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Review

Design of composite racing car body for student based competition

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In this paper, total design method is used to develop a systematic route to design a car body fabricated by Faculty Engineering, University Putra Malaysia for competition and research purpose. A design of car body is implemented in this paper as a case study to enhance students understanding on developing a creative design. The design was carried out to meet the rules and regulation of "Formula Varsity UTeM 2008" competition organized by University Teknikal Malaysia (UTeM). The material selected in this car body design is carbon fiber reinforced polymer composite. The performance and reliability of the designed car body are considered by the means of engineering analysis, such as aerodynamic and stability.

Key words: Total design method, car body, carbon fiber reinforced composites, engineering analysis.

INTRODUCTION

Formula Varsity UTeM 2008 is an inter university racing competition where each competing university is required to design and build their own race car in Malaysia (FaMESA, 2008; Faieza et al., 2009). The car is a small-scale open wheel single-seat car. A detail design specifications were given by the event organizer complete with dimensions, rules and regulations.

Body design is an important criterion for race car. Its level of importance can be easily seen through the amount of investment from some major car manufacturers. Ferrari, BMW, Toyota, Renault, Honda and Mercedes have spent up to 400 million dollars per year to design a successful Formula One (F1) car body. Race car body is particularly important in aerodynamic. It reduces drag and hence provides smooth air flow along the race car. Also, the body design is analogous as an up side down wing, providing negative lift or downforce for stability. Besides that, car body encloses the driver and all important components so that to protect him against any projectiles created by the race car in front. Lastly, car body is a major contributor in a race car appearance. A race car with eye-catching body always is an attraction in racing competition.

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Total design method

Total design (Figure 1) is the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need an activity that encompasses product, process, people and organization. This is sometimes referred to as the product delivery process or the product development process, abbreviated in either case in PDP. In this research work, the total design is primarily carried out to meet the need of competition.

The achievement of the integration of technological or non-technological subject material in an effective and efficient manner is greatly enhanced by having a visible operational structure. Visibility is crucial factor in bringing about integration.

Total design has a central core of activities, all of which are important for any design, irrespective of domain. Briefly, this core consists of market investigation, product design specification, conceptual design, detail design and fabrication. Fabrication is not reported in this paper. All designs start with a need that, when satisfied, will meet requirement in competition. From the statement of the need, a product design specification (PDS) must be formulated.

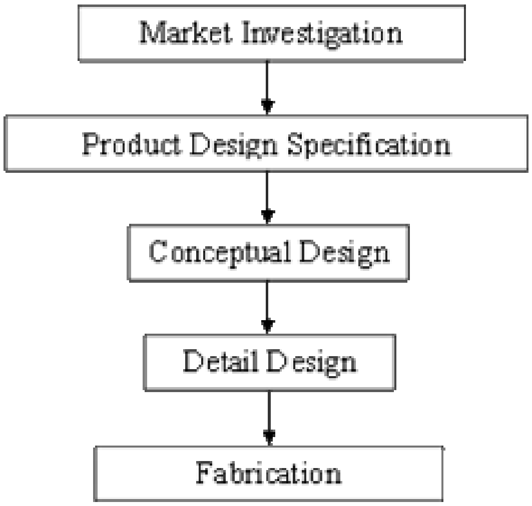


Figure 1. Design Core (Pugh, 1991).

Market investigation

In the real Formula One (F1) competition (2008 Formula One Technical Regulations, 2008), an automobile designned is solely for speed races on circuits or closed courses. The performance of the cars is highly dependent on aerodynamics, electronics, suspension, tires and driver skill. All the racing cars must strictly obey the Formula One Technical Regulation for safety reasons. Its economic effect is very large as millions of people watching races worldwide. The market is huge due to its attractive racing event. Its high popularity brings to the investment of big company by the mean of technology advancement to improve the performance of car in all aspect. In this field, car body design is one of the main concerns in championing the circuit.

Before starting the design of automobile, it is very crucial for a designer to entirely understand the rules and regulation stated by organizer, Universiti Teknikal Malaysia Melaka. Cars (FaMESA, 2008) designed must comply with these regulations in their entirety at all times during an event. Previous paper (Faieza et al., 2009) has reported on the design and fabrication of the entire car but the body was not design and fabricated due to time constraint. Therefore, this paper reported on the design of the car body.

In this design, the car is entirely following "Formula Varsity Technical Specification" provided by organizer (FaMESA, 2008). Rules are intended to give freedom and fair competition to the competitors in order to raise the involvement of undergraduates in the safety, research and future development of car design. In this design, the rules involve are material, weight, dimensions and bodywork. Material is a very important aspect for a car body design. It is convenient to have a high strength and low weight of material because it can enhance the safety of driver and at the same time fulfill the requirement of competition that restricts the weight of car. The material selection process was conducted in selecting the most optimum material for the varsity car body but details on method of selected in not reported in this paper. In that work, carbon fiber reinforced polymer composite material was selected in fabricating the body of car due to its outstanding performance. In actual F1 car, carbon fiber reinforced epoxy composite is used in making car body.

All the maximum dimensions and bodywork of car are stated clearly under the technical specification. The related requirement has been accomplished by the chassis construction. Therefore, the main concern body design is left to the aerodynamics. Aerodynamics plays a fundamental role in car performance. Aerodynamics is one of the most important factors of in the design of car body. It mostly affects the overall performance of racing car. The aerodynamics study of car can be learnt by referring to the real F1 racing car (2008 Formula One Technical Regulations, 2008) and reference books. It makes the designs more reliable and feasible. Beside the performance, aesthetic of the designed car also has to be considered. Its good appearance can carry a better image to the university and it can bring confident to the driver during the competition.

Product Design Specification (PDS)

PDS is acting like a mantle enveloping the whole core activity. In order to establish a balance PDS, we need to encompass every major elements as they are the primary triggers from which the PDS evolves (Table 1).

Conceptual design

Conceptual design involves two stages of work as shown below:

i) The generation of solutions to meet the stated need.
ii) The evaluation of these solutions to select the one that is most suited to match the PDS.

There are different (creativity methods) used by design teams to generate ideas to find many conceptual design solutions. These methods are:

i) Brainstorming method.
ii) Gallery technique.
iii) Problem decomposition.
iv) Morphology method.

For this particular design, the gallery technique was used to come up with the conceptual designs. Below is an explanation on the gallery techniques:

1. Problem introduction (more effectively advance notification for more readings and preparation).

Table 1. Product design specification for formula varsity car body.

	Product design specification	
	Formula varsity car body	
	Date: 24/09/2008	**Sheet: 01/01**
Ref. No.	**Requirements**	**Rev. No.**
1	Performance	
	Aerodynamics Stability - downforce generation Engine cooling	
2	Dimension	
	2.1 Maximum height: 900mm 2.2 Maximum width: 1500mm 2.3 Maximum length: no constraint	
3	Weight	
	3.1 Total weight: 140kg	
4	Material	
	4.1 Carbon fiber 4.2 Fire -resistant composite based on fiber glass	
5	Standards and Specifications	
	5.1 Formula Varsity Technical Specification	
6	Safety	
	6.1 Protection on driver 6.2 Enclosure of interior components	
7	Installation	
	7.1 Easy and quick assembly	
8	Ergonomics	
	8.1 Easy to aboard	
9	Manufacturing Process	
	9.1 Simple 9.2 Joining	
10	Aesthetic	
	10.1 Shape 10.2 Colour	
11	Target Product Cost	
	11.1 Low fabrication cost 11.2 Minimum maintenance cost	

2. Idea generation stage (each member work for his own for 15 to 20 min to generate solutions to the problem-no opportunity for criticism or discussion- ideas are externalize as text and/or drawings on papers).
3. Association of ideas stage (all ideas are displayed, ideas are spared over large table- 15 to 20 min time is given for discussing ideas- seeking the promising compensations). At the end of this stage, new concepts may be generated or just focusing on developing the already proposed.
4. Idea generation stage 2 (each member works for his own again to generate new ideas or to develop existing ideas from the previous interaction. Stages 3, 4 can now be repeated if necessary.
5. Idea selection (promising ideas are selected for further development).

Solution generation

In order to generate ideas for body design, our team hadvisited machining shop for several times to collect accurate measurements of the chassis. Then, a 10 to 1 scale engineering model of the chassis was drawn to provide a basic platform for our body design. The master drawing was photocopied so that there are more chassis models for the designers to design and draw new car making the body design process easier. Figure 2 illustrates the chassis model we drawn on an A3 paper while

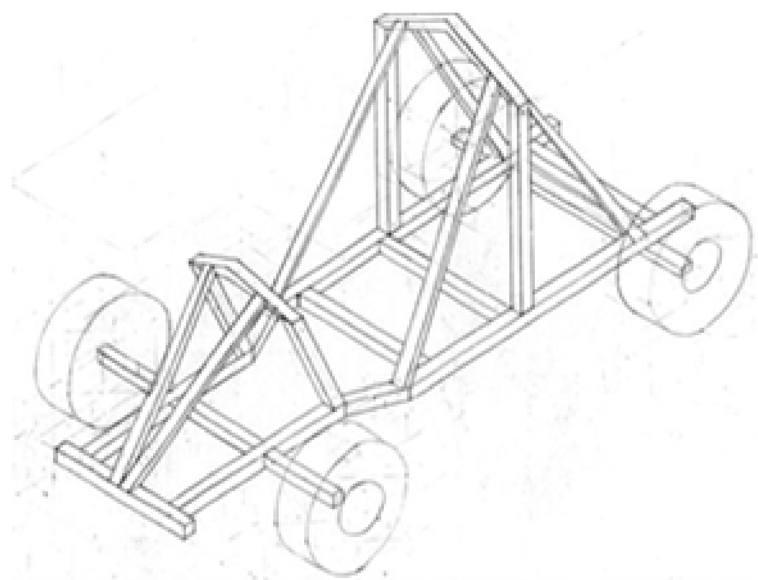


Figure 2. Sketch of chassis of varsity car.

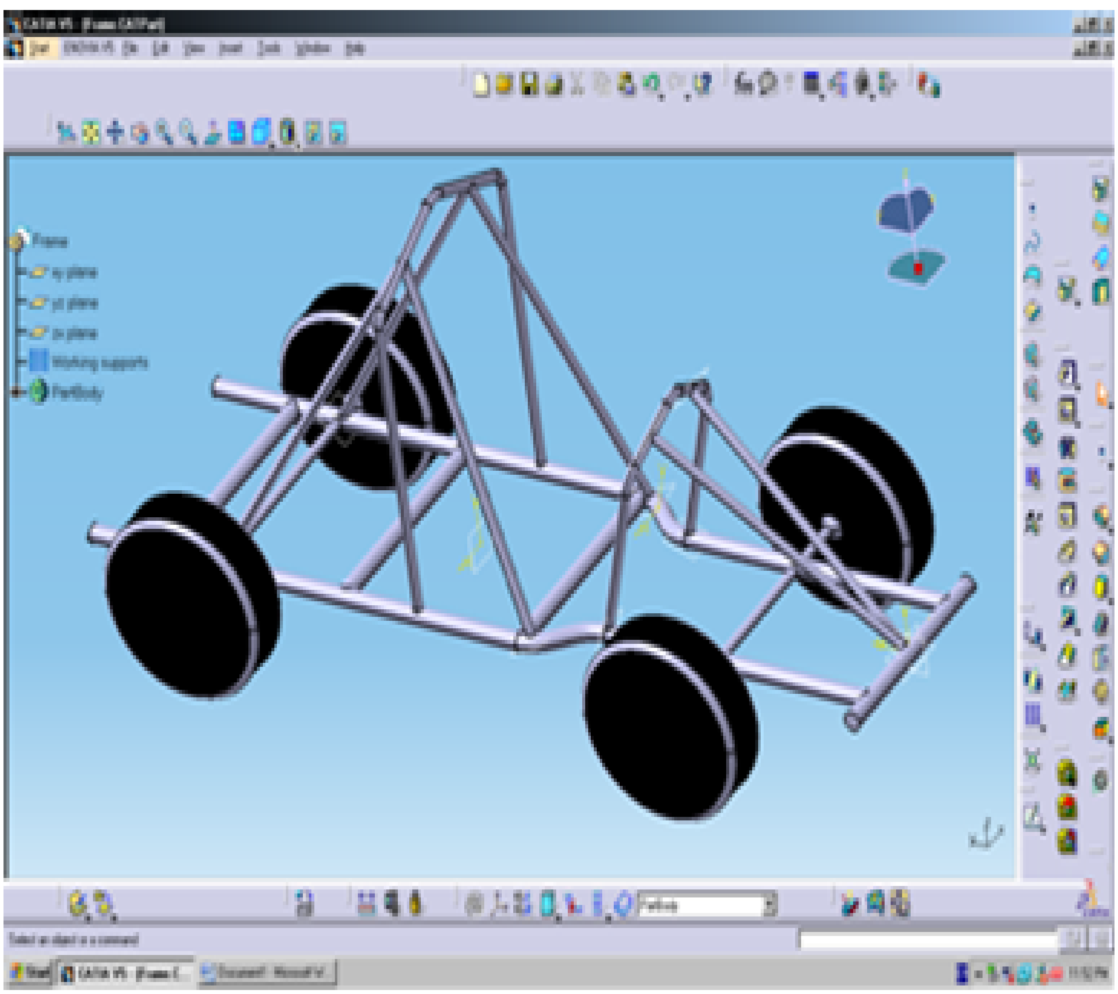


Figure 3. 3D solid model of the chassis.

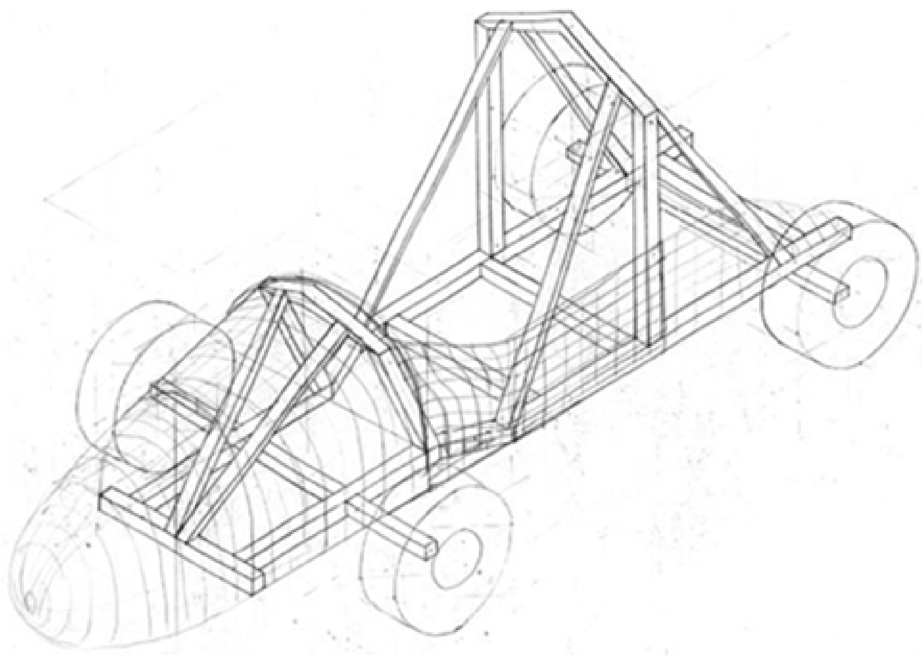


Figure 4. First concept of design.

Figure 3 shows the 3D solid model of the chassis.

Concept 1

This concept mimics the design of an aero plane where the vehicle nose is made in cone shape for aerodynamics purposes. The tip of the nose was designed to be spherical to reduce drag and ensure smooth air flow. Each curving on the body was made as smooth as possible to reduce air resistance. The body does not cover the chassis up to the top section because it does not favor the aerodynamic aspect. Also, by building the body low helps to reduce the car's center of gravity. This concept does not involve many parts. Hence, it is easy to be fabricated and installed (Figure 4).

Concept 2

This concept emphasizes on driver's safety, it covers the driver from bottom to the top of the chassis. A windscreen is included in the design to allow clear view for driver. This design is considered revolutionary. It has several advantages that other designs do not have. This concept utilizes minimum material at the same time provide maximum protection to the driver. Using less material is an advantage in racing as it reduces weight and allows higher speed and reaction for the race car. It is considered as the easiest one to be fabricated due to its simplicity (Figure 5).

Concept 3

Concept 3 (Figure 6) is designed by benchmarking Formula One's standard. It has front wing, side pod, real wing and diffuser. These components not only designed for aerodynamics purposes, they also provide downforce for stability. This design reduces the car's center of gravity to the minimum. Hence, further improve its stability. In safety aspect, these wings protect driver during body. Besides, photocopied drawings are inerasable, collision from every directions.

Evaluation and selection of concept

There are ten criteria to be concerned in the effort to determine the best selection of design concept:

1. Aerodynamics
2. Stability
3. Weight
4. Safety
5. Fabrication
6. Installation
7. Ergonomic
8. Cost
9. Engine cooling
10. Aesthetic

Weighting method is used to determine the relative important of the selected criteria. This method is used to

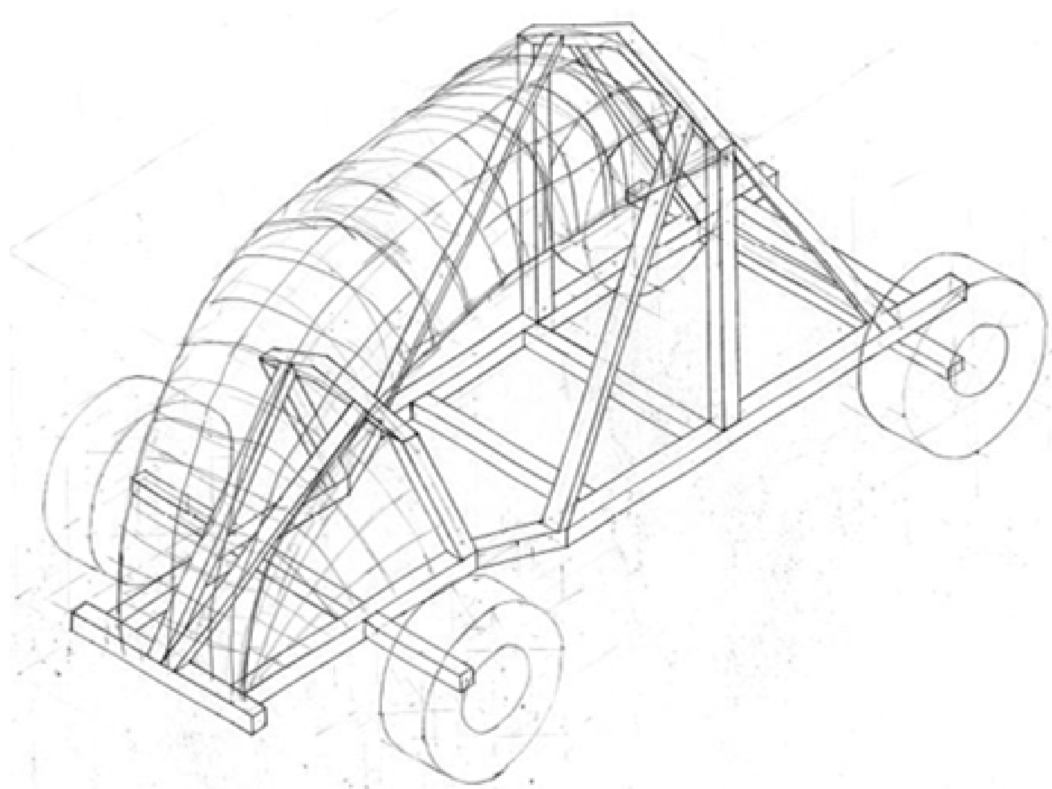


Figure 5. Second concept of design.

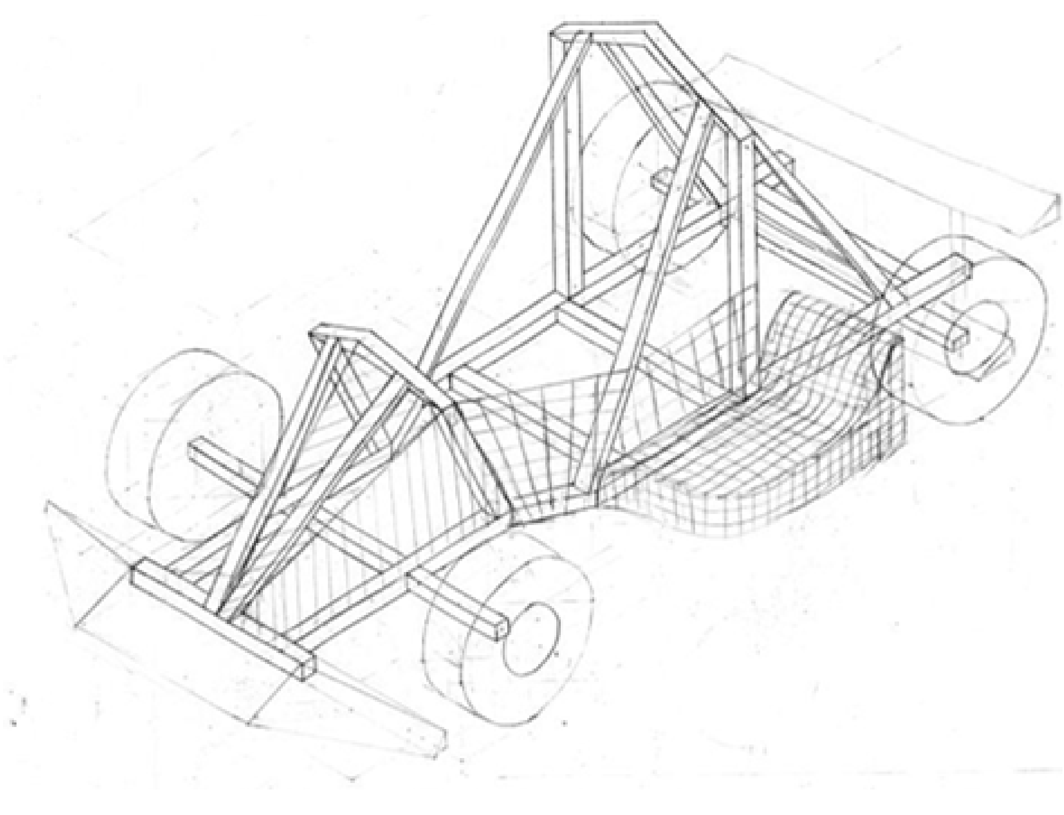


Figure 6. Third concept of design.

Table 2. Application of digital logic method to criteria of car body.

Property	**Decision number**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Aerodynamics	1	1	1	1	1	1	1	1	1						
Stability	0									1	0	1	1	1	1
Weight		0								0					
Safety			0								0				
Fabrication				0								0			
Installation					0								0		
Ergonomic						0								0	
Cost							0								0
Engine cooling								0							
Aesthetic									0						

Property	**Decision number**														
	16	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Aerodynamics															
Stability	1	1													
Weight			0	1	1	1	1	0	1						
Safety			1							1	1	1	1	1	1
Fabrication				0						0					
Installation					0						0				
Ergonomic						0						0			
Cost							0						0		
Engine cooling	0							1						0	
Aesthetic		0							0						0

Table 3. Weighting factor for criteria of car body.

Property	**Positive decision**	**Weighting factors, α**
Aerodynamics	9	0.200
Stability	7	0.156
Weight	5	0.111
Safety	8	0.178
Fabrication	3	0.067
Installation	2	0.044
Ergonomic	2	0.044
Cost	2	0.044
Engine cooling	5	0.111
Aesthetic	2	0.044
Total	45	1.000

enhance the selection process to carry out the most optimum design.

Total number of decision = $N(N-1)/2$.

In this case, total criteria to be considered is 10, therefore $N = 10$.

Therefore, total number of decision = 10 (10 – 1)/2 = 45 .Then, the table is tabulated to find out the positive decision number of each criterion as shown in Table 2.

Table 3 and Figure 7 show weighting factor for criteria of car body. From Table 3, it is obvious that aerodynamics is the most important criteria in designing car body. It is followed by safety, stability, weight, engine cooling and fabrication. Installation, ergonomic, cost and aesthetic is the least important in this analysis.

Table 4 shows the evaluation process of the concepts

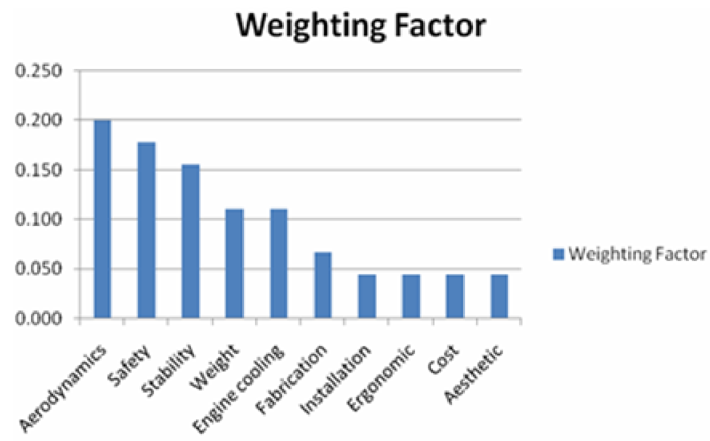
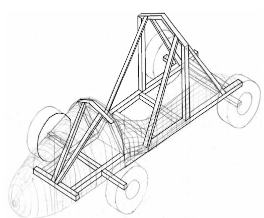
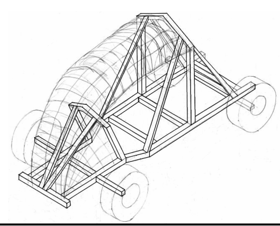
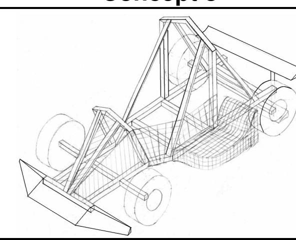


Figure 7. Weighting factor of criteria.

Table 4. Conceptrating.

No.	Criteria	Concept rating (1 as lowest, 5 as highest)					
		Concept 1		Concept 2		Concept 3	
							
		Normal rating	Weighting factor	Normal rating	Weighting factor	Normal rating	Weighting factor
1	Aerodynamics	4	0.800	3	0.600	4	0.800
2	Stability	3	0.467	2	0.311	5	0.778
3	Weight	4	0.444	5	0.556	3	0.333
4	Safety	3	0.533	4	0.711	4	0.711
5	Fabrication	4	0.267	5	0.333	3	0.200
6	Installation	4	0.178	5	0.222	3	0.133
7	Ergonomic	4	0.178	3	0.133	4	0.178
8	Cost	4	0.178	5	0.222	3	0.133
9	Engine cooling	4	0.444	3	0.333	4	0.444
10	Aesthetic	3	0.133	2	0.089	5	0.222
	Balance		3.622		3.511		3.933

developed. Based on the concept evaluation above, Concept 3 was selected as it scores the highest rating among three conceptual designs. Hence, Concept 3 is analyzed further in the sub-following section.

Analysis on the selected design

The detail drawing of the selected conceptual design is developed with the aid of CATIA software. Figures 8 and 9 are the detail drawings of car concept 3. In this section, extensive analysis is performed on the selected concept of car body. With the help of clear visualize of drawing, the analysis can be carried out in better way. The analysis is conducted by evaluating several important parts of the car body designed.

Front Wing

The front wing is vital in the design as it is the first part of the car contacting with the air. The purpose of the design

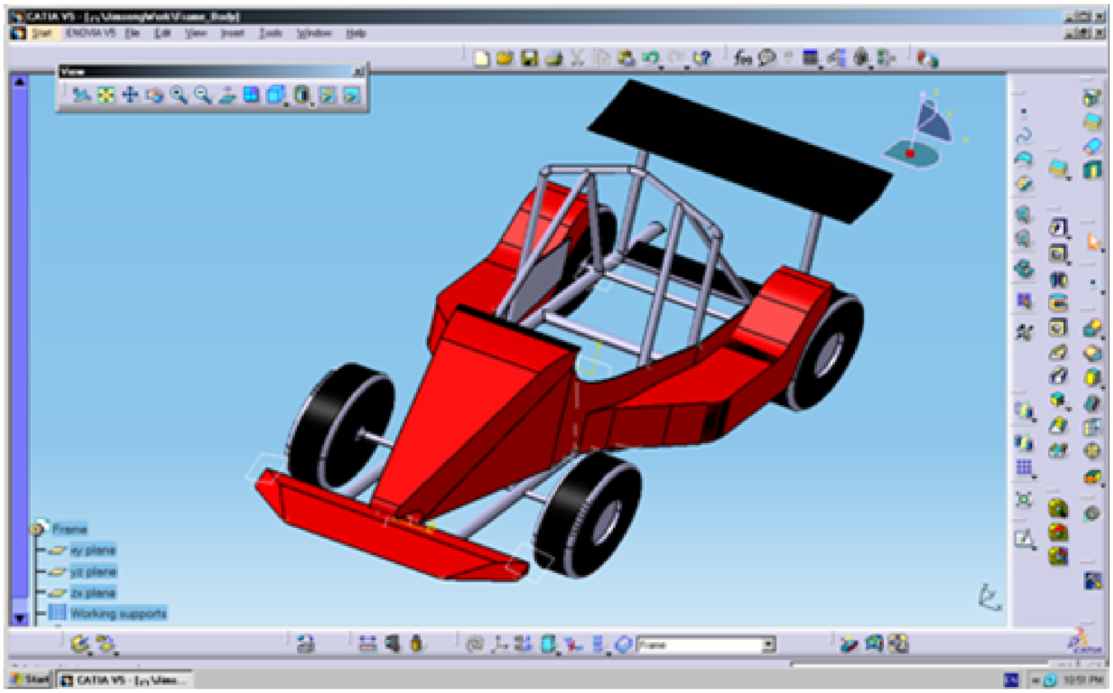


Figure 8. Three dimensional view of car body designed.

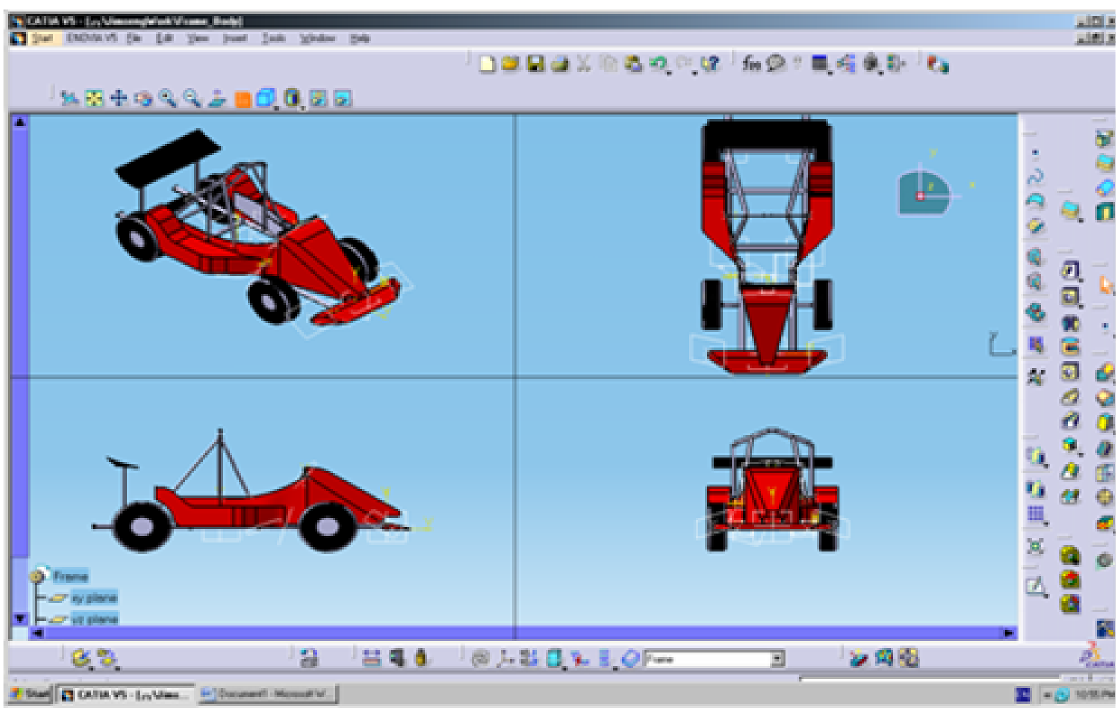


Figure 9. Multiple view of car body designed.

is trying to minimize the resistant of air flow on the car as shown in Figure 10. The fast incoming air flow is deviated to other direction through the smooth surface of front wing (white arrows represent the direction of air flow). The airflow passes above and beneath the wing rather than around it. By this way, the unwanted drag can be minimized effectively.

The objective of the design is also trying to generate as

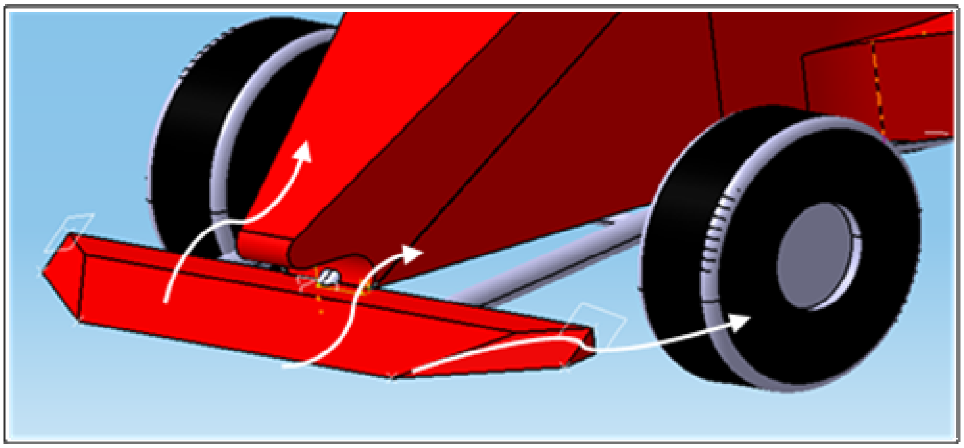


Figure 10. Air flow on front wing.

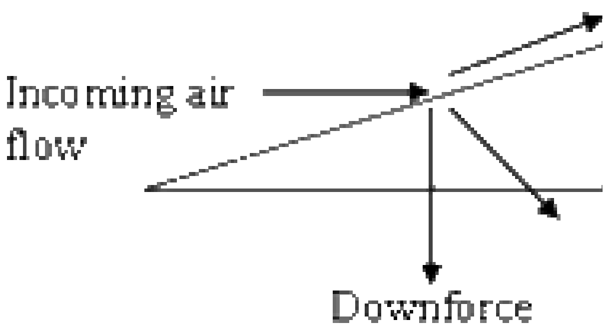


Figure 11. Downforce created due to incoming force of air.

much downforce as possible to stabilize the fast moving car. It is primarily important when taking into account the safety aspect of the car. The front wing plane is made with nearly complete width of the car which can allows more downforce to be generated at the front. In this design, the downforce is generated as shown in Figure 11. By using this design, the best compromise between the greatest possible downforce and the lowest possible air resistance can be accomplished.

The endplate of front wing is designed by purpose to split the air flows to other sides so that it does not hit on the front wheels. It overcomes the main problem of turbulence around the wheels. The turbulence generated reduces aerodynamics efficiency and contribute to undesired drag that may down grade the overall performance of car.

Nose

The major significant factor in designing nose is friction drag. The flow air passes through above and aside of the nose without creating turbulence force. The surface smoothness of nose must very good so that less resistant

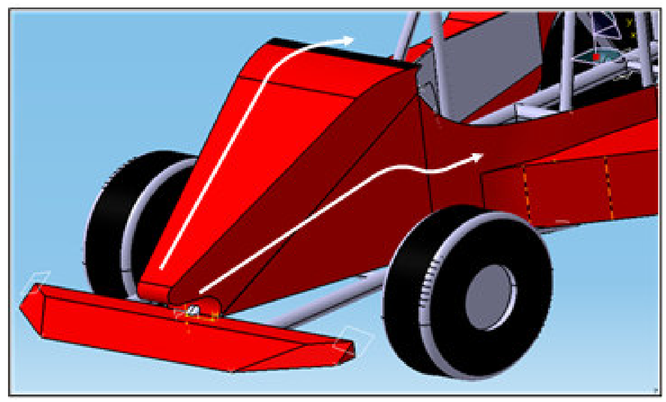


Figure 12. Air flow on nose.

and drag force will act on it. The flow of air on nose is shown in Figure 12. The design of nose should be made as low as possible to generate more downforce. Generally, the nose itself does not generate much downforce but in term of ergonomics, lower noses may have good visibility from the driver's point of view.

The other main purpose of nose is to protect the driver. It must comply with several strength and measurement rules that are set by organizer. Nose is functioning as the frontal energy absorbing structure which is able to absorb energy in the case of a head-on collision. It is one of the reasons for choosing carbon fiber reinforced composite material to construct car body.

Side pod

The air that passed through the nose is then guided to the side of the car by the splitter located just in front of the side pods. The design of side pod can smoothen out the air flow that has been disturbed by front wheels. It separates the flow into two parts; one is directed into the side

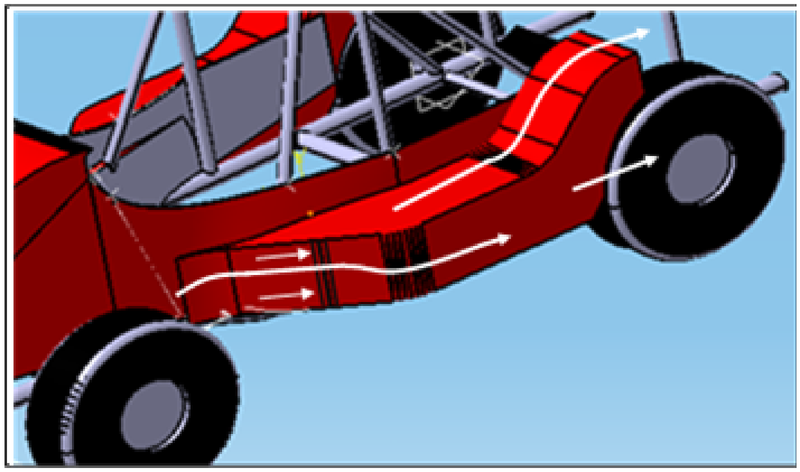


Figure 13. Air flow on side board.

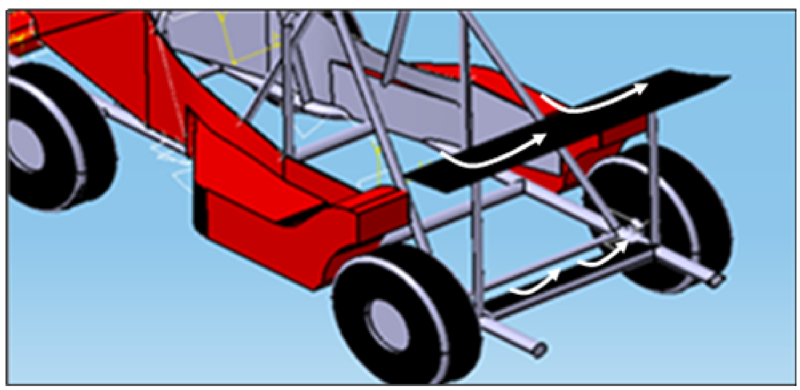


Figure 14. Air flow on real wing.

side pod and other is diverted outside as shown in Figure 13.

The air passes through the smooth surface of side pod with minimum drag force. It acts to block the air flow from hitting the rear wheels. The direct hit of air on the wheels may create turbulent which disturbs the whole air flow dynamics on the real part of car. The design makes the air flows in steadier ways. Besides, the installation of side pod increases the safety of the car. It is able to stabilize the whole body of car and protects driver from side collisions.

Air directed into the side pod is used to cool the engine. It acts like a radiator intake. This design is essential to enhance the performance of engine and protect it from overheating.

Top and bottom rear wing

The rear wing is a crucial component for the performance of a race car. It creates the most drag on the car. Trailing vortex or induced drag is the dominating drag on rear wings. There is about one third of total down force comes from the rear wing. The wing angle designed is decided carefully because more wing angle increases the downforce and therefore produces more drag, thus reducing the cars top speed.

In this design, two rear wings are assembled on the car as shown in Figure 14. The rear wings are used to create downforce and stabilize the car. In usual condition, the front wing is producing much more downforce than the real wing. It makes the front tyres of car much heavier at high speed. If such situation happens, it is very hard to control the movement of the car. Therefore, two real wings are installed in the design to make it safer to be controlled and increase its stability in high speed.

Beside creating downforce, the bottom rear wing can work as a diffuser. It is used to guide and control airflow underneath the car. It works to increase the speed underneath the car. The air flow moves at higher speed below the car and it lowers the pressure on it. Therefore, higher pressure above the car pulls the car down to the track. The suction effect is a result of Bernoulli's theory.

Conclusion

From the outcomes at the end of this design and fabrication planning, there are a few highlights that can be considered as meeting the objectives and gaining values. The initial idea was to find out if there is an alternative in producing a Formula Varsity race car body. As total design method is carried out throughout the whole design and planning process, it is believed that this proposed alternative can lead to a better product in a few different perspectives and this is supported by the figures and conceptual analyses included in the design and planning process.

It is proven that the final product had added value to the race car. As discussed in the detail design section, the Formula One analogous design had given the car better aerodynamic properties and stability. Besides, the use of high strength fiber reinforced composite material improves the race car safety factor. This is a plus point as safety is an important criterion in motor racing. Also, substantial weight reduction is achieved when the car body is fabricated using composite material as this material is low in density.

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