

Design of the Space Frame Racing Car Front Clip and Rear Clip for Torsional Rigidity

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Abstract

To improve the speed performance in a racing car industry, the need to use a latest development on computer modeling and simulation to assist the race car design has been increased recently in the past years. In this paper, the Computer Aided Engineering (CAE) technology was applied to design and to analyze the structural members of the space frame front clip and rear clip which greatly dominate the handling performance of a racing car. Various modifications of the front clip and the rear clip structures were carried out along with a designed cockpit. The optimum design was then identified based on the torsional rigidity and the torsional rigidity per weight ratio determined from the Finite Element Analysis (FEA) technique. The final design of a spaceframe racing car was determined using these optimized parameters. The selected structure provides great improvement on the torsional rigidity and the torsional rigidity per weight ratio leading to better racing car performance.

1. Introduction

Handling performance of a race car is mostly accounted on a torsional rigidity of a chassis, a suspension geometry, and weight. Increased torsional rigidity of a race car chassis improves vehicle handling by allowing the suspension components to

control a larger percentage of a vehicle's kinematics [1].

By using a spaceframe chassis in a race car, the high torsional rigidity can be achieved as well as its light weight. The torsional rigidity of a spaceframe can be increased by placing more frame members strategically. Nevertheless, the weight of the spaceframe chassis is increased as additional frame members are installed. Race car designers must optimize those two parameters to yield the optimum performance of their race car.

The main goal of this study is to develop a method of improving a race car spaceframe chassis. The research specifically focuses on the front clip and the rear clip structures. In order to achieve this task, the chassis design principle will be studied. Various modifications of the front clip and the rear clip structures models will then be created using the Computer Aided Design (CAD) software. Next, the torsional rigidity of the chassis models will be evaluated using the Finite Element Analysis (FEA) technique. Finally, the final chosen design of the spaceframe front clip and rear clip will be proposed by the maximum value of the torsional rigidity per weight ratio.

2. Chassis Description

The main components of the spaceframe chassis are a front clip, a cockpit and a rear clip as

depicted in Figure 1. The standard cockpit consists of a chassis floor, a roof, side bars, front and rear firewalls as shown in Figure 2.

In this study, the circular tube members with a specified outside diameter of 38 mm and a wall thickness of 2.3 mm are used for a roof, front and rear firewalls and side bars of the designed cockpit. The chassis floor is constructed using 50.8 x 50.8 mm square tubes with 2.3 mm thickness.

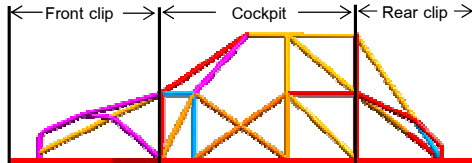


Figure 1. Example of chassis main components.

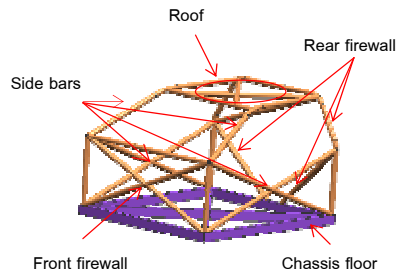


Figure 2. Cockpit components.

3. Chassis Design Principle

The fundamental principle of a chassis design states that the chassis is to be designed to achieve adequate torsional rigidity and light weight in order to achieve a good handling performance of a race car.

Torsional Rigidity (TR) is an ability to resist twisting force or torque. In the other words, torsional rigidity is the amount of torque required to twist the frame by one degree (See Figure 3.).

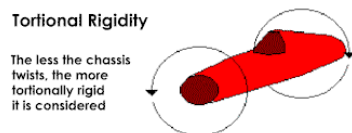


Figure 3. Torsional rigidity on a race car chassis [3]

By strategically positioning a frame member, torsional rigidity increases remarkably. The principle is to place the frame members in a triangulated format as shown in Figure 4.

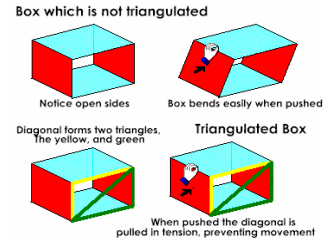


Figure 4. The strategy on positioning a spaceframe member [3].

The triangulated box imparts strength by stressing the diagonal in tension and compression [6]. The box is no longer easily deformed by bending force. Therefore, race car chassis designers usually design their spaceframe chassis in triangulated format. Figure 5., 6., and 7. show the triangulated spaceframe chassis from various race car manufacturers.

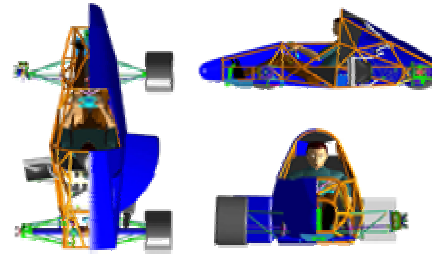


Figure 5. Example of a spaceframe chassis from Mracing [4].



Figure 6. Example of a spaceframe chassis from Juno Racing Ltd. [5].

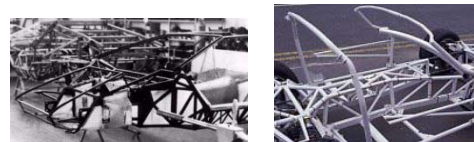


Figure 7. Example of a spaceframe chassis from AutoZine Technical School [6].

As mentioned before, the weight of the spaceframe chassis is increased as more frame members are installed. The torsional rigidity per weight ratio (TR/W) is then calculated to assist in selecting appropriate combinations of additional spaceframe members.

4. Determination of the Torsional Rigidity

The actual torsional rigidity of a completed chassis can be measured by twisting a frame with a known torque as shown in Figure 8. The torque is generated by actuators attached to the frame rails at a point in the vicinity of the front suspension pick-up points. The rear suspension spring mounts are fixed to the fixtures that bolted to the ground while the torques are applied. The displacement at the point that attaches to the actuator is then measured by a dial gauge.

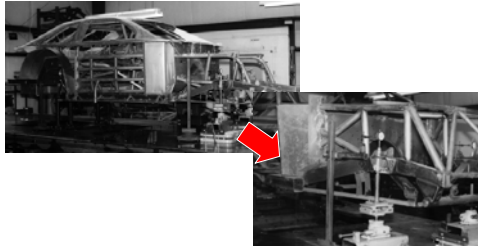


Figure 8. Practical method of determining the torsional rigidity of a spaceframe of a NASCAR chassis [4].

After collecting the empirical displacement data, the torsional rigidity of a spaceframe can be found as stated in equations (1) and (2) [1], [2].

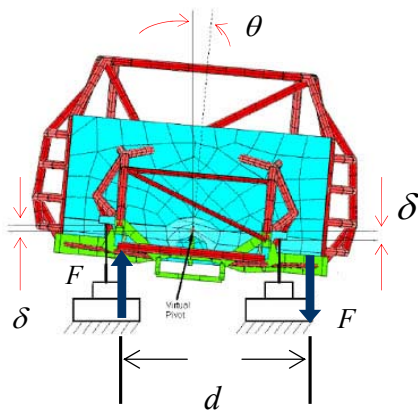


Figure 9. Force diagram for a torsional rigidity.

$$TR = \frac{Fd}{\theta} \quad (1)$$

TR = Torsional Rigidity (N-m/degree)

F = Reaction force (N)

d = Lateral distance between left and right supports (m)

θ = Twist angle (degree)

and

$$\theta = \frac{2|\delta|}{d} \times \frac{180}{\pi} \quad (2)$$

δ = Displacement at the point that the reaction force is applied (m)

5 Finite Element Analysis of a Spaceframe Chassis

The initial chassis geometry was constructed using Unigraphics NX2. The geometry was then converted to IGES format and transferred to ABAQUS 6.4.1 to create a finite element model. The coordinate system is defined such that the positive x-axis is directed toward the rear, the positive y-axis is directed toward the left along the front lateral cross-member, and positive z axis is perpendicular to this x-y plane directed up. Linear beam elements are chosen to model the floor frame member with box-beam cross-section. The tube members are modeled using straight pipe elements with circular cross-section. Figure 10. shows the finite element model of the initial spaceframe chassis. The chassis model was constructed of steel with material properties given in Table 1.

Table 1. Material properties of a spaceframe

Modulus of Elasticity	207 MPa
Poisson's Ratio	0.3
Weight Density	7800 kg/m ³

In addition, the following assumptions are applied for the chassis model [1]:

- Contact of tube members of the chassis, which may be created by deflection and, as a result, would interfere with the normal deflection of those members is ignored in the FE model [1]

- Tube and beam connections were assumed under the usual structural frame assumptions of neutral axis intersection, with full coupling of shear and moments [1].
- The material is assumed linearly elastic and calculations are performed using linear static analysis with small deformations resulting in the constant torsional rigidity prediction [1].

6 Chassis Torsional Rigidity Analysis

In order to evaluate the torsional rigidity of the chassis, the specified structural boundary conditions are applied to the model as shown in Figure 10.

- A torque is applied to the front suspension pick up points by applying equal and opposite vertical forces on the frame rails at a point in the vicinity of the front suspension pick-up points on the driver's and the passenger's side. A force $F = \pm 3400$ N is applied producing a torque, $T = Fd = 1598$ N-m, where $d = 0.47$ m, is the lateral distance between the driver and the passenger load application points.
- At the rear suspension spring mounts, the chassis is restrained in all x, y and z translations ($U_x = U_y = U_z = 0$) and in lateral and vertical rotations ($\theta_y = \theta_z = 0$), with no constraints on longitudinal rotation at these points (θ_x is left free) [1], [2].

These boundary conditions are the representative of constraints applied by a twist fixture used by several race car teams to measure torsional rigidity [1], [2].

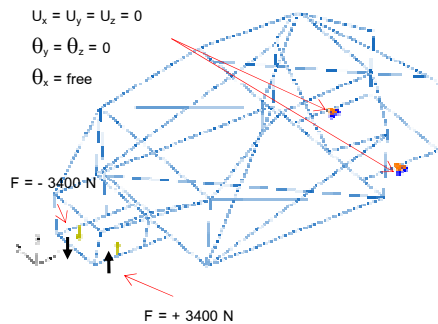


Figure 10. Applied forces, torque and the restraints used to twist chassis models.

Using ABAQUS 6.4.1 to solve the initial chassis model with those boundary conditions and constraints, the result revealed that the displacement in z direction of a point in the vicinity of the front suspension pick-up points was 1.3213 mm, producing 4962 N-m of a torsional rigidity and 40.40 of a torsional rigidity per weight ratio where the weight of the chassis was 122.80 kg.

7. Torsional Rigidity of Alternative Cockpit Design

Using the chassis design principle as a previously described, various structural modifications applied to the initial design of a cockpit spaceframe are considered with the objective of an increased torsional rigidity. A total of eight design combinations of front clip and rear clip are considered in this study, leading to the selection of a final design with significantly increased torsional rigidity yet only a small increase in weight.

7.1 Front Clip

A total of four front clips were proposed for torsional rigidity per weight ratio comparison (See Figure 11.). The predicted torsional rigidity and torsional rigidity per weight ratio were shown in Table 2. It is noted that the front clip2 has the highest value of TR/W of 59.60. N-m/degree/kg.

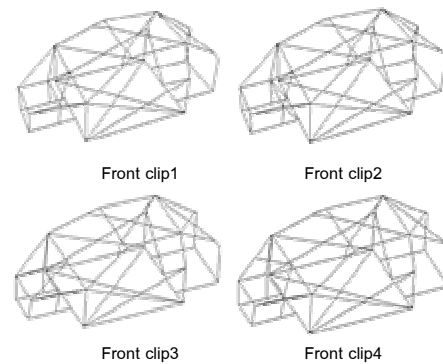


Figure 11. Alternative front clips modified from the initial spaceframe chassis.

Table 2. Torsional rigidity and torsional rigidity per weight ratio of the alternative front clips

	Weight (kg)	TR (N-m/degree)	TR/W (N-m/degree/kg)
Front clip1	124.71	7306	58.58
Front clip2	126.44	7536	59.60
Front clip3	126.10	6765	53.65
Front clip4	125.33	5606	44.72

7.2 Rear Clip

Four rear clips were evaluated for torsional rigidity per weight ratio comparison (See Figure 12.). The predicted torsional rigidity and torsional rigidity per weight ratio were shown in Table 3. It is noted that the rear clip4 has the highest value of TR/W of 40.23 N-m/degree/kg.

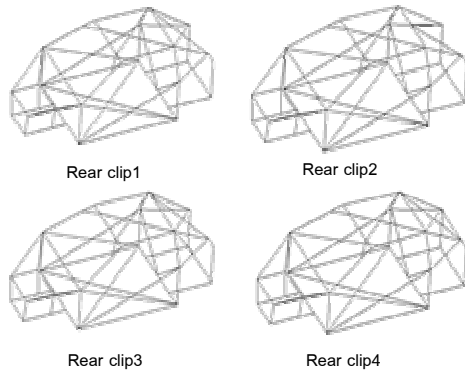


Figure 12. Alternative roofs modified from the initial spaceframe chassis.

Table 3. Torsional rigidity and torsional rigidity per weight ratio of the alternative rear clips.

	Weight (kg)	TR (N-m/degree)	TR/W (N-m/degree/kg)
Rear clip1	125.81	5052	40.15
Rear clip2	124.70	4953	39.72
Rear clip3	127.86	5065	39.61
Rear clip4	127.23	5118	40.23

8. The Final Design of a Spaceframe Racing Car

Each of alternative components of the chassis was selected by choosing the models that yield maximum torsional rigidity per weight ratio. The selected components are chassis types of rear clip2, and rear clip4. Figure 13. shows the final design of a spaceframe that gives the torsional rigidity of 7966 N-m/degree with the chassis weight of 130.88 kg based on those selected combination.

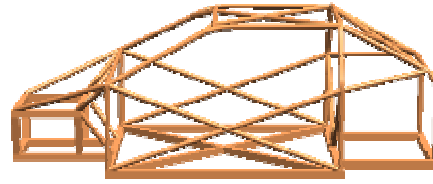


Figure 13. The final design of a spaceframe racing car.

9. Conclusions

In this research, the CAE technique was applied to assist a design of a spaceframe racing car front clip and rear clip. The torsional rigidity and torsional rigidity per weight ratio of the spaceframe structure were considered as key parameters. The final proposed structure yields a torsional rigidity of 7966 N-m/degree and weight of 130.88 kg which give a ratio of torsional rigidity and weight of 60.87 N-m/degree/kg.

10. References

- [1] Lonny L Thomson, et. al., "Design of a Twist Fixture to Measure the Torsional Stiffness of a Winston Cup Chassis", SAE Paper No. 983054, Motorsports Engineering Conference and Exposition, Dearborn, Michigan, November 16-19,1998.
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