was used to investigate the air stream profile that goes through the MUAV. From the picture, the curve at the back of the MUAV created the turbulence air stream. The drag force is increase as the velocity increase because, the resistance increase as the rate of change of momentum increase. Furthermore, the turbulence air streams at the bottom of the MUAV also answer the question of the negative forces that were gained on Lift Force.

CHAPTER 6

CONCLUSION

As the conclusion, the core materials of the compound must be changed with the new one as to avoid using the materials that already mixed with the other substances. Besides, I also need to consider the right ratio of the resin and hardener as to make sure the final product will be ductile. On the other hand, this MUAV is fabricated using other process beside Rapid Prototyping and Rapid Tooling.

Fabrication process of MUAV should be done in proper way in order to produce a rigid prototype which can sustain certain amount of load. This project is to study the relevant manufacturing process and fabricate the prototype of MUAV according to the structural design which was done previously in FYP of Mohd Anuar bin Sulaiman. The fabrication process must include the three main components of the MUAV which are the main structure, casing, cover for controller and cover for power pack.

The process for producing the casing for the prototype is based on the fiber glass layout using epoxy as the raisin and hardener. It was perfectly done after 24 hours of curing time. The final product was done a little modification in order to produce the hole for camera casing. Besides, the body was also perfectly attached after the cutting process and now can fit the casing perfectly.

After the finishing process is done, the wind tunnel testing in performed in order to study its aerodynamic features that will be influenced by other characteristics such as drag force. This model was modified as to be mounted in the wind tunnel chamber. Then, the data gain will help proving of the analyzation on the MUAV as the drag coefficient then calculated.

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APPENDICES

Appendix 1

Cutting Process

The cutting process of ABS sheet was done using the Hydraulic Shearing Machine. The ABS sheet was cut into pieces according to the drawings.

Figure 25: Hydraulic Shearing Machine

Operations Procedure

1. Place the ABS sheet on the Hydraulic Shearing Machine
2. Press the start button
3. Press the pedal
4. Wait until the process finish before taking the ready parts.

Appendix 2

Conventional Lathe

Figure 26: Conventional Lathe Machine

Conventional Lathe Machining Process

Table 10: Machine and Material Specifications

	Parameters	**Value**
1	Foot Length, L	15.5mm
2	Original Diameter, D_o	7mm
3	Final Diameter, D_f	5mm
4	Rotational Speed of the workpiece, N	400rpm
5	Surface Speed of workpiece, V	200mm/min

Operations Procedure

1. Take the ABS rod and cut into pieces.
2. Clamp one of the pieces at the spindle and tighten it.
3. The spindle rotation speed was set to 60 rev/sec.
4. Adjust the coordinate for X and Z rotation.
5. Start the facing process to the needed dimension.
6. Stop the process when the needed dimension obtained.
7. Measure the workpiece using vernier caliper.

Repeat the process to the other three foots.

Calculations on Material Removal Rate, MRR of Lathe Machine.

Foot Length, L = 15.5mm

Original Diameter, D_o = 7mm

Final Diameter, D_f = 5mm

Rotational Speed of Workpiece, N = 400rpm

Surface Speed of Workpiece, V = 200mm/min

$V = \pi \mathrm{DoN}$

$$V = \frac{\pi(7mm)(400rpm)}{1000} = 8.8m/min$$

$$V = \frac{\pi(5mm)(400rpm)}{1000} = 6.28m/min$$

$$d = \frac{7mm - 5mm}{2} = 1mm$$

$$f = \frac{200mm/min}{400rpm} = 0.5mm/rev$$

- ⇨ $MRR = \pi(\text{Davg})\text{dfN}$
- ⇨ $= \pi\,(6mm)(1mm)\left(\frac{0.5mm^{3}}{rev}\right)(400rpm)$
- ⇨ $= 3769.91\,\frac{mm\,3}{min}$
- ⇨ $or\ 3.77x10 - 6m^3/min$

Appendix 3

Fiber Glass layout

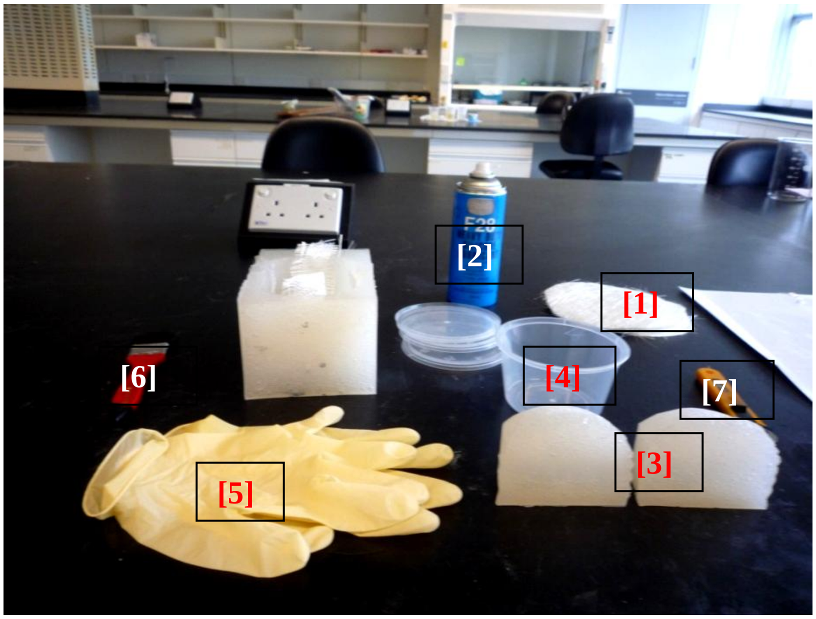


Figure 27: Fiber Glass Layout Apparatus Preparation

Apparatus: Fiber sheet Layer, Release Agent, Silicon Rubber Mold, Container, Gloves, Brush, Roller Knife, Aluminium Plate, Epoxy (Raisin & Hardener)

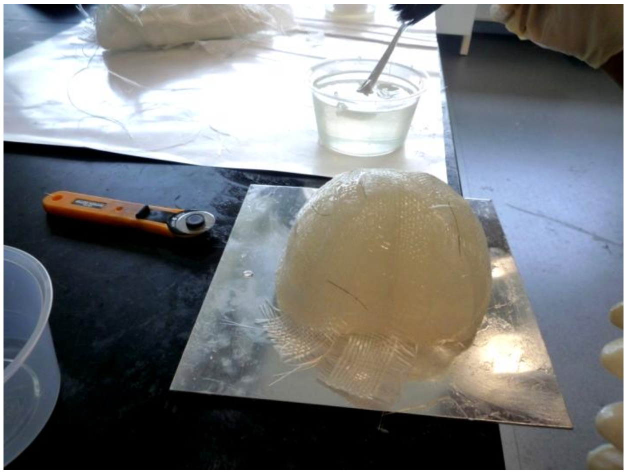


Figure 28: Fiber Glass Layout Process

Operations Procedure

1. Calculate the amount needed for raisin and hardener. The ratio is 5:3 for raisin and hardener. For this case, the amount use is: Raisin = 252g and Hardener = 151.2g.
2. Mix the raisin and hardener together in a container.
3. Prepare the mold by attaching the quarter of sphere together on an aluminum plate.
4. Cut the fiber layer using roller knife into the required shapes and lay down on the mold.
5. Then, apply the mixture on the mold that was ready with the fiber layer on top of that using brush.
6. Repeat the steps until reaching the required thickness which is 1mm.
7. Let the mixture on the mold cure for a night and get the final product the next day by removing the cured shape from the mold.
8. Repeat the process again for the second product.

Appendix 4

Rapid Prototyping

1. Sketch the model for male and female parts.

2. Redraw the model using (Sketch up Pro) CAD software.

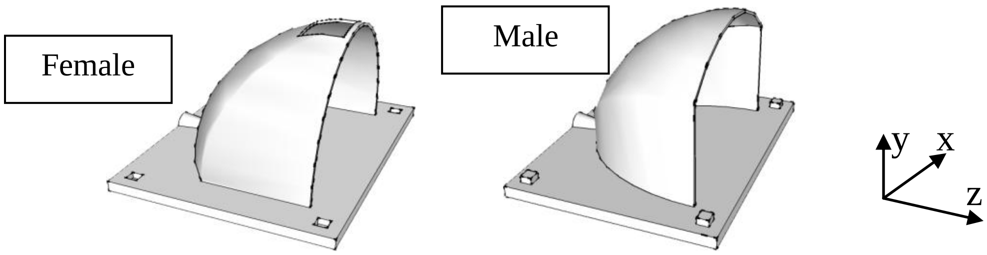


Figure 29: Male and Female Casing Sketch

3. Convert the parts into stl format.

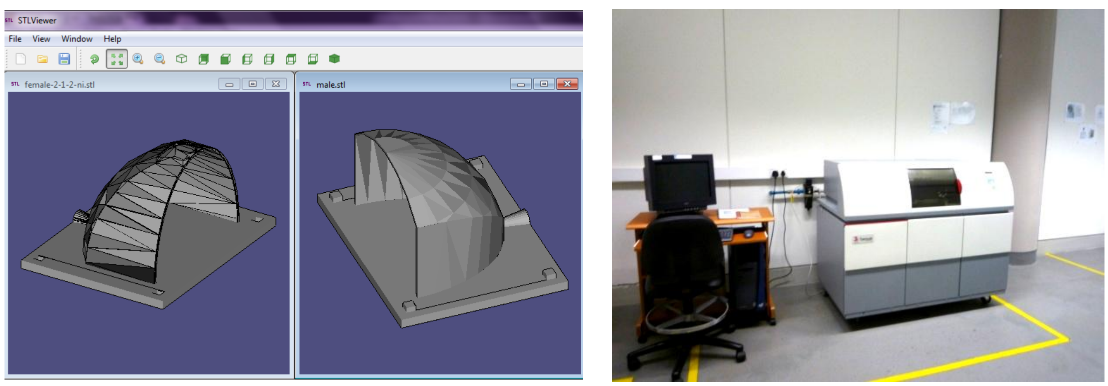


Figure 30: Casing part in stl format and Thermoject 3D printer

4. Arrange the parts in the ThermoJet Printer Software v1.01

5. Print the parts in stl format using ThermoJet 3D printer.

6. The part will be obtained within 6 to 8 hours.

Appendix 5

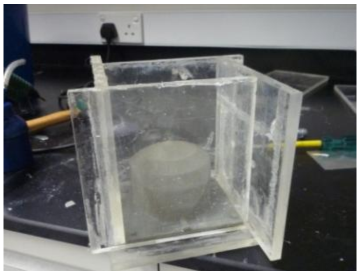
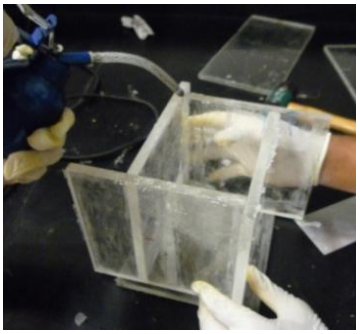
Rapid Tooling

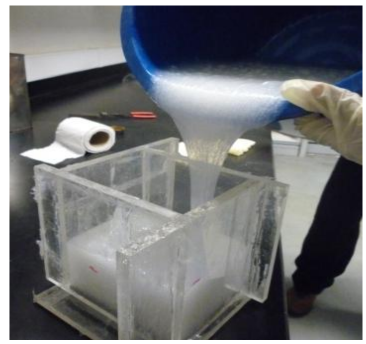
1. Preparing the Silicon Rubber Mold

Apparatus: Perspex, Chloroform, Gloves, Wax Parts, Pail, Silicon Rubber Raisin and Hardener, Weight Scale, Drill machines, Container

Operations Procedure

Table 11: Mold Preparation Process

Step	Description	Illustration
1.	Create a box around the wax male and female part using Perspex as the wall.	
2.	Stick them using chloroform.	
3.	Calculate the needed volume for the mold.	
4.	Weight the silicon rubber and the hardener with the ratio of 2:1. The total compound should be 0.9kg. So, the weight of the silicon rubber mold is 0.6kg and the hardener is 0.3kg.	

5.	Mix them together and stir using drilling machine using the suitable blade.	
6.	Pour the silicon rubber mold mixed with hardener into the box with the appropriate height. At this stage, we have to make sure that the wax did not break off.	
7.	Put both box into the vacuum chamber to be degassed. This process will clear out all the bubbles in the mold.	
8.	Thus, leave the mold for 24 hours to harden.	

2. Preparing the resin and hardener

Apparatus: Resin (Polyol), Hardener (Isocyanate), Container A and B, Weight Scale, Vacuum Chamber, Blade

Operations Procedure

Table 12: Resin and Hardener Preparation

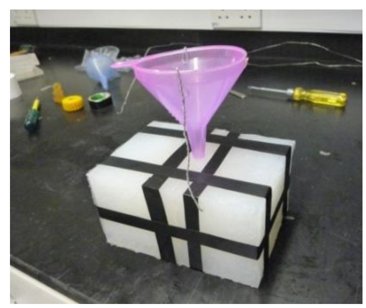
Step	Description	Illustration
1.	Determine the volume for the hardener and resin. The ratio should be 2:1.	
5	The total weight of the compound is 180gram. Thus, the weight of the Isocynate 120gram and the Polyol would be 60gram.	
6	Pour the resin and hardener into cup A and cup B.	
7	Place them into the vacuum chamber.	

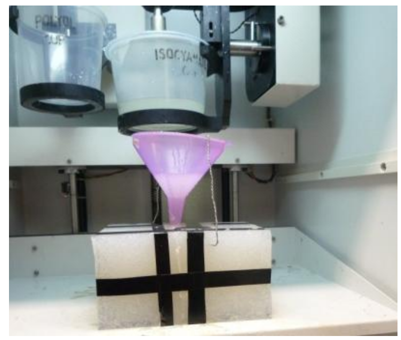
3. Rapid Tooling Final Product Preparation

Apparatus: Silicon Rubber Mold, Cone, Insulation Tape, Iron Chord, Oven, Vacuum Chamber, Resin and Hardener, Blade, Mixture

Operations Procedure

Table 13: Final Product Preparation

Step	Description	Illustration
1.	Separate the mold into four pieces in order to take out the wax parts using scalpel.	
2.	Spray them with the release agent, so that the compound will not stick to the mold and will be easier to be removed.	
3.	Attached the male and female part and then wrapped them using insulation tape.	
4.	Attached together the cone using steel rod before put the mold into oven.	
5.	After 15 minutes, take out the mold from the oven and put them into the vacuum chamber.	

<table>
<tr><td>6.</td><td>Close the vacuum chamber and start the degassing process until all bubbles disappear.</td><td></td></tr>
<tr><td>7.</td><td>Left the mold for approximately 2 hours before take out the final product.</td><td></td></tr>
<tr><td>8.</td><td>Take out the mold from vacuum chamber and peel off the insulation tape.</td><td></td></tr>
<tr><td>9.</td><td colspan="2">The process will be done all over again using different ratio of hardener and resin until the final product gain is right.</td></tr>
</table>

Appendix 6

Final Product Preparations

1. Casing

The end product of the casing is made of fiber glass with epoxy. After a 24 hours curing time, the fiber glass is ready for some modification and final touch. For better result, the filing process was done on the surface. Thus, smoother surface was gained. However, based on the design, the casing needs some modification. A hole for camera casing needs to be prepared. So, the casing base was cut through using electrical saw and a square hole was made using drilling machine and a file.

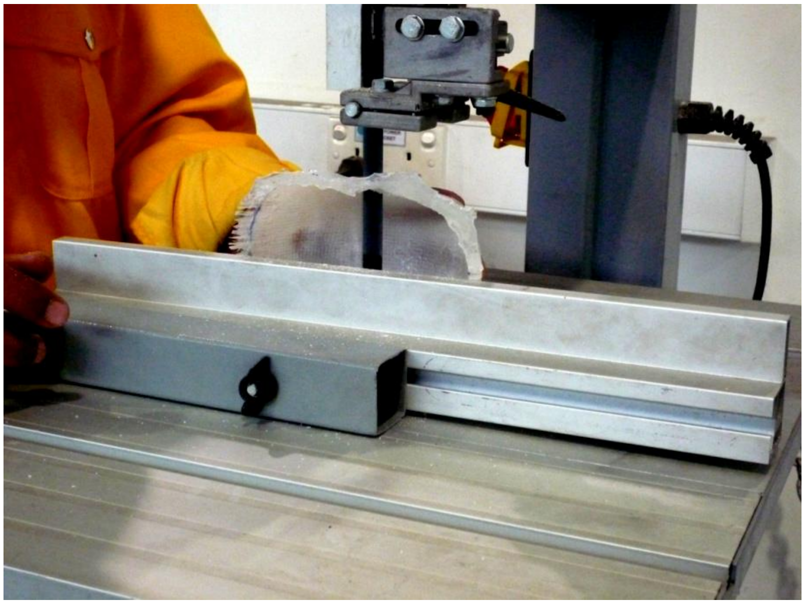


Figure 31: Electrical Saw Cutting Trough the Casing Base

2. Body Structure

Body structure final preparation is done for the camera casing and also the motor casing. The motor casing is added as for a better air circulation system. Besides, there was a pole added as to attach more securely the body structure with the casing.

Appendix 7

Wind Tunnel Testing

Apparatus: MUAV model**,** Wind Tunnel**,** Data Collector (Computer)**,** Screwdriver**,** Mounting rod

Operations Procedure

The procedure of the wind tunnel test is as follows:

1. Mount the model. Make sure that the mounted model is not inclined.
2. Ensure all parts are properly secured and all loose parts tightened.
3. Turn on the blower fan.
4. Click reset data.
5. Adjust the wind speed by turning the speed knob clockwise.
6. All relevant parameters are measured.

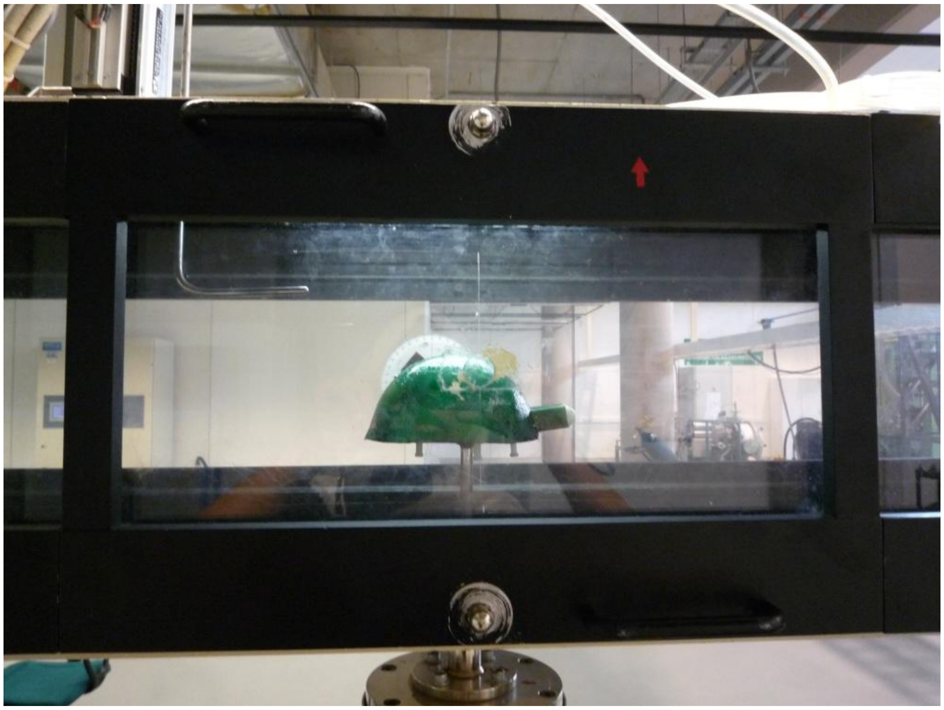


Figure 32: The MUAV Is Mounted In The Wind Tunnel Chamber

The data obtained in the wind tunnel test are:

1. Free stream (wind) velocity (m/s)
2. Drag force (N)
3. Velocity pressure (mm$H_2$0)
4. Lift force (N)
5. Fan speed (rpm)
6. Pitch moment (Nm)

The test is repeated at different speeds to obtain different data. The Picture of A Wind Tunnel Graphical User Interface And Data Measurement

1. V=2m/s

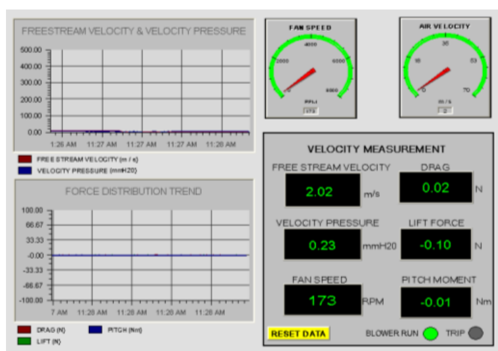


Figure 33: Velocity of 2m/s

2. V=4m/s

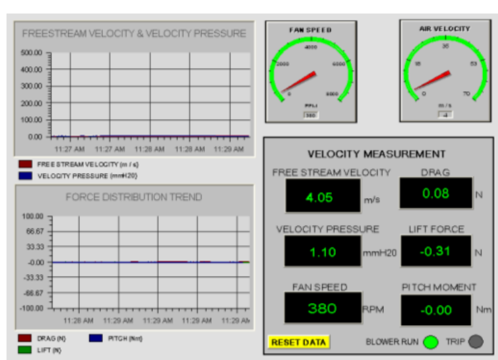


Figure 34: Velocity of 4m/s

3. V=6m/s

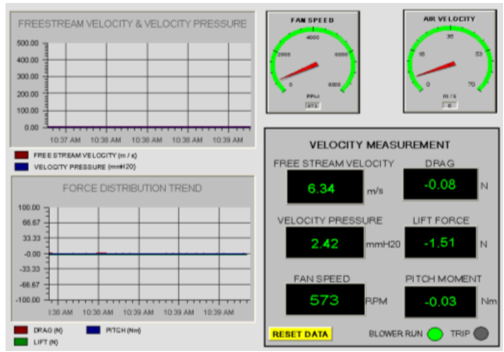


Figure 35: Velocity of 6m/s

4. V=8m/s

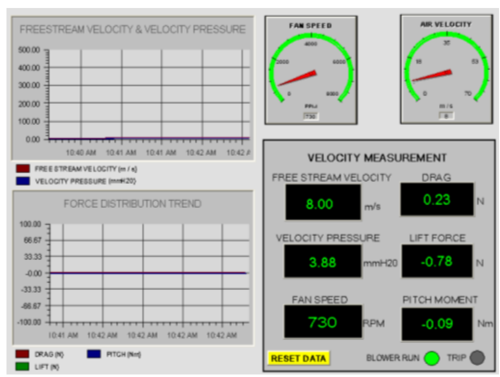


Figure 36: Velocity of 8m/s

5. V=10m/s

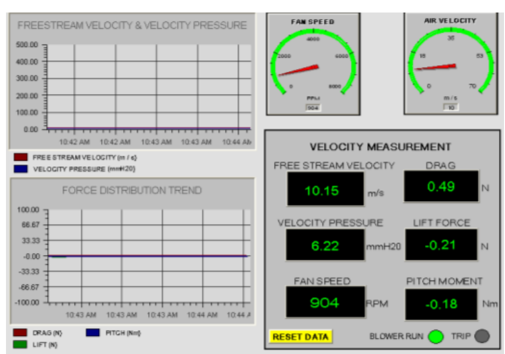


Figure 37: Velocity of 10m/s

6. V=12m/s

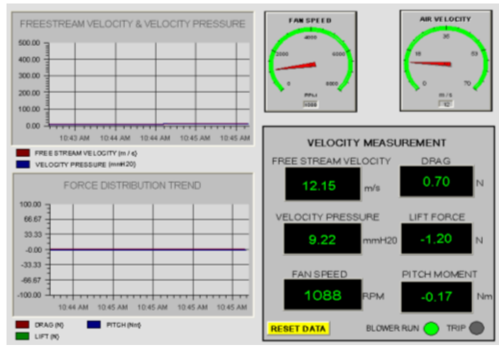


Figure 38: Velocity of 12m/s

7. V=14m/s

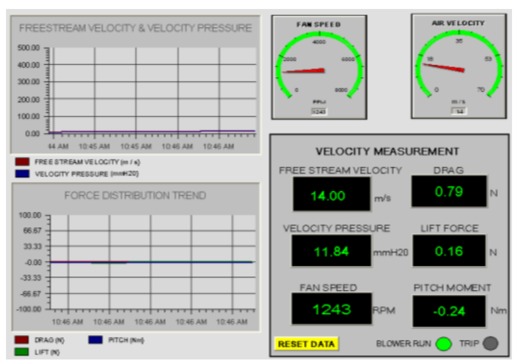


Figure 39: Velocity of 14m/s

8. V=16m/s

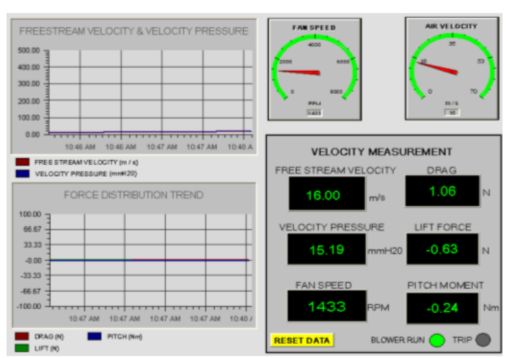


Figure 40: Velocity of 16m/s

9. V=18m/s

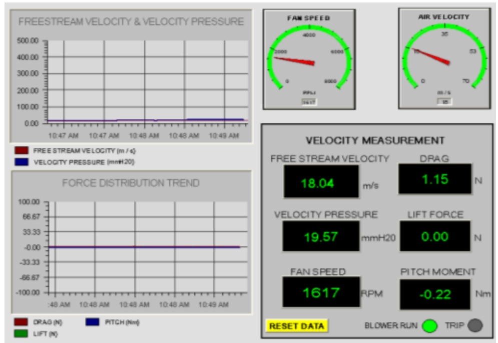


Figure 41: Velocity of 18m/s

10. V=20m/s

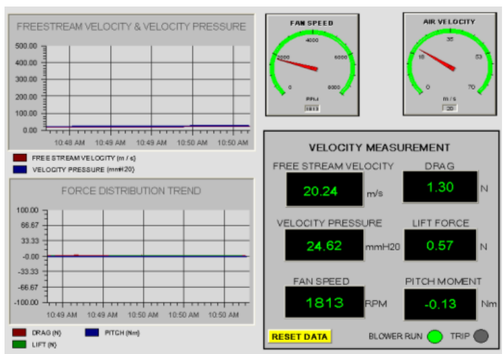


Figure 42: Velocity of 20m/s

Appendix 7

Calculation of the Drag Coefficient, Cd from Wind Tunnel Data Measurement

ρ_L= fluid density (density of air 1.2 kgm^3)

A = 44899.1mm^2 @ 0.0448991m^2

$$C_d = \frac{F_d}{\frac{1}{2} \cdot A \cdot \rho_L \cdot v_\infty^2}$$

1. **V=4m/s D=0.08N**

$$Cd = \frac{0.08N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2 \text{ kgm}^3 \cdot (\frac{4m}{s})^2} = 0.1856$$

2. **V=6m/s D=0.14N**

$$Cd = \frac{0.14N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2 \text{ kgm}^3 \cdot (\frac{6m}{s})^2} = 0.1444$$

3. **V=8m/s D=0.23N**

$$Cd = \frac{0.23N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2 \text{ kgm}^3 \cdot (\frac{8m}{s})^2} = 0.1334$$

4. **V=10m/s D=0.49N**

$$= \frac{0.49N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2 \text{ kgm}^3 \cdot (\frac{10m}{s})^2} = 0.1819$$

5. V=12m/s D=0.70N

$$= \frac{0.70N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2\ \mathrm{kgm}^3 \cdot (\frac{12m}{s})^2} = 0.1804$$

6. V=14m/s D=0.79N

$$= \frac{0.79N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2\ \mathrm{kgm}^3 \cdot (\frac{14m}{s})^2} = 0.1496$$

7. V=16m/s D=1.06N

$$= \frac{1.06N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2\ \mathrm{kgm}^3 \cdot (\frac{16m}{s})^2} = 0.1537$$

8. V=18m/s D=1.15N

$$= \frac{1.15N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2\ \mathrm{kgm}^3 \cdot (\frac{18m}{s})^2} = 0.1318$$

9. V=20m/s D=1.30N

$$= \frac{1.30N}{\frac{1}{2} \cdot 0.0448991m^2 \cdot 1.2\ \mathrm{kgm}^3 \cdot (\frac{20m}{s})^2} = 0.1206$$

Average of drag coefficient;

$$Cd = \frac{0.1856+0.1856+0.1444+0.1334+0.11819+0.1804+0.1496+0.1537+0.1318+0.1206}{10} = 0.1567$$