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DESIGN OF A SPACE FRAME CHASSIS FOR UTEM FORMULA VARSITY RACE CAR

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***Abstract*-This paper presents the design of a space frame chassis for a new UTeM Formula Varsity race car. New single-seat open wheel race car chassis was designed as a tube chassis construction as per required in the UTeM Formula Varsity racing competition rules and regulations. Design selection method was performed to select the final concept design of the chassis and 3D CAD model of the selected design was later constructed using CAD software. Later, load analysis used to determine the load acting on the chassis. Low carbon steel A36 was selected for the space frame chassis construction due to low cost and good structural strength properties. Theoretical structural performance of the chassis was analyzed for both bending and torsion load cases through finite element analysis method performed using Generative Structural Analysis module. Results from the simulation shows that the new chassis design has a minimum torsional stiffness of 4874.5 Nm.deg^{-1} and it is 9.5% stiffer than the previous 2010 UTeM race car chassis. The new chassis was founded to have a factor of safety approximately 15.1 in static bending condition. The results show that the new chassis is capable to operate safely as per design requirements for future Formula Varsity race event.**

***Keywords*—Space frame chassis, design, race car, Formula Varsity.**

I. INTRODUCTION

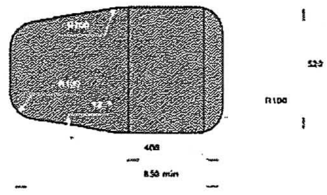
UTeM Formula Varsity is a racing competition where engineering students from various Malaysian higher learning institutions participated in the challenge to design, fabricate and race a working prototype of an open wheel, four-wheel formula style race car in real track condition. The event was organized by Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) and in the 2010 event, saw the participation of over 20 cars from 16 institutions all over Malaysia including 2 teams from Universiti Teknikal Malaysia Melaka. Through experienced gathered in the event, a new team was formed to construct a similar race car as the preparation for the upcoming 2012 event. Among the initiaves made is to design the new UTeM space frame race car chassis which is aim to be able to maintain the structural strength needed for safety during its operation. This paper describes the development process of the new UTeM race car chassis as well as the analysis done to determine the structural properties of the structure during its operation.

II. CHASSIS CONCEPT DESIGN

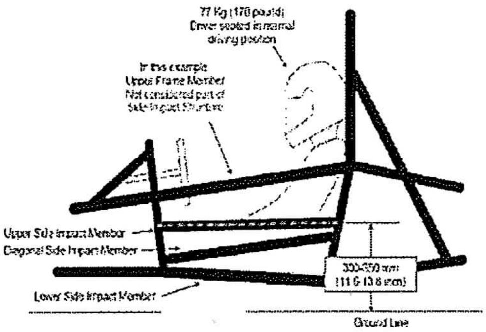
The development of the new UTeM race car chassis started with the evaluation of the rules and regulations as stated by the 2010 UTeM Formula Varsity organizer. It is very important that all the rules and regulation are followed by designers to avoid penalties by the organizer later during the event which could lead to disqualification of the car from the event. Among the rules and regulations that govern the final chassis design are as follows [1]:-

i. Rule 3.0: The car must have only 1 seat, located at the center at the width of the car
ii. Rule 5.3: Except for the rollover structure, no part of the car can be higher than 900mm from the ground. However, any part of the rollover structures more than 900mm from ground must not be shaped to have significant aerodynamic influence on the performance of the car.
iii. Rule 10.1: Main Frame Body - The main frame must be space-frame tube construction, with engine positioned at the centre of the car at the back of drivers. Any kind of monocoque for the main frame construction is prohibited. Main frame must consist of ferrous metal as the basic material. The paint scheme is not restricted.
iv. 10.2.1 Cockpit Opening - The opening giving access to the cockpit must allow the horizontal template, shown in Drawing 1, to be inserted vertically, from above the car into the survival cell and bodywork, with the steering wheel, steering column, seat and all padding removed. The forward extremity of the cockpit opening must be at least 50mm in front of the steering wheel. The driver must be able to enter and get out of the cockpit without it being necessary to open a door or remove any part of the car other than the steering wheel or cockpit padding. Sitting at his steering wheel, the driver must be facing forward. On both sides of the cockpit, two impact beams must be installed.
v. 10.10 Roll Structure - The basic purpose of safety structures is to protect the driver. This purpose is the primary design consideration. The chassis must include both a main hoop and a front hoop as shown in Drawing 2. The main hoop and front hoop design must be integrated into the chassis design.

Descriptions related to Drawing 1 and Drawing 2 as stated in the design Rule 10.2.1 and Rule 10.10 above are shown in Fig. 1 and Fig. 2 below.



(a)



(b)

Figure 1. (a) Cockpit opening, (b) Side impact structure

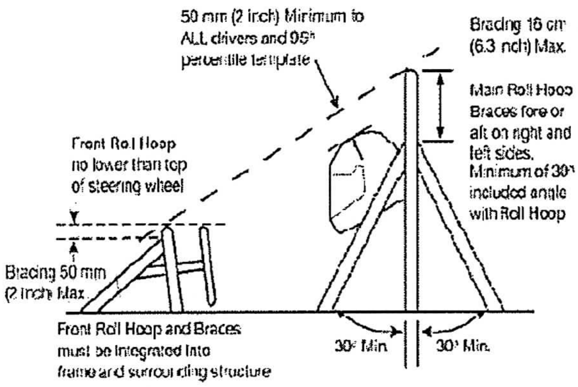


Figure 2. Roll structure

After examining the rules and regulation set for the chassis design, three concept designs for the new chassis was developed and modeled in 3D using CATIA V5R16 CAD software. Concept selection method as proposed by Sapuan et al. (2009) was used to select the final design of the chassis [2]. The final chassis design selected is shown in Fig. 3 below.

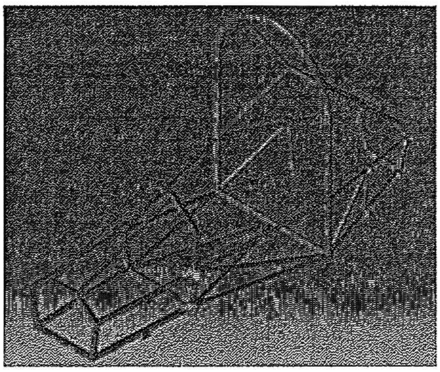


Figure 3. 3D model of the final chassis design

From Fig. 3, it can be seen that the new UTeM race car chassis can be distinctly divided into 3 main sections, which are the front bulkhead, driver's cockpit and the engine bay. The front bulkhead is design to place several key systems such as front suspension, steering mechanism, and the pedal components. The driver's cockpit shall host the driver's seat, gear pedal, steering wheel and main control panel. The engine bay compartment at the rear end of the structure shall accommodate the motorcycle engine and fuel tank, drivetrain system, rear suspension system and brake system. Thus, the load distribution of the new chassis is estimated to be 40:60 for the front and rear section. Another main feature of the chassis that can be seen is the main roll hoop, front roll hoop and the side impact bars of the race car as required in the design rules and regulations.

III. CHASSIS CONSTRUCTION MATERIAL

As stated in the Formula Varsity 2010 technical specifications, the chassis material is only allowed to be constructed from ferrous metals as the basic material. Thus, low carbon steel A36 was selected as the material for the chassis construction due to low cost, ease of manufacturing and good structural properties. Table 1 below shows in detail the material properties for the A36 low carbon steel.

Table 1. A36 low carbon steel material properties [3]

Material Properties	Value
Density (kg/m^3)	7860
Yield Tensile Strength (MPa)	250
Ultimate Tensile Strength (MPa)	400-550
Modulus of Elasticity (GPa)	200
Poisson's Ratio	0.266
Composition:	
Carbon, C	0.260 %
Copper, Cu	0.20 %
Iron, Fe	99.0 %
Chromium, Cr	-

Manganese, Mn	0.75 %
Phosphorous, P	≤ 0.040 %
Sulfur, S	≤ 0.050 %

IV. CHASSIS STRUCTURAL ANALYSIS

The designed chassis was later analyzed to determine its structural performance for the race event. In the 2010 Formula Varsity event, every race car must be able to complete 1.6 km race track for the total of 30 laps without failure. Thus, the chassis integrity to adhere the forces subjected to it is very crucial not only to achieve success for the race, but also most importantly be able to provide safety to the driver inside the car. This is more crucial since every car in the event is driven with maximum speed it could achieve with maximum load that the car carries along with it.

The new UTeM race car chassis was analyzed using CATIA V5 Generative Structural Analysis module, in both static bending and torsion condition. Based on the CAD data, the predicted weight of the chassis was found to be 31.76 kg.

The analysis started with calculating the load subjected to the chassis. Based on the data for the previous 2010 UTeM Formula Varsity race car, a maximum mass of 300 kg (with driver and fuel) or 2943 N was used in the analysis. Using load distribution of 40:60 for the vehicle, the load subjected at the front section of the car is 1177.2 N while for the rear section, the load subjected is 1765.8 N. Thus, each tyre at the front section is subjected to 588.6 N of force while for the rear section each tyre is subjected to 882.9 N of force. These values were later applied in the structural analysis.

In static bending condition, the chassis is subjected to the total weight of the car. The aim is to determine the maximum stress subjected to the structure. Fig. 4 and Fig. 5 below show the boundary condition used and result of the static bending analysis conducted.

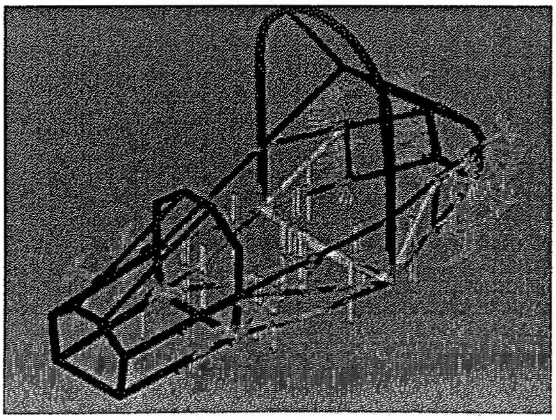


Figure 4. Load and boundary conditions position for bending analysis of the new chassis design

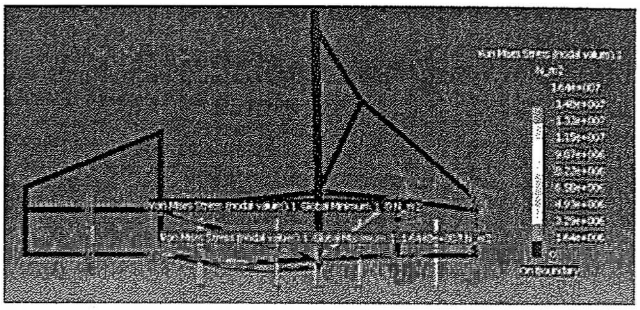
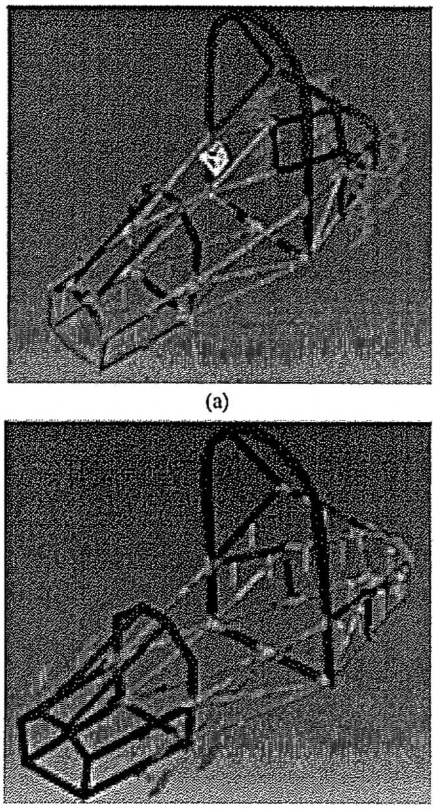


Figure 5. Static bending results of the new chassis design

Meanwhile, for the torsion condition, the analysis was done separately for the front and rear section of the chassis. Thus different set of load and boundary conditions are applied during the analysis as shown in Fig. 6 below.



(a)

(b)

Figure 6. Load and boundary conditions position for torsional analysis of the new chassis design (a) front, (b) rear

From the analysis, the maximum displacement of the structure was taken to calculate the chassis torsional stiffness. The chassis torsional stiffness value is determined using Eq. (1) below while Fig. 7 shows the free body diagram of the chassis for torsional stiffness calculation done.

Torsional Stiffness, $K = \frac{F.L}{\tan^{-1}\left(\frac{\Delta y_1 + \Delta y_2}{2L}\right)}$ (1)

where F = force applied on suspension point (N)
L = distance from suspension point to centre line of chassis (front view) (m)
Δy_1 = displacement of suspension point 1(m)
Δy_2 = displacement of suspension point 2 (m)

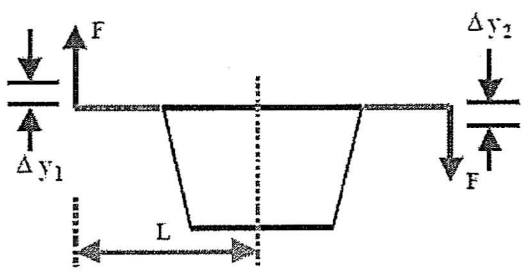
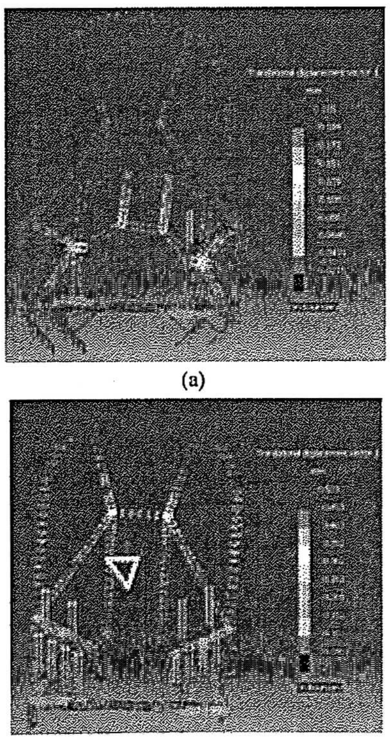


Figure 7. Free body diagram for torsional stiffness calculation

Results of the torsional analysis are shown in Fig. 8 below.



(a)

(b)

Figure 8. Torsional results of the new chassis design (a) front, (b) rear

Thus, using Equation 1, the torsional stiffness can be determined and all results of the structural analyses are shown in Table 2 below.

Table 2. Overall Result for the Chassis Structural Analysis

Analysis Parameters	Front	Rear
Torsion load, $F_{\_Torsion}$(N)	588.6	882.9
Bending load, $F_{\_Bending}$ (N)	2943	
Material used	Low carbon steel (A36)	
Density, ρ (kg.m^{-3})	7860	
Ultimate tensile strength, S_{uts} (MPa)	400	
Yield strength, S_y (MPa)	250	
Modulus Young, E (GPa)	200	
Maximum deflection due to torsion, δ (mm)	0.215	0.503
Torsional stiffness, K (Nm.deg^{-1})	4874.50	5552.36
Maximum Von Mises stress due to bending, σ (MPa)	16.45	
Factor of Safety$_{_Bending}$	15.1	

Based on results in Table 2 above, it can be seen that the maximum stress subjected to the chassis is below the maximum yield strength of the low carbon steel material, thus indicate that the structure is able to perform safely without failure. Factor of safety of 15.1 for the new chassis design in bending condition is also relatively acceptable for the intended application.

A part from that, the torsional stiffness of the chassis for front and rear section was found to be 4874.5 Nm.deg^{-1} and 5552.36 Nm.deg^{-1} respectively. Compared to the previous 2010 UTeM Formula Varsity race car which has torsional stiffness of 4415.189 Nm.deg^{-1}, the new chassis design is 9.5% stiffer than its predecessor. The analysis also shows that the new UTeM race car chassis that was developed have acceptable torsional stiffness values such as suggested by Miliken and Miliken [4] where in design practice, the torsional stiffness recommended range is from 3000 lb.ft.deg^{-1} (or 4068 Nm.deg^{-1}) for small race car to 12,000 lb.ft.deg.$^{-1}$ (or 16,272 Nm.deg^{-1}) and above for a Formula 1 race car. The high value of torsional stiffness for both chassis is valuable to gain best handling performance when the value is high enough to be approximated as a rigid structure. This is because a chassis that flexes is more susceptible to fatigue and subsequent failure and suspension compliance may be increased or decreased by bending or twisting of the chassis [5].

V. CONCLUSION

In conclusion, a new design of space frame chassis for UTeM Formula Varsity race car was developed in this project. Simulation on the structural performance of the chassis showed in both bending and torsion condition showed that the chassis structure is able to perform safely for the intended application as per design requirement. The use of computational engineering analysis (CAE) tools in the design stage in the project also helps to speed up the overall project development and is a very useful tool for designers in executing such similar projects in the future.

ACKNOWLEDGMENT

The authors would like to express sincere thanks to Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka for giving endless support throughout this project and special thanks to the crew members of the UTeM Formula Varsity racing team.

REFERENCES

[1] http://www.formulavarsity.utem.edu.my, retrieved online on April 2011.

[2] S. M. Sapuan, K. W. Ham, K. M. Ng, C. K. Woo, M. K. A. Ariffin, B. T. H, T. Baharudin, A. A. Faieza, E. E. Supeni, and N. A. A. Jalil (2009). "Design of composite racing car body for student based competition". Scientific Research and Essay. Vol.4. No 11. pp. 1151-1162.

[3] Cambridge Engineering Selector (CES) EduPack 2010 software, Granta Design

[4] W. F. Miliken and D. L. Miliken. *Race Car Vehicle Dynamics*, Society of Automotive Engineers Inc., pp. 673-667. Warrandale. 1995

[5] R. Abrams (2008). "Formula SAE Race Car Analysis: Simulation & Testing of the Engine as a Structural Member", FISITA World Automotive Congress (Student Congress Section), F2008-SC-005.