# Improving car chassis stiffness

## Introduction

The purpose of the project is to increase the stiffness and reduce the weight of the existing car chassis, without disturbing the shape provided for engine mountings and driver's space and other constraints provided by the existing chassis model.

## Why is it so important to increase the stiffness and reduce the weight of the chassis?

In general to define chassis in this way, first a clear meaning of structure should be known. In general perspective a structure can be defined as a specific arrangement of material to resist loads. This structure should also enable to the location of the components such as engine mountings, transmission, fuel tank, suspension system etc.

So it must resist loads without breaking, and without more deflection. If the chassis cannot resist loads it leads to a serious handling problems, and will not support the engine and transmission system, also the chassis should be light enough to maintain weight to power ratio and better handling in corners.

## 1. 1 Background to project

The principle loads that includes on the chassis are, by the engine, the aerodynamics, brakes, road irregularities, the inertia loads due to masses under accelerations and vibrations. Also the chassis must with stand impact loads, having absorbed part of crash energy by deformation which includes the bending, torsion, combined bending and torsion, also lateral and longitudinal loads. So the chassis structure should be strong in stiffness in design case rather than strength.

The chassis and body developments should also reduce weight because it improves the vehicle ride, handling, improves the performance of car by reducing the drag because of high weight to power ratio, and also will reduce the need for power there by increases the fuel efficiency. Because of this now even mass produced passengers cars lightened up by the most detailed weight-watcher engineering techniques due to corporate Average Fuel Economy (CAFE) regulations of the federal government. Lighter vehicle requires less power, hence less fuel, for equal performance.

## History

The demand for the chassis with high torsion stiffness and low weight had increased from the World War 2. This demand had led to the innovation of many kinds such as Space frame, stressed skin etc. These types had become universal among the European road race cars following its appearance in the Lotus MK and the Mercedes-Benz 300SL in 1952. These are the cars which used strictly space frame chassis and the attention they received had popularized the idea.

Major automobile industries in present era are purchasing the competitive vehicles and disassembled them carefully to study the weight and stiffness of car for comparison with the equivalent part of their own vehicle. So this lead to a competitive reasons than for increase fuel economy.

Today have been included to expand the following three reasons:

- A means for recognising opportunities for overall weight reduction for better fuel economy.

- The means for determining centre of gravity (CG) location and polar moment of inertia.
- Detail weight estimates provides target figure of cost estimates of all parts.
- To resist inertial loads under accelerations, accidents etc.

## Structural efficiency

A designer can achieve enough stiffness for a chassis from any form of construction, if enough material is used. This is not the criteria of a designer, to assess the efficiency of structure its stiffness must be considered in relation to the weight. The below shows the absolute increase in stiffness achieved in recent years is the increase in stiffness to weight ratio.

| Vehicle | year | Torsional stiffness(lb-ft/degree) | Structure weight (lb) | Stiffness/weight ratio |
|---|---|---|---|---|
| Lotus 21 F1 | 1961 | 700 | 82. 0 | 8. 5 |
| Lotus 24 F1 | 1962 | 1, 000 | 72 | 13. 9 |
| Mc Laren F1 | 1966 | 11, 000 | Na | Na |
| Lotus 79F1 | 1979 | 3, 000 | 95 | 31. 6 |

| | | | | |
|---|---|---|---|---|
| Lotus 79 F1 | Late 1979 | 5, 000 | 85 | 58. 8 |
| Lotus F1 | 1980 | 10, 000 | 75 | 133. 33 |
| Lola F1 | 1993 | 30, 000 | 80 | 375 |

Table1: Demand for increase in structural efficiency.

## Literature Review

### Introduction:

The loads that are experienced on a chassis are light commercial loads due to normal running conditions are considered. That is caused as the vehicle transverses uneven ground as the driver performs various manoeuvres. Basically there are five load cases to consider.

Bending case.

Torsion case.

Combined bending and torsion case.

Lateral loading.

Fore and aft loading.

### 2. 1. 1. Bending case

This type of loading is caused due to the weight of components distributed along the frame of the vehicle in the vertical plane which causes the bending about y-axis.

The bending case depends mainly on the weight of the major components in the car and the payload. First the static condition is considered by determining the load distribution along the vehicle. The axle reaction loads are obtained by resolving the forces and by taking the moments form the weights and positions of the components.

### 2. 1. 2. Torsion case

The vehicle body is subjected to the moments applied at the axels centrelines by applying both upward and downward loads are at the each axle in this case. Because of this it results in a twisting action or torsion moment about x-axis of the vehicle.

The condition of pure torsion does not exist on its own because of the vertical loads always exist due to gravity. However for the calculation purpose the pure torsion is assumed. The maximum torsion moments are based on loads at the lighter loaded axle, its value can be calculated by the wheel load on the lighter loaded axle multiplied by the wheel track. The loads at the wheels are shown in the above figure. So the torsion moment is given as:

$R_F t_f = R_R t_r$

2 2

Where $t_f$ and $t_r$ are front and rear track respectively and $R_f$ and $R_r$ are front and rear loads. These loads are based on the static reaction loads but dynamic factors in this case are typically 1. 3 for road vehicles (Pawlowski, 1964).

### 2. 1. 3. Combined bending and torsion

In practice the torsion will not exist without bending as gravitational forces are always present. So the two cases must be considered when representing a real situation.

Fig3: combined bending and torsion.

### 2. 1. 4. Lateral loading

This type of loading is experienced by the vehicle at the corner or when it slides against a Kerb, i. e. loads along the y-axis. The lateral loads are generated while cornering at the tyre to ground contact patches which are balanced by the centrifugal force $MV^2 / R$, M stands for vehicle mass, V vehicle velocity , R is the radius of the corner.

The disaster occurs when the wheel reactions on the inside of the turn drop to zero, that means that the vehicle ready to turn over. In this case vehicle will be subjected to bending in x-y plane. The condition that applies to the roll over is shown in the below figure and it also depends up on the height of the vehicle centre of gravity and the track. At this particular condition the resultant of the centrifugal force and the weight that passes along the outside wheels contact patch.

And hence lateral acceleration is $V^2/R = gt/2h$

Lateral force at the centre of gravity $MV^2/R = Mgt/2h$.

Front tyre side forces $Y_F = Mgt\, b/2h(a+b)$.

At the rear tyres $Y_R = Mgt\, a/ 2h(a+b)$.

From the lateral acceleration it is clear that it is t/2h times that of the gravitational acceleration. Kerb bumping will cause high loads and will roll over in exceptional circumstances. And also this high loads will cause in the bending in the x-y plane are not critical as the width of the vehicle will provide the sufficient bending strength and stiffness.

### 2. 1. 5. Fore and aft loading

At the time of acceleration and breaking longitudinal forces will come into picture along the x-axis. Traction and braking forces at the tyre to ground contact points are reacted by mass time's acceleration inertia forces as shown in below figure. The important cases such as bending, torsion, bending and torsion will come into play as these determine the satisfactory structure (Pawlowski, 1964).

### 2. 1. 5. 1 Longitudinal loading

At the time of vehicle accelerates or decelerates, the inertia forces are generated. The loads generated can be transferred from one axle to another by the inertia forces as the centre of gravity of the vehicle is above the road surface. While accelerating the weight is transferred from front axle to the rear axle and vice versa at the time breaking and decelerating condition.

To have a clear picture of forces acting on the body a height of the centres of gravity of all structures are required. And it's not so easy to determine. A simplified model considering one inertia force generated at the vehicle centre of gravity can provide useful information about the local loading at the axle positions due to breaking and traction forces.

Front wheel drive, the reaction on the driving wheel is:

RF = Mg(L-a) – Mh(dV/dt)

L

Rear wheel drive, the reaction on the driving wheel is:

RR = Mga + Mh(dV/dt)

L

In braking case the reactions on the axles are:

RF = Mg(L-a) + Mh(dV/dt)

L

### 2. 1. 6. Allowable stresses

From the above discussed loads it is clear that it will induce stresses in all over the structure. So it is important that under the worst load conditions that the stresses induced into the structure are kept to acceptable limits. In consideration of the static loads of a limited amount should give a stress level certainly below the yield stress. If analysed the bending case for a road gong car is considered the maximum allowable stress should be limited as follows:

Stress due to static load ×Dynamic factor ≤ 2/3× yield stress.

The above equation says that under any worst load condition the stress should not exceed 67% of the yield stress. Alternatively the safety factor against yield is 1. 5 for the worst possible load condition.

### 2. 1. 7 Bending stiffness

It is equally important to consider the bending stiffness weather to say the structure is sufficiently strong or not. So an equal and important assessment is given to the structural stiffness. Therefore many designers consider the stiffness is most important than strength. It is possible to design a structure which is sufficiently strong but yet unsatisfactory because of insufficient stiffness. Designing for acceptable stiffness is therefore often more critical than designing for sufficient strength.

For vehicles the bending stress is determined by the limits of deflection of the side frame door apertures. In case of excessive deflection the doors will not shut properly. Local stiffness of floor is also important because it minimises the safety of the passenger.

### 2. 1. 8 Torsion stiffness

If the stiffness is low the driver may feel that the vehicle in front will be shaking with the front wing structures moving up and down. The practical problems of doors failing to close properly will also be seen. A similar thing will be seen in the jacking points that are positioned at the corners of the vehicle. For fast moving cars the torsion stiffness is very important because it may cause serious handling problems. Therefore care should be taken in maintaining sufficient torsion stiffness.

So from the all above dimensions of forces and handling of a vehicle chassis should be stiff enough and also should be less in weight.

### 2. 1. 9 Chassis types

Chassis are classified into several types they are:

Ladder frames.

Cruciform frames.

Torque tube back bone frame.

Space frame.

Monocoque.

In the present era of automotive industry designers are using the space frame and monocoque for the justification of design problems and to sufficient structural stiffness.

### 2. 1. 9. 1 Space frame

A space frame chassis is a development of four tube chassis, both of them look quite similar. But the space frame differs in several key areas and offers very good advantages when compared to the predecessor. A space frame is an arrangement of many straight tubes in which the loads acting are either in tension or compression. The figure below shows the clear idea of a space frame.

But from the above figure it is clear that the diagonal member is pulled in tension when a load is acted on it. This above illustration is the simple idea of the space frame chassis.

This experiencing of loads in either tension or compression is a major advantage. So none of the tubes will be subjected to the load will tend to bend in the middle. Since the space frames are very good in torsion stiffness.

The three dimensional space frame chassis are used for specialist cars such as sports racing cars. This type of vehicle design is used for low volume and mass production as well. In this type of structure it is imperative to ensure that all planes fully triangulated by doing so the beam elements are essentially loaded in tension and compression.

In the space frame welded joints are done it retains bending and torsion at the joints, but to rely on this restrains will render the structure less stiff. The stiffness is provided by the diagonal member subject to direct tension or compression.

### 2. 1. 9. 2 Space frame principles

A space frame is three dimensional arrangements of tubes loaded in pure tension and compression. The joints between them can be replaced by the ball joints without affecting the stiffness. Other important feature is all loads enter and leave the structure at the points of intersection of three or more tubes. The structural elements do not have to be tubes and the joints do not have to be welded. In terms of torsional stiffness the space frame attempts to connect the four spring anchorages so that is impossible to twist the pair without stretching and compressing the tube.

### AIMS

The first thing to undertake this research is to set some basic aims that need to be achieved.

As the aim of the project is stated to reduce the weight and increase the stiffness of existing vehicle chassis. So the main aims are in terms of weight, stiffness, and size.

### 3. 1. Weight

Weight was a main consideration in the research it is very crucial to reduce it to that of original weight. It helps in improving the weight to power ratio, better fuel efficiency and performance.

### 3. 2. Stiffness

It is also another key factor to be considered in the research. The stiffness must be improved to that of existing one in case of torsion, bending.

### 3. 3. Size

Last but not the least, the above reduction in weight and increase in stiffness must be achieved without effecting the size and shape of the chassis. This is important because it should not affect the driver to get in the car, and appearance of the car. And also the constraints set for the positioning of the engine etc should not be changed.

### 3. 4. Requirements

Certain requirements beyond my research boundary and aims are needed to be specified, to make up and achieving success in my research they are:

- The elements in the space frame which should not disturb must be specified.
- The dimensions of the chassis, and the materials used must be specified.
- The specification of the loads on the chassis.
- The original weight of the chassis which is going to be modified.
- The stiffness that chassis must be in terms of torsion, bending.

## Project Objectives

The objectives of the project are:

- To analyse the original chassis, its structure, weight, stiffness, torsion, and materials used.
- Research the characteristics of space frame chassis and discover the effects with respect to vehicle handling and performance in case of bending and torsion loads.
- The benefits and performance of materials when replaced by the original one in terms of weight and stiffness.
- The research should be done with resources available.
- From testing and changing the elements, dimensions other than the constraints in lab, modifying the improvements in chassis.
- Analysing the results to that of the original chassis and comparing.

## Research Questions

- What are the materials used for the chassis construction?
- What are positions in the chassis which should not be disturbed?
- What is maximum allowable weight, stiffness and loads that being subjected by the chassis?
- What will be effect on stiffness and weight if certain elements of the chassis were replaced by the other materials?
- If the diameter and size of the elements were changed what will be the effect on weight and stiffness?

- If the positions of the elements other than the elements which should not be disturbed, i. e. by mix and matching, replacing the positions. What will be the effect on stiffness and weight?
- If the circular tube cross-sectional elements of the chassis in some areas are replaced by square tube cross-sectional elements, what will be the effect on stiffness and weight?

## Research Approach and Design

### 6. 1. Introduction

The problem being researched is quantitative rather than qualitative. It deals in numerical values and variables, predetermined categories, focuses on specific knowledge and control of variables. The approach of this research is different to that of qualitative research which would involve human subjects, questionnaires and interviews. The approach will be analytical which will include experimental analysis, analysing the data, interpreting the results, comparisons etc.

### 6. 2. Approach and design

The research is about how to increase the stiffness and reduce the weight of existing vehicle chassis. The research is based on a lot of literature, experimental design and analysis. It should be well designed, planned and managed to ensure that the results can be analysed, interpreted and presented. Throughout the period of the research a process was followed to produce a successful report on the analysis done with that of the original chassis they are:

- Setting some benchmarks in regarding to the design of chassis.

- Analyse the previous chassis, and getting an idea in terms of stiffness, weight, shape.
- Developing the modelling, and analysing techniques that allows the process to be simple and can be modified easily.
- Gaining the information regarding the dimensions of the chassis from the designers and the areas in the chassis which should not be disturbed in terms of design.
- Looking for the possibility of the new considerations that were not previously included in the design.
- Considering the feedback of the supervisor as the process of the research goes on.

## 6. 3. Experiment design

It includes a statement of problem to be solved. Before going to do the research on the experimental design it is important to consider all points of view of what the experiment is intended to do.

### 6. 3. 1 Response variable

The problem must include reference to at least on characteristic of a unit on which information is to be obtained. Those characteristics are called response or dependent variables. In this research the response variables are weight and stiffness, which are dependent on material, design, etc. In addition to reference of the response variable, some questions should be asked. They are measurements methods, what tools are required to measure the variable? Can variable can be measured accurately or not?

### 6. 3. 2 Independent variables

The variables which control the response variables are called Independent variables. In this piece of work the independent variables are:

- Load on the space frame chassis.
- Material used for the chassis.
- Design of the chassis.
- Size and shape.

The independent variables will be chosen randomly one at a time or by considering more than one independent variable. The response on the dependent are analysed and compared to that of original chassis.

### 6. 3. 3. Design

Before the data is collected and results are drawn, it is important to know how to solve the problem with a limited amount of time and available resources. It is important to note how many observations should be taken, what is the maximum amount of deviation in terms of stiffness and weight in comparable to original one. Also attention is required in handling the independent variables.

### 6. 3. 4. Analysis & comparison

The final step in the experiment is to compare the results of the optimised chassis to that of the results on the original one, and approach the problem by checking and comparing the results. This will be done by the preparation of the graphical displays of the values in terms of weight and stiffness. It's important to make sure that the results are within the prescribed limits. If it's not, follow the investigation again by controlling the independent variables.

### 6. 4. FSAE chassis Rules and Requirements.

There are some rules that must be followed throughout the design and construction of chassis. If these rules are not followed strictly the FSAE car will be eliminated from the competition. The rules that have to be followed are.

- Structural requirements.
- Minimum material requirements.
- Alternative tubing and material.
- Steel tubing requirements.
- Aluminium tubing requirements.
- Composite material requirements.
- Roll hoops requirements.
- Tube frames.

### 6. 4. 1 Structural requirements.

The structure of the vehicle must include two roll hoops, front bulk head with support system and impact Attenuator, and side impact structures.

### 6. 4. 2 Minimum material requirements.

### 6. 4. 2. 1 Baseline Steel Material.

The structure of the car must be constructed with:

Round, mild or alloy, steel tubing (minimum 0. 1% carbon) of the minimum dimensions according to the following table.

| Item or Application | Outside diameter × Wall thickness |
| --- | --- |

| | |
|---|---|
| Main and Front hoops,<br><br>Shoulder harness mounting bar. | inch (25. 4 mm) x 0. 095 inch (2. 4 mm)<br><br>25. 0 mm x 2. 50 mm metric |
| Side Impact Structure, Front Bulkhead<br><br>Roll Hoop Bracing, Driver’s Restraint Harness attachment. | inch (25. 4mm) × 0. 0065 inch (1. 65mm)<br><br>or 25. 0mm × 1. 75mm metric<br><br>or 25. 4mm ×1. 60mm metric. |
| Front bulk head support. | 1. 0 inch (25. 4mm) × 0. 049 inch (1. 25 mm)<br><br>Or 25. 0 mm ×1. 5 mm metric or 26. 0mm × 1. 2 mm metric. |

Table 6. 4. 2: Minimum material requirements. (Source: FAE rules 2008)

### 6. 4. 2. 2 Alternative Tubing and Material

The chassis can be constructed with alternative tubing and material but not for the Main Roll Hoop and Main Roll Hoop Bracing. These must be constructed only with the Steel, to say in other words the use of Composites and other materials such as Aluminium or alloys are strictly prohibited. If the chassis was to constructed with alternate tubing rather than material, the tubing must not be thinner than as shown below.

**6. 4. 2. 2. 1: Minimum wall thickness for steel tubing requirements**

| Material and Application: | Minimum wall thickness: |
|---|---|
| Steel tubing for front and Main Roll Hoops | 2. 0 mm (0. 079 inch) |
| Steel tubing for Roll hoop Bracing, Front bulk head & driver's harness attachment. | 1. 6 mm (0. 063 inch) |
| Steel tubing for side impact structure & front bulk head support. | 1. 2 mm (0. 047 inch) |

**Table 6. 4. 2. 2. 1: Minimum wall thickness for steel tubing requirements**
Source: FSAE 2008 rules.

**6. 4. 2. 3: Aluminium tubing requirements**
Minimum wall thickness:

| Material & Application : | Minimum wall thickness: |
|---|---|
| Aluminium tubing | 3. 0 mm (0. 118 inch) |

Table 6. 4. 2. 3: Aluminium tubing requirements. (Source: FSAE 2008 rules).

**6. 4. 3. Roll Hoops**
The Roll hoop design criteria must justify the following:

**6. 4. 3. 1. Main Hoop**

- The drivers head and hands must not contact the ground in any rollover attitude.

- The frame must include both Main Hoop and Front Hoops
- The Main Hoop must be constructed of single uncut tubing made of steel as per the minimum tubing requirements.
- The use alternate material is prohibited for construction of main hoop.
- The main hoop must extend from the lowest member on one side of the frame, to the down towards the lowest Frame member on the other side of the frame.
- In the side of the car the portion of the attachment of the Main Roll Hoop which lies above the attachment point of the main structure of the frame must be within 10 degrees to the vertical.
- The vertical members of the Main Hoop must be at least 380mm apart at the location where the Main Hoop is attached to the Major Structure of the Frame. In the Front view of the vehicle.

#### 6. 4. 3. 2. Front Hoop

The Front Hoop must be constructed of closed structure of steel as minimum tubing requirements.

The use composite materials are prohibited.

The Front Hoop Frame member must extend from one side of the Frame, to the down over and towards the lowest Frame member on the other side of the Frame.

The top most surface of the Front Hoop should not be below the top of the steering wheel in any angular position.

The front Hoop should be no more than 250 mm forward of the steering wheel when measured horizontally through the vehicle centre line.

No part of the Front Hoop should be inclined at not more than 20 degrees in the side view.

### 6. 4. 3. 3. Main Hoop General Requirements

A straight line drawn from the top of the main hoop to the top of the front hoop must be clear by 50. 8 mm of the helmet of the team’s drivers and the helmet of a 95 $^{th}$ percentile male. When seated normally and restrained by the Drivers Restraint system.

95th Percentile Male Template Dimensions

A two dimensional template used to represent the 95th percentile male is made to the following dimensions:

A circle of diameter 200 mm (7. 87 inch) will represent the hips and buttocks.

A circle of diameter 200 mm (7. 87 inch) will represent the shoulder/cervical region.

A circle of diameter 300 mm (11. 81 inch) will represent the head (with helmet).

A straight line measuring 490 mm (19. 29 inch) will connect the centres of the two

200 mm circles.

A straight line measuring 280 mm (11. 02 inch) will connect the centres of the upper

200 mm circle and the 300 mm head circle.

The 95th percentile male template will be positioned as follows: the seat will be

Source: FSAE rules 2008.

### 6. 4. 4. Front Impact Structure

The driver’s feet are always with in the Major structure of the Frame.

No part of the driver’s feet should be above or outside the Frame in the side and front views, while touching the pedals.

Forward of the Front bulk head must be energy- absorbing Attenuator.

#### 6. 4. 4. 1. Bulk Head

The requirements of the Bulk head in a Front impact structure are:

It should be constructed of closed section tubing.