Design and Fabrication of Simple Vehicle Body Panel

by

Mohd Zulhilmi bin Zainuddin

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

MAY 2011

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CERTIFICATE OF APPROVAL

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Approved by,

____

(Dr. Zainal Ambri bin Abdul Karim)

Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

MAY 2011

CERTIFICATE OF ORIGINALITY

This is the 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.

Mohd Zulhilmi Bin Zainuddin

ABSTRACT

This report discussed the research and work done of the chosen topic which is design and fabrication of simple vehicle body panel. A body panel is designed and fabricated for the use of a single seat vehicle (simple vehicle) that promotes fuel efficiencies. In conjunction with the vehicle promotes, the body panel should have the criteria that support the vehicle purpose which is fuel efficiencies.

In related to the issues above, the criteria that being considered in order to build the body panel is the body panel shape itself which related to its aerodynamic properties, the body panel material which related to the body panel usage safety and its weight, and the way the it is fabricated in order to achieved optimum result for the final product.

Firstly, the existed body panel is studied and made benchmark to obtain the first idea of the body panel design. The design is then finalized and adjusted to its optimum level in accordance to its suitability to be fabricated here in Universiti Teknologi Petronas. To ensure that the finalized design is good in term of its aerodynamic characteristic, some adjustment is made on the basic model and a wind tunnel test is done on all of the scaled models for its drag and lift force values. As a result, a design with drag forces of 0.08N and lift force of 0.16N at the speed of approximately 35kmph is obtained.

Lastly, the final design based on the wind tunnel result is fabricated. The material chosen to fabricate the body panel is fiber glass and it is fabricated by using resin infusion method which found to be optimum in term of cost needed and final product result reliability. The fiber glass materials helps in weight reduction issue and the resin infusion process helps in cost reduction and final product solidarity.

As the result, the body panel is nicely done at the drag force of 0.08N, lift force of 0.16N at the vehicle optimum speed which is 35kmph and the resultant weight of the body panel is 12kg. All objective of this project achieved and the body panel is successfully tried and used on the vehicle.

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my supervisor, Dr Zainal Ambri bin Abdul Karim for his undivided attention and guidance throughout the Final Year Project. He had provided me with vital recommendations and ideas that were crucial towards the completion of this project. I would also like to thank the Examiners from the Mechanical Engineering department especially to Dr Vuu Triu Min and Dr. Masri Baharom bin Zainuddin for taking their time to evaluate my presentations throughout the whole progress of Final year project and also to Mr Muhamad Ridzuan Abdul Latif for helping me in completing this project through their support, constructive comments and opinions. On another note, I would also like to express my gratitude to all my UTP Shell Eco-marathon teammates who have helped me by sharing their knowledge and skills. I would also like to extend my thanks to all the technicians of the UTP technical labs who have lent their hand in the completion of the project. Also a special thanks to al the Mechanical Engineering staffs and the FYP project coordinator. Last but not least, I would like to express my greatest appreciation for my family members for their continuous support, motivation and encouragement.

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21 AUGUST 2011

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INTRODUCTION

1.1 Project Background

The awareness of the world regarding pollution and petroleum economic issues lead most industries all around the world to react in order to overcome the problem in various way related their field. The energy industries are now desperately researching for other energy resources to replace current resources as the fossil fuel depletion issues are widely spoken, The Greenpeace International very busy with their "green" purpose activity, and the automotive industries are now hardly thinking of new technology to reduce the usage of fuel, minimizing emissions produces by automobile engines, and also with their newly developed hybrid technology.

Regarding to this matter, the project is conducted to construct a simple vehicle that promotes fuel efficiency. Part of the simple vehicle is the body panel which is the outer body covering the vehicle. It conjunction with the simple vehicle purpose, this project is conducted to design and fabricate a body panel which support the simple vehicle purpose. The body panel possesses the criteria that promote fuel efficiencies as the vehicle needed. The criteria considered are the aerodynamic characteristic, weight, simplicity, and its toughness as we want a body panel that safe to be used.

1.2 Problem Statement

The simple vehicle supposed to promote fuel efficiency and to achieve that, some of things need to be considered are its engine performance, running chassis functionality, total vehicle weight and also, the body that covering it, which is

In term of body panel, what can be considered to supports the vehicle main purpose is the shape, weight and body toughness. The shape or design should be the most unrestricted by the wind during cruising, the weight should be the lightest so that overweight will not be one of the burdens of the engine to drive the vehicle, and it should be built tougher for safety reason.

1.3 Objective

The objectives of the project are;

- To design best shape and design for the body panel
- To ensure the body panel is light weight and tough
- To fabricate the finalized body panel

1.4 Scope of Study

The project will cover the studies over basic aerodynamic concept such as drag force and lift force effect over moving vehicle. Other than that, certain material which is suitable for the fabrication of the body panel is studied for selecting best material to be used to fabricate the body panel. Material used should be the most important matter for weight reduction purpose.

The manufacturing process of the body panel is in the scope of studies as well. The way the body panel is fabricated determine the quality of the final product.

CHAPTER 2

LITERATURE REVIEW

2.1 Design Fundamentals

As to achieve a design having good aerodynamics characteristic, the main concern will be on reducing the drag, minimizing wind noise emission, preventing undesired lift force, obtaining perfect downward force and any other things related to the instability the design aerodynamics.

For Shell Eco Marathon challenges vehicle, they will travel at the speed of about 35km/h, driven by one passenger only, and the size will be as compact as it can. In addition, its movement is more to be said as gliding instead of racing to complete the challenges. So, the main concern of its automotive aerodynamics matter will be very different from any other racing or dominant car. The frontal area size, body streamlines profile and the height of the vehicle is the things that matter. By manipulating all these three things, the optimum drag forces, drag coefficient and aerodynamics stabilities can be achieved.

2.2 General Aerodynamic Principals

2.2.1 Drag

Generally, aerodynamics is a study of how fluid flow around an object moving through the fluid. In case the object is a car, the aerodynamics study will be on how air flow moving through when the car is in its motion. To understand this flow, a car is visualized moving through the air. It takes some energy to move the car through the air, and this energy is used to overcome a force called Drag.

Drag, is comprised primarily of two forces. In our cases, related to a car moving through the air, frontal pressure is caused by the air attempting to flow around the front of the car. The air molecules approaching the frontal part of the car will all be compressed. As the process continues, the high pressure airs molecules will try to get away to any area possess lower air pressure. In this case, it will be the top area and the side area of the car, equalizing the pressure around the car's body (Figure 1).

Figure 1: Frontal Pressure

2.2.2 Rear Vacuum

For a car moving through the air, it will always leave portion of "empty space" behind it. To understand this, imagine a bus driving down a road; the blocky shape punches a big hole in the air with the air rushing through the body as mentioned above. The space left behind will be "empty" or like vacuum (Figure 2; the green shaded area). The vacuum area will suck the air around it. Inability of the air to fill the space accordingly will cause a condition called FLOW DETACHMENT. The force created by the vacuum far exceeds that created by frontal pressure, and this can be attributed to the turbulence created by the detachment. The turbulence created by this detachment can then affect the air flow to parts of the car which lie behind the car. Therefore, the entire length of the car really needs to be optimized (within reason) to provide the least amount of turbulence (Figure 3).

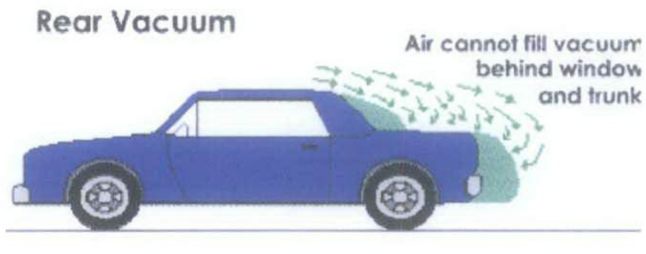


Figure 2: Flow detachment

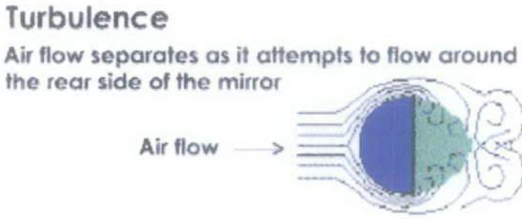


Figure 3: Turbulence behind rear side of the mirror

Giving the air molecules time to follow the contours of a car's bodywork and to fill the hole left by the vehicle will overcome this problem. In other words, it is needed to keep the air flow attach the car body. Take a look at a Le Mans race car in Figure 4 where the tails of these cars tend to extend well back of the rear wheels, and narrow when viewed from the side or top to prevent these Flow Detachment matter. This extra bodywork allows the air molecules to converge back into the vacuum smoothly along the body into the hole left by the car's cockpit, and front area, instead of having to suddenly fill a large empty space.

Figure 4: Le Mans Car (front)

Figure 5: Le Mans Car (back)

2.2.3 Vehicle Bodyworks

Looking at all the designs of the previous Shell Eco-marathon entrees, all of the vehicles are compact with a small width and height while having a long, streamlined body. The drivers are in the lying down position to reduce the height of the vehicle and there is usually little or no space for the drivers to move about freely in the cockpit. Most of the recent vehicles have the teardrop shape which enhances the aerodynamics and thus reducing the air drag. Some of these vehicles also have their wheels covered or contained within the body of the vehicle, which in turn reduces the air turbulence created by the rotation of the wheels. Taking the PAC-Car II for instance, it stands only at 0.61m, a width of 0.57m and a length of 2.78m (ETH PAC-Car II 2009). The shape of the vehicle is that of a teardrop, with all its wheels covered. The cockpit is accessed by removing the top rear half of the body. The PAC-Car II was able to travel 5382 kilometers with one liter equivalent of fuel.

2.3 PAC – Car II

PAC-Car II is currently the world record holder which is able to travel 5385 kilometers with hydrogen equivalent to 1 liter of gasoline (ETH PAC-Car II 2009). It was the product of the students from the Swiss Federal Institute of Technology Zurich. The PAC-Car II prototype has a body structure that does not have a chassis as its body is capable of self-supporting. It utilises a rigid carbon fibre monocoque body which is able to support structural load by using the external skin without the use of an internal frame or truss. This configuration can reduce the vehicle's mass without compromising its structural integrity. Using this carbon fibre exoskeleton design, the vehicle weighs at 29 kilograms. In terms of aerodynamics, the PAC-Car II is equipped with 3 wheels, whereby the single rear wheel is powered and steered whereas the two fixed front wheels have a camber angle of -8°. This solution allows for a reduced frontal surface area by eliminating the room required to steer the wheel. The wheel configuration provides sufficient ground clearance and an optimal weight distribution on each wheel, while allowing for rollovers to be avoided under normal driving conditions, including cornering, passing or obstacle avoidance. Experiments which they conducted show that the camber angle does not provide too much rolling resistance. With this, the PAC-Car II has a drag coefficient of 0.075 and a frontal area of 0.254 meter squared; while it's rolling resistance with MichelinRadial Tires are 0.0008 (ETH PAC-Car II 2009). Although the monocoque body has the highest potential for increasing vehicle strength by increasing its rigidity, it also has its drawbacks:

- Restricted possibility for modification due to the high level of component integration
- Poor accessibility of internal parts
- Narrow opening for the driver to enter the vehicle
- Expensive and sophisticated fabrication process
- Limited choice of raw material.

Figure 6: PAC - Car II

2.4 Remmi 7

The Remmi 7 of the Tampere University of Technology is 0.6m high, 0.6m wide and 2.8m long (Tampere University of Technology 2009). The shape is very much similar to that of the PAC-Car II, with covered wheels and a teardrop shape. The entire top half of the body is removable to provide access into the car. The Remmi 7's best performance was at 3306 kilometers per liter of fuel. The vehicle of Team Crocodile from Cambridge University, have a dimension of 2.75m long, 0.9m high and 0.75m wide (Cambridge University Team Crocodile 2009).The vehicle has a platform tub shape, which sports many curves on the body. The driver enters the vehicle by removing the entire top half of the body. Team Crocodile's vehicle is able to achieve 1275 kilometers with one liter of fuel. Pingu II, a vehicle designed and created by the HAW Hamburg has a rather unique design. It is shaped like the head of a penguin. It is 3m long, 0.8m wide and 0.75m high (HAW Hamburg Pingu II 2009). The entire top half of the vehicle is removed for the driver to enter and exit the vehicle. This vehicle can go 1621.9 kilometers per liters of fuel.

Figure 7: Remmi 7

As seen from these selected prototypes, it is evident that every one of them is designed to have a minimal frontal area, by having the vehicle as small as possible. This is done by limiting the vehicle's dimensions to the size of the driver. Also, the vehicle is designed such that the top portion of the vehicle can totally open for the ease of accessing the interior part of the car like the driver cockpit and the engine site.

2.5 Resin Infusion, vacuum bagging, hand lay – up

Some of the issues that to be considered in building the body panel are the weight of the body panel, the stiffness and its odors produced when being exposed to the open air temperature. After doing some investigation lead by the material expertise on existed body panel, it was found that those problems were not occurred because of the material of the panel which is the fiberglass. The main reasons for those issues to arise are because of the way of how the body panel was fabricated.

Existed body panel possess unreasonable fiberglass thickness which may cause by the improper way of laminating the fiberglass; resin applied manually on the fiberglass. "Manually applied" means the fiberglass are fabricated by using the traditional way which is the "hand lay-up" way.

By using the hand lay-up process to fabricate the body panel, the fiber to resin ratio will not at the very good condition. Over limit resin used will lead to thicker product of fiberglass, hence, heavier fiberglass will be obtain. Other than that, the processes of drying the fiberglass are fatal. A slight error in temperature or time of drying will affected the stiffness of the final result of the fiber glass. In addition, the improper dried resin will produce smelly odors when being exposed to ambient temperature.

So, in order to overcome those smelly odors, stiffness and heavy body panel issues, the way of fabricating the new body panel will be changed.

There three ways of fabricating a fiberglass product which in this case, the body panel.

- Hand lay-up
- Vacuum bagging
- Resin infusion

Basically, all those three process mainly talk about on how to laminate the fiberglass or how to apply the resin on the fiberglass. Each way have their pro and cons which are listed on table 1.

"+ "= advantages

"– "=disadvantages

Table 1: Comparison of Hand lay – up, Vacuum bagging, and Resin infusion

Quality	**Hand Lay-up**	**Vacuum Bagging**	**Resin Infusion**
	The traditional wet laminate	Uses a sealed plastic film to apply atmospheric pressure to the traditional wet laminate in order to remove some excess resin	Uses a sealed plastic film to achieve a net vacuum on dry fabric in order to draw resin through that fabric
Fiber to resin ratio	--	+	++
		Instead of a dry laminate, vacuum bagging state of the laminate. A typical hand lay-up usually results in excess of 100% fabric weight by resin. Vacuum pressure will pressure will remove much of the excess resin, but the amount	Better fiber-to-resin ratio. Resin alone is brittle, so any excess will actually weaken the part. The reinforcement

		removed still depends on a variety of variables.	materials are still dry, but compressed, when the resin is introduced. Any excess resin is introduced. This lowers weight , increases strength and maximizes the properties of fiber and resin .
Heat build up	+	+	-/+
		No heat buildup. Most excess resin is collected in the bleeder fabric, without an extreme heat buildup.	Excess resin is collected in the resin trap. With larger projects one has to change the resin traps to prevent accidents due to extreme heat buildup.
Amount of resin	-	-	++
		The human variable is of great influence on resin usage.	Less wasted resin. Due to the nature of vacuum infusion, resin usage is very predictable. Waste can even be zero after some practice.

Vacuum bag	0	+	-
		Less critical leaks. A leak in the bag will provide a lower vacuum, but often will not really be fatal to the part.	A leak in the bag can be fatal for the part.
Resin pot-life	-	-	++
		The resin pot-life is extremely critical. Depending on when the vacuum pressure is applied, the amount of resin removed can vary from part to part. Bagging can quickly turn frantic when a pesky leak in the vacuum seal cannot be bound.	The set up time is unlimited. Because the vacuum is applied while reinforcements are still dry, there is no resin clock to work against. After the bag is applied, leaks can be patiently sought out. If something is not sitting properly, simply release vacuum and readjust. No time constraints are introduced until it is decided that it is time to infuse the resin. Until that moment, changes can be made again and again.
Tubing	0	++	-
		Easy tubing. Vacuum bagging requires	Vacuum infusing

		the placement of only the vacuum tubing.	requires the placements of vacuum tubing, resin inlets and in-bag extensions of these tubes. The placements of these tubes are critical and vary from part to part, depending on size and shape, and there is no one way to set them up. These considerations must be evaluated prior to lay-up.
Health	--	--	++
		Vacuum bagging begins with a hand-lay-up laminate, with all the necessary equipment and health precautions. The vacuum bag is applied to a wet surface, with all the accompanying troubles to maintain a clean environment and to prevent foul vacuum seals.	Cleaner process. Vacuum infusion provides a cleaner, safer and friendlier work environment. There are no brushes or rollers, and therefore no splashing, spattering or dripping on you. There are almost none resin fumes to contend with. It is merely mixing the

			resin and pours it into a bucket, from whence it is sucked in fully automated fashion into the laminate.
Quality risks	-/+	+	-
		Straightforward. Vacuum bagging begins with a hand-lay-up laminate. When something goes wrong, one still can end with this part, still suitable, however not as good as being vacuum bagged	Due to the complexity and ease of error in the infusion strategy, it is very easy to destroy a part. Once infusion begins there is little that can be done to correct a strategy error.
Quality	-	-/+	++
		The human variable is of great influence.	Due to the complexity and ease of error in the infusion strategy, it is very easy to destroy a part. Once infusion begins, there is little that can be done to correct a strategy error.
Costs	++	-/+	++
		Extra costs for vacuum pump, vacuum bag, sealant tape, tubing, connectors,	Extra costs for vacuum pump,

		release film and bleeder material.	vacuum bag, sealant tape, tubing, connectors, release film and resin distribution material. Vacuum pump must be able to achieve a high vacuum.
Handling materials	-	--	++
		Not easy	Easy. All materials are used in a dry and clean condition.
Size of job	+	--	++
		Larger lay-ups are only possible with the help of a lot of extra hands.	Unlimited. Even large lay-ups are possible for a single-handed builder.
Mixture quality	--	--	++
		Risk of inaccuracy. Larger lay-ups require a lot of small mixing batches.	Excellent wetting out, even the exotic fibers and sometimes the only way to be sure.
Time	++	-/+	+

		Extra time is needed for applying vacuum materials and vacuum bag. Once the hand-lay-up has started, there is no way back and one has to finish the job. Wetting-out and squeegee work is time consuming and not very forgiving and there is additional time involved with getting the bag and other stuff on while the resin is kicking off, adding time to an already long and potentially hectic process.	At your leisure. Approximately the same as with vacuum bagging but because of the absence of the "resin clock" one can divide the job in smaller jobs and at a moment that suits best. A single person can take as long as they like to drape the fibers, apply release cloth and flow media, seal the bag, and check for leaks. Having a much more forgiving timeline one can spread this out over many evenings after work, and could walk away or be interrupted at any time without consequence.

Simultaneous sandwich laminating	--	-/+	++
		A pity it has to start with hand-lay-up	

CHAPTER 3

METHODOLOGY

3.1 Benchmarking

In order to obtain basic idea of the desired shape of the body panel, the current and previous existed body panel is bench marked. As discussed in the literature review session, some of the body panel which has been benchmarked are like the PAC – CAR II from Shell which currently holding the farthest travel distances record with 5385 kilometer per liter fuel.

Other than the record holder, due to many reason like cost issue, expertise, material source availability, wide range of example from any other universities and institution, from the most simple to the most complex kind.

Figure 8: California State Polytechnic University

Figure 9: Shell PAC – Car II

3.2 Design concept

By referring to the studied and benchmarked design, basic design and concept is decided. The decided design is not finalized yet. Modification need to be done through certain test so that the design meet the criteria needed as stated in the objective session

The body panel should be meet the needed aerodynamics criteria, weight, ease of utilization and ease of fabrication. In addition, it should be optimum in term of project cost.

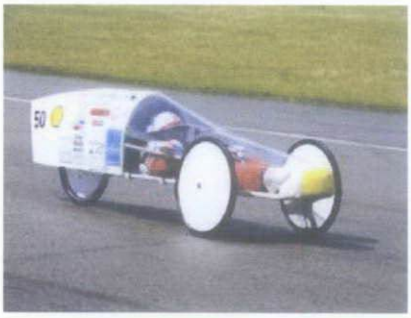


Figure 10: The Sandbach School

3.3 Design Finalization

As discussed in literature review session, the findings are in terms of shape aerodynamic, the part which is most effecting is the back shape of a vehicle. In this case, the back or tail shapes of the body panel.

The front shape is not too crucial as it was patented. Most of the studied body panel having the same shape. In addition, from the from the drag coefficient formula:

$$F_d = \frac{1}{2}\rho v^2 C_d A$$

Where; F_d = Drag force

ρ = Fluid density

v= Fluid velocity

C_d = Drag Coefficient

A= Frontal area

The drag force, F_d experiences by moving object is in the function of its frontal area, A. The frontal area for this body panel is constraint by the chassis itself. The given frontal area is about 0.12m^2 which is in the range of all benchmarked products.

In order to deal with the tail shape issue, different kind of tail shape proposes. Different shape causes different streamline and different back pressure. This may affect the body panel performance. A wind tunnel test is conducted on some scale model to determine the best shape should be chosen.

3.4 Material Selection

The design selection will be based on the following criterion:

- Weight and stiffness of body material
- Price of material
- Availability
- Ease of handling

The material of the body must be able to withstand the drag forces that will be experienced by the vehicle when going at a maximum speed of 35km/h without noticeable deflections. Also the material of the body should be made out of lightweight material to overall reduce the weight of the vehicle which will ultimately increase the vehicle's fuel efficiency.

- Aluminum

  Aluminum has a low density and high strength. However it is hard to form and is easily deformed due to its low elasticity. Aluminum is easily obtained and recycled, and possesses corrosion resistant properties. There are many different alloys available to suit the formability and strength requirements (Davies 2003).

- GFRP

  Commonly known as fiberglass, GFRP is widely used in the automotive industry. GFRP is advantageous due to its high formability, controllability of material properties, wide scope of applications, and relative ease of production. GFRP has a lower density compared to aluminium but its production must be carefully controlled to achieve the desired properties and effect. It easily formable but not easily repaired and cannot be recycled. GFRP also provides good corrosion resistance as well as good dimensional stability and scratch resistance qualities (Davies 2003).

- CFRP

Commonly known as carbon fiber, CFRP is very similar in its advantages and disadvantages to GFRP however is has a lower density and higher strength. These improved material properties lead to a much higher material cost. CFRP is 30% lighter than GFRP, making it a better material albeit it's higher cost (Balfour 2000). For the project, Aluminum is deemed not feasible due to its inability to be formed easily. This is important because the shape of the body that was decided is heavily contoured and smooth, thus requiring a material that can be shaped easily to acquire the desired result. Between Fiberglass and Carbon Fiber, both have the properties to be formed easily as they are produced using a liquid mixture of matrix and reinforcement fibers. Once harden it will take the shape of the mold that was used to hold the composite in place. The only major difference between the two composite are their weights. As mentioned above, Carbon Fiber is 30% lighter than Fiberglass and stronger, but causes the material cost to increase tenfold. Since the price of the material is the secondary criterion, Carbon Fiber, despite its superior properties and advantages is deemed not suitable due to its hefty price. Hence, fiberglass would be used for the construction of the body.

By referring back to the criteria needed in selecting the right material; considering the cost, suitability with the resultant weight aimed, ease of handling ease of availability, the final decision is to choose the fiberglass (GFRP) as the material to build up the body panel.

The criteria that being considered in making the fiberglass interesting than those aluminum and carbon fiber are;

- Cost;
  - Reasonable with the budget proposed.
- Weight;
  - Reasonable weight with the expected weight proposed.
  - GFRP has a lower density compared to aluminum
- Availability;
  - Easy to be obtained within the market.
- Ease of handling;
  - The material is already in stock and the facilities of fabricating it into desired fiberglass product are in stock.
  - We have the expertise to assist in handling the fiberglass fabricating process.
- Characteristic;
  - Provides good corrosion resistance as well as good dimensional stability and scratch resistance qualities

3.5 Fabrication

Based on fact obtain regarding those 3 method of fabricating the fiberglass body panel, the most suitable and reliable method is the resin infusion process. In addition, the equipment to get the process done is available. The schematic of the process are as shown in

Other than that, the advantages of using resin infusion process will be;

- high quality laminate (low void content, high fiber to resin ratio)
- user friendly
- large objects can be infused with a minimum of workforce

- environmentally friendly (reduction of VOC, when using polyester)
- repeatable results
- weight reduction of the part

The procedure of resin infusion process will be;

a) Mold Preparation – The mold surface should be prepared using favored release agent; wax
b) Lay – up process
    i. Fiber glass layer(s) is cut with the size that can cover the size of the mold and laid into the mold firmly.
    ii. Add the peel-ply layer – Peel-ply is the first layer of the infusion 'bagging stack' and is a removable barrier that is peeled off the finished part, leaving a relatively consistent surface that is also ideal for bonding to. In this project, the peel – ply layer is the compoflex
    iii. Add the infusion mesh – The infusion mesh (also known as 'flow media') is used to ensure that the resin can flow from the resin feed line (and spiral tube) freely through the laminate.
    iv. Position the resin feed spiral – The resin feed spiral is spiral wrapped plastic tube that is used to improve the flow of the resin from the feed tube into the laminate. Resin will be disbursed along the full length of the spiral therefore the standard configuration is to position the spiral all the way down one side (the side where the feed tube will be positioned). This means that the resin is quickly distributed along one side of the mold and then advances more evenly towards the other side

v. Position the resin feed connector – this is where the resin will flow through going inside the bagging. The bag will be vacuumed through here as well.

vi. Apply vacuum bagging tape – Vacuum bagging 'tack-tape' is a type of very sticky gum tape. The tape is used extensively in all vacuum bagging processes where its pliable nature makes it highly effective at providing an air tight seal.

vii. Position and tape down the vacuum bag - everything is enclosed within the vacuum bag. It is crucial to ensure that the vacuum bag firmly stick on the tacking tape so that so problem will occur during vacuuming and infusing the bag

viii. Connect and seal the resin feed hose – With all the bagging stack and reinforcement sealed within the vacuum bag, 'breach' the bag to connect the resin feed hose. Connect and seal the vacuum hose – The process is repeated, this time using another length of PVC tube that will connect the catch-pot to the red silicone vacuum connector at the opposite end of the part to the resin feed connector..

ix. Connect the vacuum pump and catch-pot – catch pot is a pot where excess resin will be trapped during infusion.

c) Vacuuming – when everything is ready, the pump is turned on and vacuuming process takes place. All the stuff will tightly stick to the mold due the negative pressure from the vacuum.

d) Resin Infusion –inlet tube as well as vacuum tube is now dipped into resin pot for the resin to be sucked into the bag and infuse with the fiber glass. The process proceeds until every inch of fiber glass is infused.

e) Finally, stop the pump and the infused fiber glass is left over night for curing and hardening process before can be taken out as an solid product.

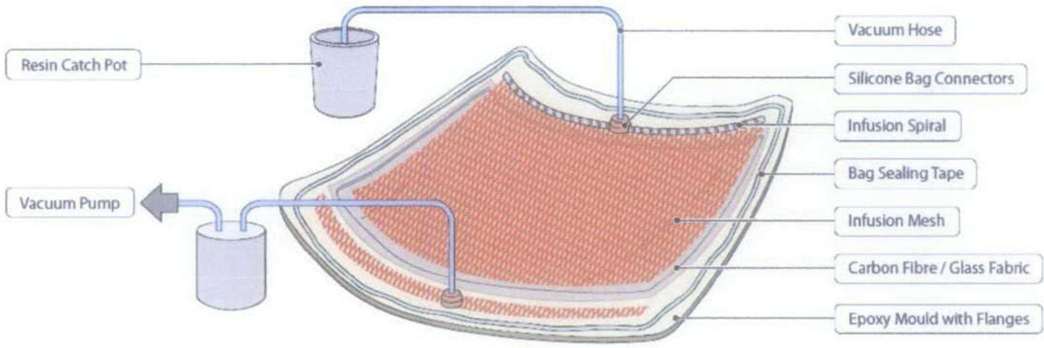


Figure 11: Resin Infusion Process

3.6 Product evaluation and testing

Hardness test is conducted to determine the body panel hardness compare to the previous body panel which is made through hand lay – up method. Other than that, product will visually evaluate to see the resin distribution, void spot, and etc.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Basic Design

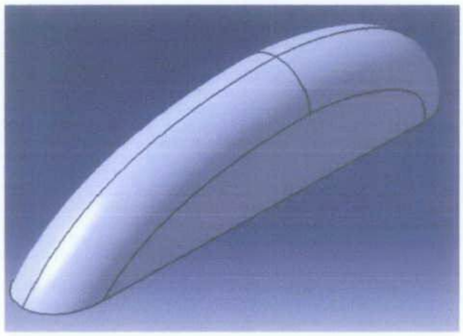


Figure 12: Isometric view

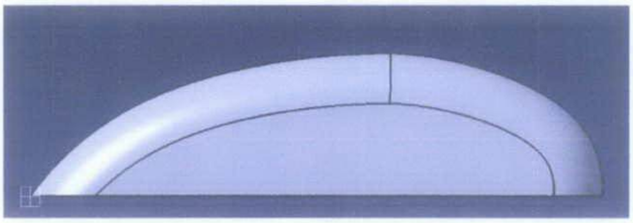


Figure 13: Side View

Based on the benchmarked simple vehicle, the very basic shape is determined to be as shown above. As planned, before being decided, different kind of tail shape proposed. 5 in total and all those shape is remodeled and tested in wind tunnel for drag and lift force coefficient evaluation.

Wooden models of those 5 different shapes is made up and tested in wind tunnel.

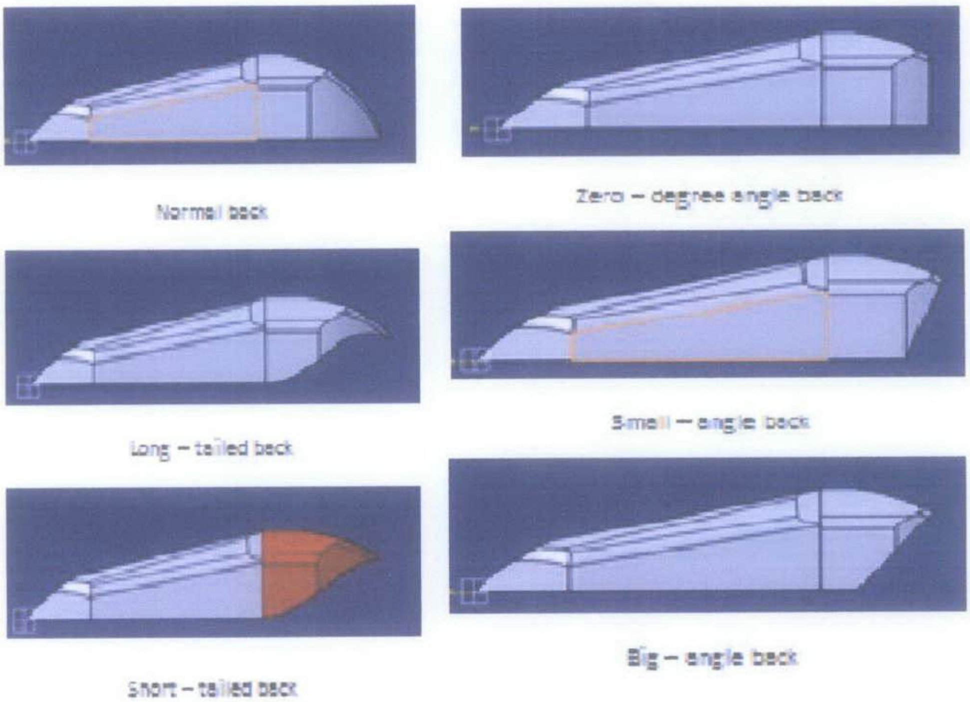


Figure 14: Different designs proposed

4.2 Wind Tunnel test – Aerodynamics Data Evaluation

Table 2: Drag force evaluation

Drag Force (Newton, N)				
Fan Speed (RPM)	1000	2000	3000	3500
Normal	0.08	0.12	0.58	1.64
Zero Degree	0.49	0.61	4.23	4.18
Small Angle	0.52	0.17	3.43	3.92
Big Angle	0.07	1.16	4.79	6.23
Tail Back	0.66	0.66	4.34	4.15

Graph of Drag Force (N) vs. Speed (RPM)

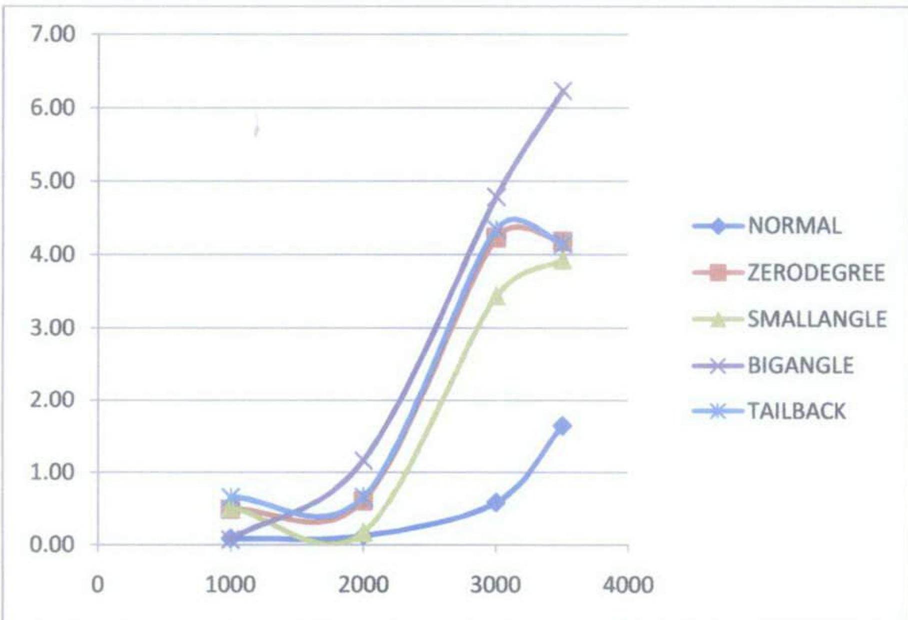
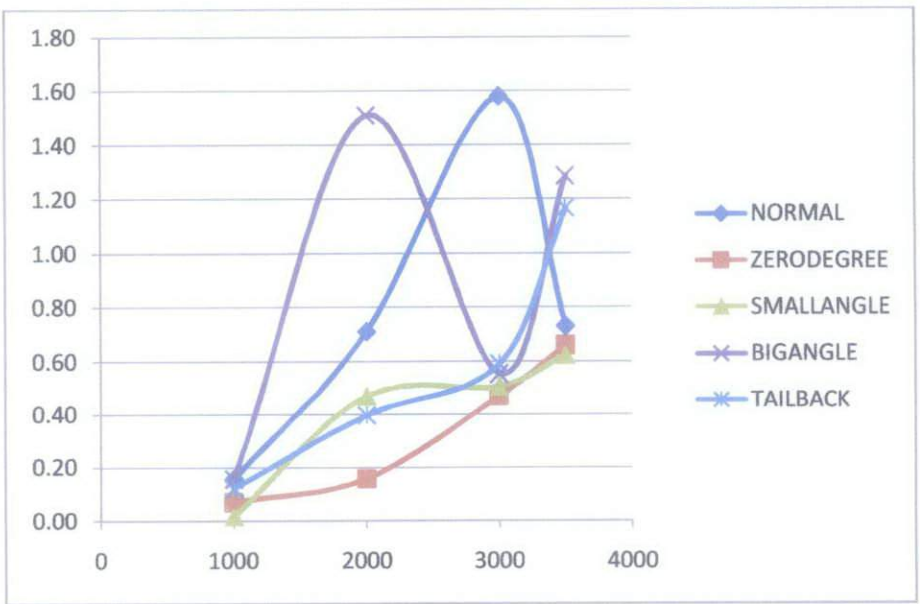


Table 3: Lift force evaluation

Lift Force (Newton, N)				
Fan Speed (RPM)	1000	2000	3000	3500
Normal	0.16	0.71	1.58	0.73
Zero Degree	0.07	0.16	0.47	0.66
Small Angle	0.02	0.47	0.51	0.62
Big Angle	0.16	1.51	0.55	1.29
Tail Back	0.12	0.40	0.59	1.17

Graph of Lift Force (N) vs. Speed (RPM)



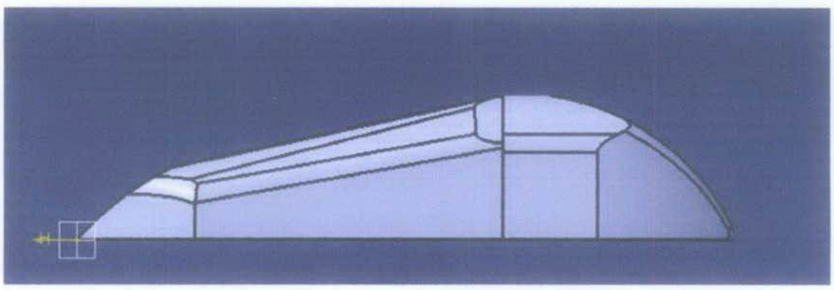
The vehicle where the body panel will be attached will move at the speed of 35 – 40 kmph. In Malaysia, highest wind speed ever achieved is about 50 – 60 kmph [MOSTI weather portal]. So, in extreme condition where the maximum vehicle speed could reach 85 – 100 kmph (vehicle speed + maximum tail wind), the design is tested under the speed of about 30 – 110 kmph which is equivalent to 1000 – 3500 rpm of wind tunnel speed.

From the drag froce result, the NORMAL design wins against the others. It possesses the lowest drag force at every speed condition.

For lift force, the differences are not significant except for NORMAL and BIGANGLE design. Each shows spike on their graph at the speed of 2000 rpm for BIGANGLE design and 3000 rpm for NORMAL design. It may due to unknown uncertainty cause by the wind tunnel itself since the wind tunnel is rarely used. Logically the graph will gradually increase accordingly to speed increased. Hence, the spike is consider error and negligible.

4.3 Wind tunnel test result

The finalized design based on the analysis is the NORMAL design.



Normal back

WIND TUNNEL SPEED (RPM)	1000	2000	3000	3500
Drag Force	0.08	0.12	0.58	1.64
Lift Force	0.16	0.71	1.58	0.73

Figure 15: NORMAL design data result

4.4 Material and Fabrication

4.4.1 Material Selection

Proposed material : Carbon fiber, fiber glass, and aluminum

Final Decision : Fiber Glass

Justification : Light, low cost, easy to handle, availability.

In conjunction with the fabrication process, to fabricate the finalized design is divided into parts for the ease of its fabrication.

The decision is to divide it into 4 parts for:

- Smaller mold
- Ease of handling of the fabrication process
- Better quality final product with minimal cost needed
- Ideal engine and cockpit access door (Back Panel as engine compartment access door and Top Panel as cockpit access door).

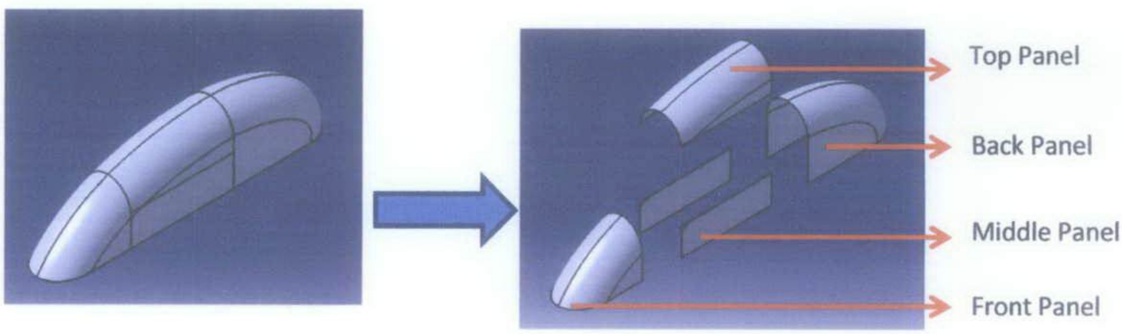


Figure 16: Actual Design (left) and Divided (right) designs

4.4.2 Fabrication

As discussed in METHODOLOGY section, the steps of fabrication start here. .Molds for Front Panel, Middle Panel, and Back Panel with exact shape and size as determined are made (for top panel, no mold required as it is made of PETG plastic, bended and framed. It is the access door as well as the vehicle windshield).

The process is as in figure below;

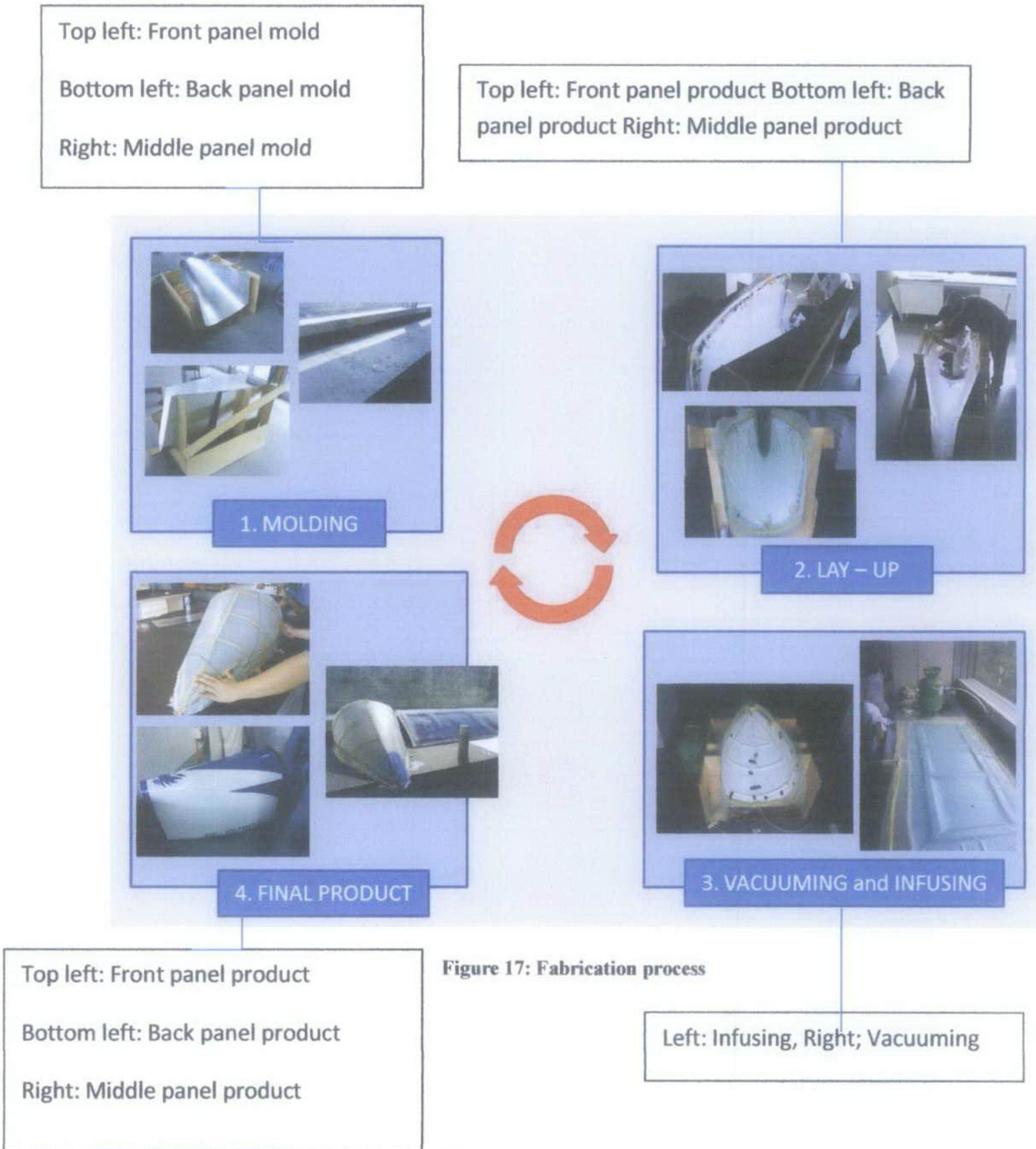


Figure 17: Fabrication process

The body panel is totally built in house. By referring to figure above;

- 1. Molding – mold of each part shape is made from plywood and aluminum. Mold structure strength is crucial as strong suction force will exerted on it during the vacuuming and resin infusion process.
- 2. Lay – up – fiber glass cloth laid inside the mold firmly to obtain firm and smooth final hardened fiber glass. In addition, the supporting material like nets; for better resin distribution flow, COMPOFLEX; to trap as much resin as it can into the fiber cloth and for better surface, and the vacuum bagging; made of thin plastic film.
- 3. VACUUMING and INFUSION – the bag is now vacuumed through suction pump. Resin is infused through its inlet and excess resin will be sucked out through vacuum line. The access resin is trapped in a tank just before the pump.
- 4. FINAL PRODUCT – infused fiber glass is left cured and hardened. It is taken out finally the surface is finished

4.4.3 Final product

Figure 18: Front and Middle Panel (raw)

Figure 19: Back Panel (finished)

Figure 20: All Part assembled (finished)

Figure 21: Top Panel – PETG transparent plastic

Figure 22: All part assembled and installed to the simple vehicle

4.4.4 Product evaluation and analysis

The resin infusion process used in this project is still new in UTP and this is the first time it was used to fabricate big scale product. Previously, this kind of product is fabricated by using hand lay – up process.

It was found that, product from resin infusion process, which is the body panel, is better in quality compare to the product of hand lay – up process. It was proven as certain test is done on each product.

Table 4: Final product evaluation 1

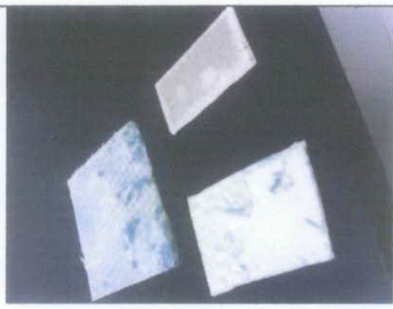
Test	Resin infusion product	Hand lay – up product
Vickers Hardness Test (HV values)	384.9	323.17
Fiber to Resin ratio (weight ratio)	1:10	1:20
Void	10% void per $100cm^2$ fiber	5% void per $100cm^2$ fiber
Weight	11 – 12 kg	>20 kg
Thickness	<1.5mm 	>10mm 

Flimsiness		

From the evaluation, resin infusion product wins most of the test. Note that void is much more in resin infusion product. This is due to improper apparatus used. Since this this is the first big scale project, the availability of certain apparatus is limited. Current suction pump found to be providing not enough power for good resin suction for a better infusion but the result is still acceptable as 10% void per 100 cm^2 fiber does not affect much the product properties and still better from the hand lay – up product. This will be discussed in more RECOMMENDATION section.

4.4.5 More product evaluation

Table 5: Final product evaluation 2

Figure:		Explanations
1.		Top specimen: Resin infusion product: - Resin is distributed fairly - Solid hardened fiber, good looking Bottom specimens (2): Hand lay – up product: - Poor resin distribution, ugly - Unfair surface thickness everywhere
2.		Inside the final product surface: - Rib (additional feature) made of sponge strengthen the structure. - A little void nearby the ribs due to lack of suction power

3.		Closer look to inside surface of final product: - Same resin thickness every surface, no excess resin - Solid surface - Good looking
4.		Closer look to product (raw) outer surface: - Very smooth surface finish - Hardness HV values of 384.9 - Solid structure

CHAPTER 5

CONCLUSION AND RECOMMENDATION

As the conclusion, the project is successful. The final results of this project achieved all objectives. All issue arose and proposed is well considered and done as needed. In addition, many findings experiences and those findings can be developed for a better result of this project. As the conclusion, the project is success.

5.1 The final result of this project achieved all objective. All issue arose and proposed is well considered and dealt. The objectives achieved and findings are:

- The shape is well design and aerodynamics as analyzed with the lowest drag coefficient and lift coefficient among the other designs
- The weight reduction from this project is >50% from previous project. It is more than expected
- The hardness of final product is >16.04% increased from previous project
- Cost reduction of this project is <30% less than the previous product

5.2 Recommendations

- More detail analysis on design like usage of advance software or bigger wind tunnel can improve more in design analysis result
- Better equipment for resin infusion process can develop more to obtain a better quality result.
- Utilization of carbon fiber material will lead to better product strength and lighter in weight

CHAPTER 6

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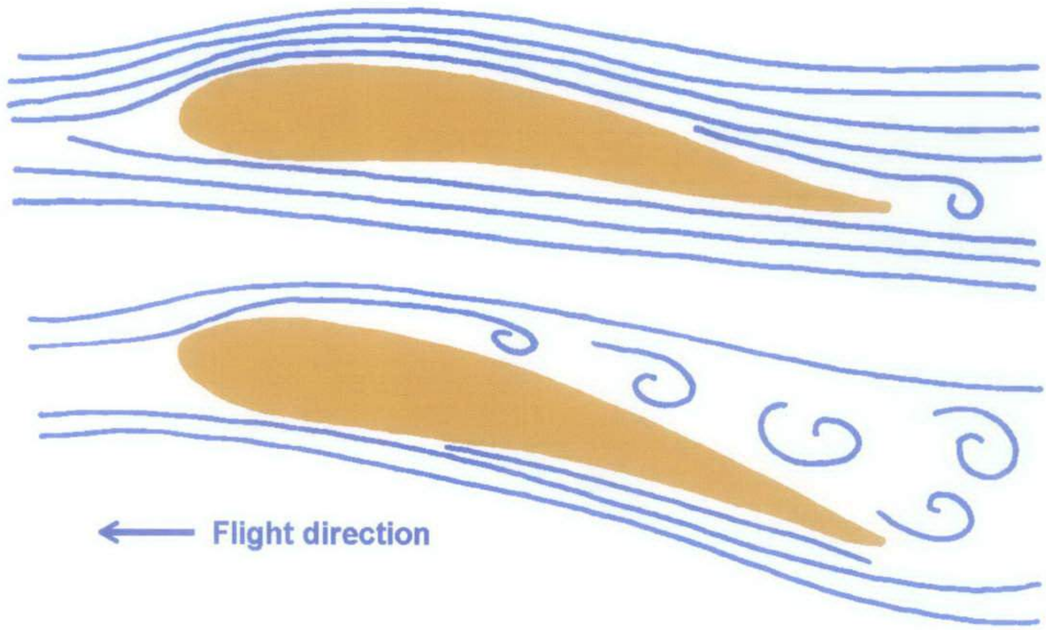
CHAPTER 7: APPENDICES

FYP 2 Gant Chart

PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	MID-SEMESTER BREAK	W7	W8	W9	W10	W11	W12	W13	W14
Wind Tunnel Test and Evaluation															
Material Collection Start on Fabrication Progress.															
Pre – Finalizing Final Product															
Test Run															
Progress Report Submission															
Finalizing Final Product															
Results															
Discussion															
Final Report Finalization and Discussion															
Oral presentation															

Streamline for object move in air



Drag coefficient for certain shape

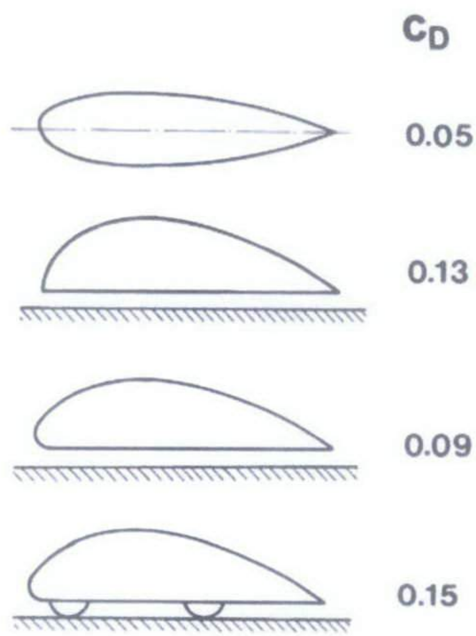
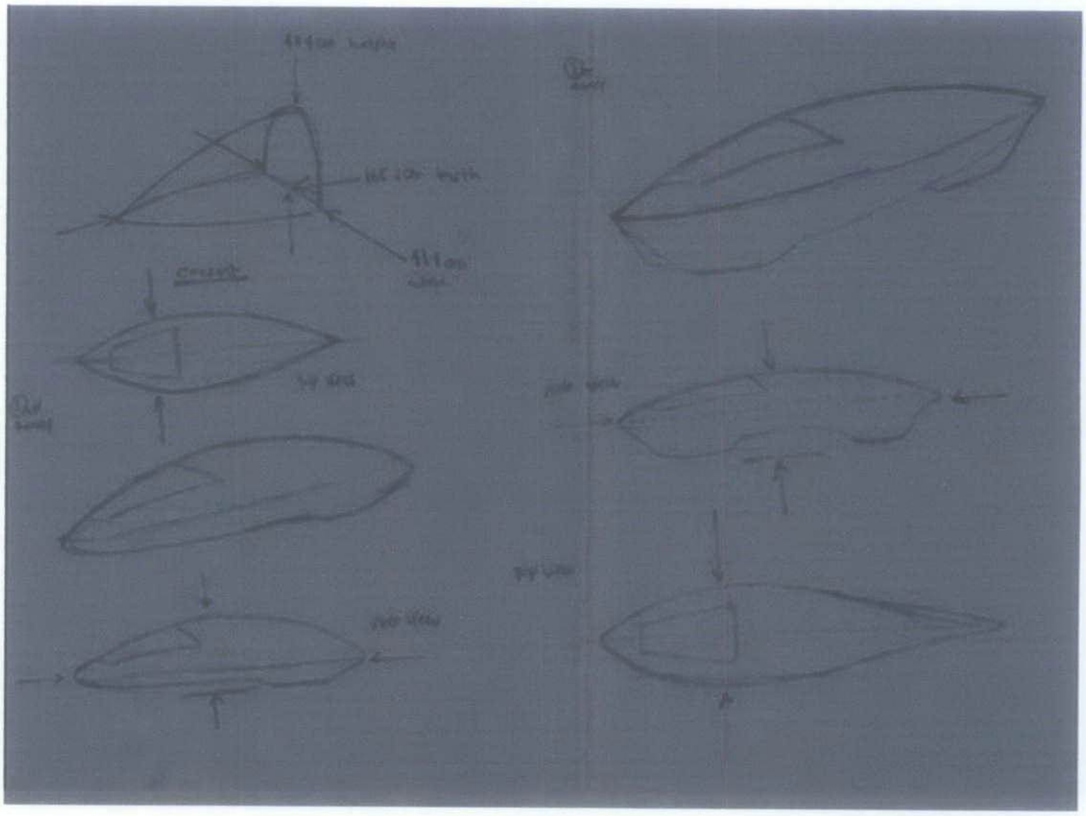
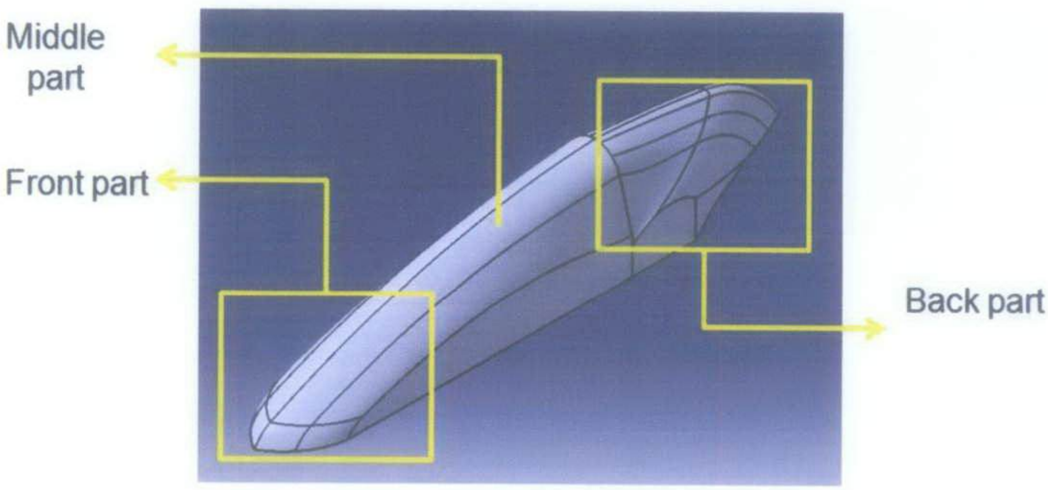


Fig. 1.20 Drag measurements with "half-bodies," performed by W. KLEMPERER [1.31] in 1922.

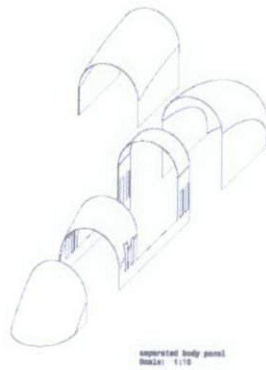
Sketches



First concept idea



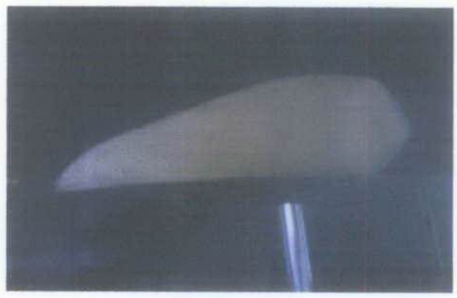
Touched – up design



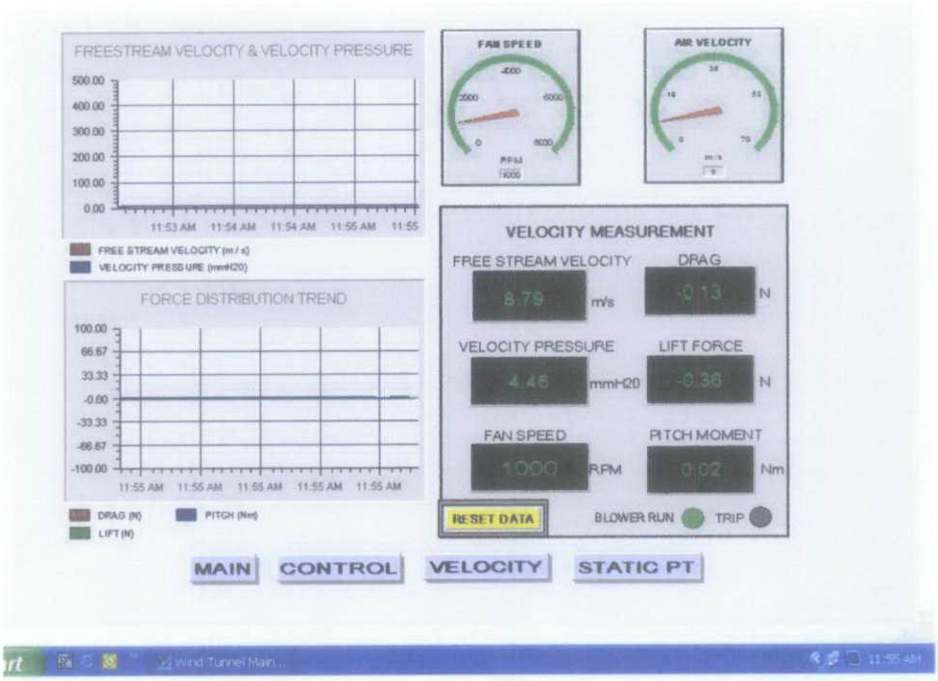
Wooden model for wind tunnel test

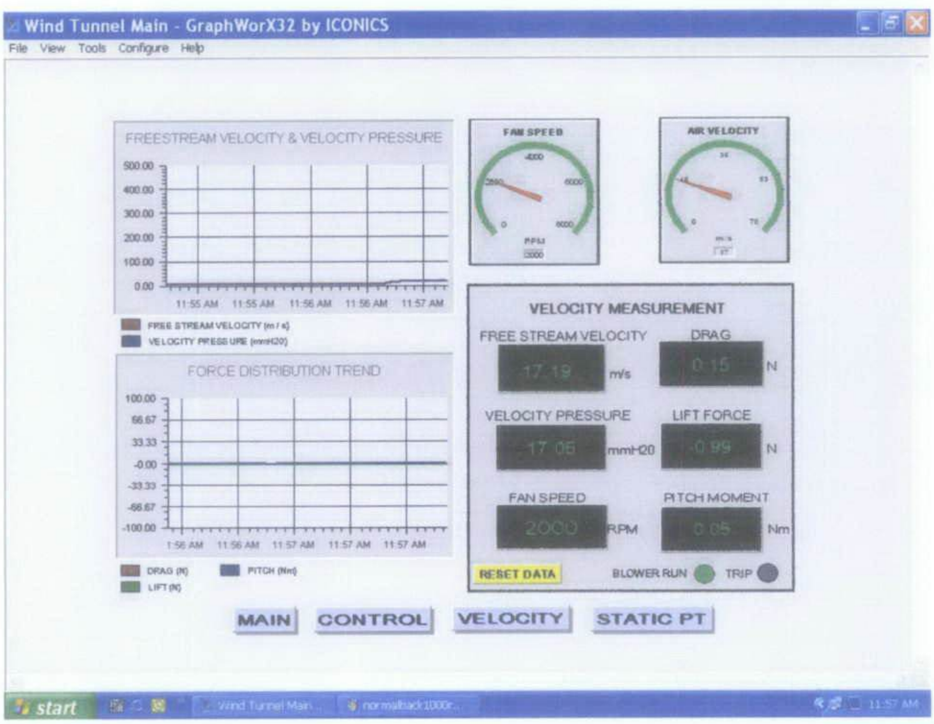
Wind tunnel and its test section

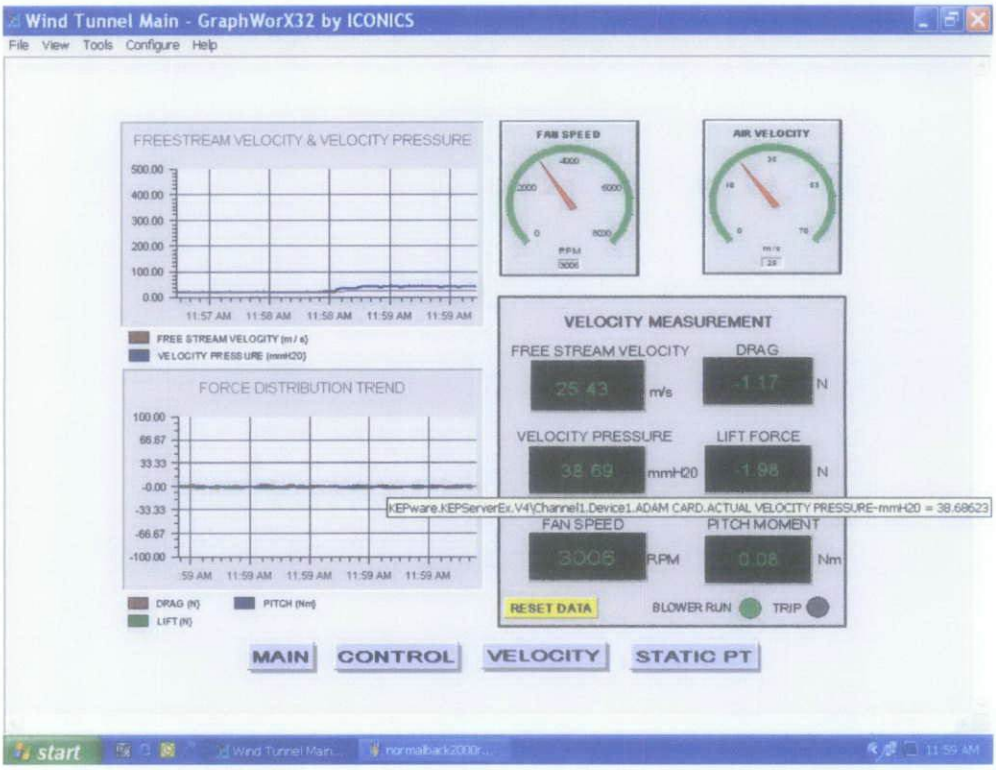
Model in test run

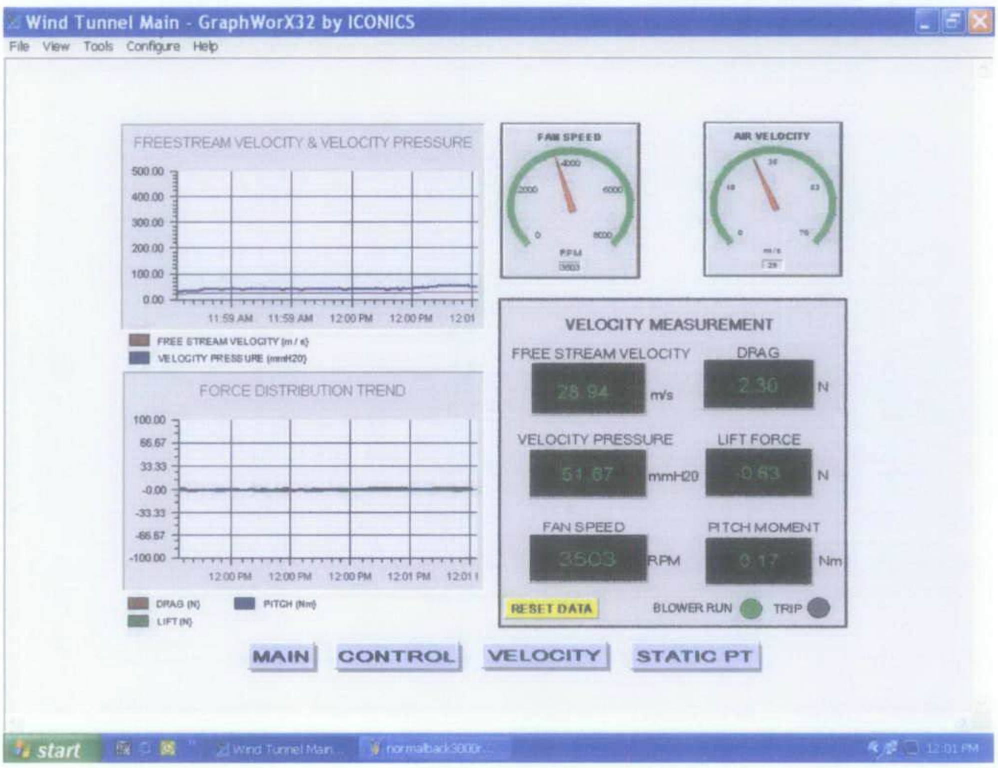


Wind tunnel test result (normalback design result 1000rpm – 3500rpm)






Wind Tunnel Main - GraphWorX32 by ICONICS
File View Tools Configure Help
FREESTREAM VELOCITY & VELOCITY PRESSURE
FREE STREAM VELOCITY (m / s)
VELOCITY PRESSURE (mmH20)
FORCE DISTRIBUTION TREND
DRAG (N)
PITCH (Nm)
LIFT (N)
FAN SPEED
AIR VELOCITY
VELOCITY MEASUREMENT
FREE STREAM VELOCITY
25.43
m/s
DRAG
-1.17
N
VELOCITY PRESSURE
38.69
mmH20
LIFT FORCE
-1.98
N
KEPware.KEPServerEx.V4\Channel1.Device1.ADAM CARD.ACTUAL VELOCITY PRESSURE-mmH20 = 38.68623
FAN SPEED
3006
RPM
PITCH MOMENT
0.08
Nm
RESET DATA
BLOWER RUN
TRIP
MAIN
CONTROL
VELOCITY
STATIC PT
start

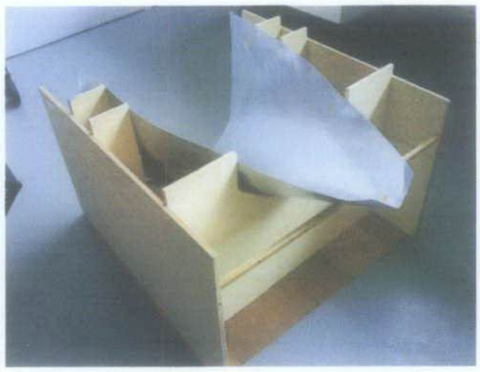

Wind Tunnel Main - GraphWorX32 by ICONICS
File View Tools Configure Help
FREESTREAM VELOCITY & VELOCITY PRESSURE
FREE STREAM VELOCITY (m / s)
VELOCITY PRESSURE (mmH20)
FORCE DISTRIBUTION TREND
DRAG (N)
PITCH (Nm)
LIFT (N)
FAN SPEED
AIR VELOCITY
VELOCITY MEASUREMENT
FREE STREAM VELOCITY
28.94
m/s
DRAG
2.30
N
VELOCITY PRESSURE
51.67
mmH20
LIFT FORCE
-0.63
N
FAN SPEED
3503
RPM
PITCH MOMENT
0.17
Nm
RESET DATA
BLOWER RUN
TRIP
MAIN
CONTROL
VELOCITY
STATIC PT
start

Fiberglass properties

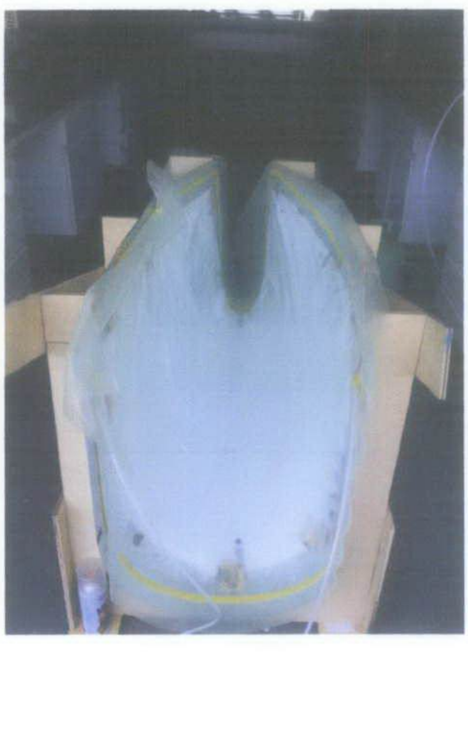
Material thickness	Typically range from 1/16" to 1/2". Can use sandwich construction to achieve lighter and stiffer parts.
Corner radius	Recommend 1/8" or larger
Shape	Will duplicate the shape of the mold. Can be heavily contoured
Dimensional tolerance	Tool side can be ± .010" of the tool Non Tool Side ± .030"
Surface finish	Tool side can be class A Non Tool side will be rough, but can be smoothed out Can be gel coated painted, or use any other surface coating
Shrinkage	.002 in/in
Electrical properties	RF Transparent Excellent insulating characteristics Can provide EMI shielding through conductive coating
Fire retarding	Resins available in fire retardant applications meeting various ASTM classes & smoke generation requirements
Corrosion	Resins available for corrosion applications, especially for hot brine, most acids, caustics, & chlorine gases

Source: http://www.performancecomposites.com/fiberglassdesignguide

Molds



Prepared molds for resin infusion



Products

Products – finished, and attached.

Hardness test