Design & Analysis of F1 Racing Car using CAE Tools

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Abstract

The main objective of this work is to design and analyze the roll cage of F1 type racing vehicle using CAE tools by taking into account the guidelines as per the SAE SUPRA rule book. The AISI 4130 roll cage is designed and analyzed using Solidworks and Ansys. The roll cage is modeled and analyzed for front impact, side impact, rear impact and roll over. The other parts of the vehicle such as steering, suspension, brakes and power transmission are designed to ensure all the design parameters fulfills the requirements of the vehicle. The design has been checked for high speed and acceleration, lowering drag coefficient, increasing the down force and reduction of weight. IST spring design software is used for calculation & validation of suspension system. The design process was essentially focused on creating a fast and robust vehicle, maintaining the aesthetics within the guidelines of SAE.

Keywords: Frame Design, brakes, CAE, SAE guidelines.

1. Introduction

Earlier design philosophy included manufacturing the product first and than checking for the flaws. The problem so identified in the prototype used to be rectified to overcome those flaws. This process was repeated again and again until a flawless product was manufactured. This process resulted in huge loss of time, resources and manpower. The solution to this problem is Computer Engineering (CAE). Computer Aided Engineering or CAE is usage of computer software to aid in engineering tasks. It includes simulation, validation and optimization of products. It is used in various engineering fields. CAE consist of three phases:

a) Pre-processing – defining the model and factors to be applied to it.
b) Analysis of the model.
c) Post-processing of results

It has major number of advantages such as – less time consumption, no loss of resources, less workforce required, results are closer to the accurate values, etc.

1.1 Requirements of The Vehicle:
    a) Cost of the vehicle
    b) Aesthetics
    c) Endurance or Life
    d) Ease of parts availability for maintenance

e) Speed and Acceleration

f) Good Manoeuvrability

g) Less Weight and Overall Dimensions

h) Low centre of gravity

i) Safety of the driver

j) Good Ergonomics

1.2 Sub-Divisions for Design:

1. Frame Design
2. Brakes
3. Steering
4. Suspension
5. Frame Design Analysis
6. Aerofoil Design & Analysis

1.3 Main Section:

a) Frame Design

The kind of body we are required to manufacture is a unitized body. The frame is of utmost importance for us as it would be the one which would provide safety to the driver, mounting points for various systems and even ergonomics and looks to the vehicle. It should be strong enough to bear the laden load and should be designed against impact load that it might encounter. The failure criterion for the frame is yielding. Our design of the frame started with ergonomic and driver comfort study. We also studied the rules and safety instructions as per SUPRA SAE INDIA 2012 rulebook1. Based on these, we designed a layout which was modified again and again in the software used by Solidworks. The material selected is alloy steel, AISI 4130.

Total length of frame = 2372 mm

Width: Maximum = 1069 mm

Front End = 363.72 mm

Rear End = 670 mm

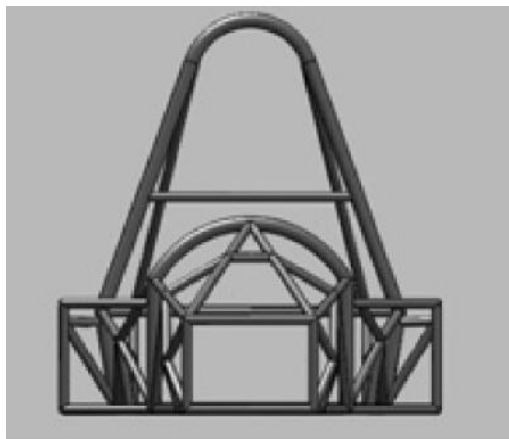Height: 1118.67 mm

Views of Frame
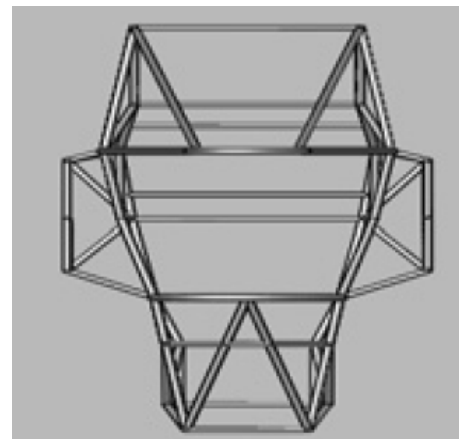

Fig. 1: Roll cage: Front View
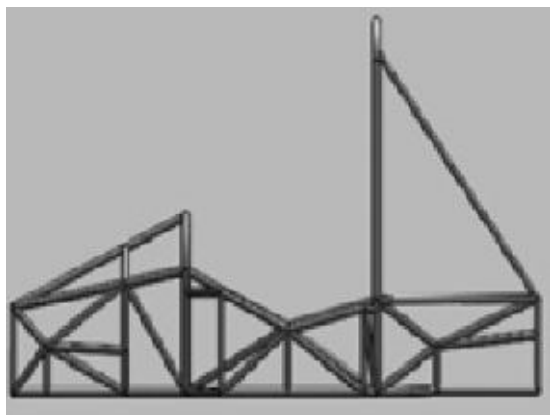

Fig 2: Roll Cage: Top View

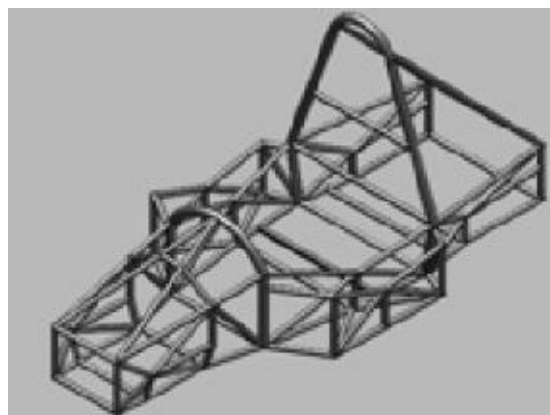**Fig 3: Roll Cage: Side View**

Fig 4: Roll Cage: Isometric View

b) Brakes

It is required to design a brake system for a vehicle of mass of approximately 450kg, maximum speeds of 105 km/hr and average speed of 60km/hr. The brake system must give high performance braking efficiency and stability during operation. The weight and the dimension of the brake system must be as small as possible because of the unsprung weight and inside wheel diameter limitation.

The braking system is made such that there are two master cylinders both for front and rear brakes, although the front and rear brakes are being operated by a single pedal

Table 4: Static load on axles

STATIC LOAD	
Front Axle	180kg
Rear Axle	270kg

Front axle dynamic load $= w_1 + (\alpha \div g) \times W \times (H \div L) \, \alpha$
Rear axle dynamic load $= w_2 - (\alpha \div g) \times W \times (H \div L) \, \alpha$
Where;

w_1 = Weight on the front axle in the static condition.
w_2 = Weight on the rear axle in the static condition.
g = Acceleration due to gravity.
W = Total weight of the vehicle.
H = Height of center of the gravity.
L = Length of the wheel base.
α = Deceleration of the vehicle

Table 5 : Dynamic load on axles

DYNAMIC LOAD	
Front Axle	249kg
Rear Axle	241kg

Hence, it has been found that the load under dynamic conditions the load on the front axle increases and the load on the rear axle decreases. Load has increased from 180kg to 249kg. Also the load on the rear axle decreases from 270kg to 201kg.

Torque developed by the brakes is more than the required therefore this results in locking of all wheels.

c) Steering System
Due to the light weight, low cost and simplicity of Rack & Pinion, we will use Maruti-800 Rack and Pinion. The improved ratio enables the car to have sharp corner, less effort and precise handling capabilities.
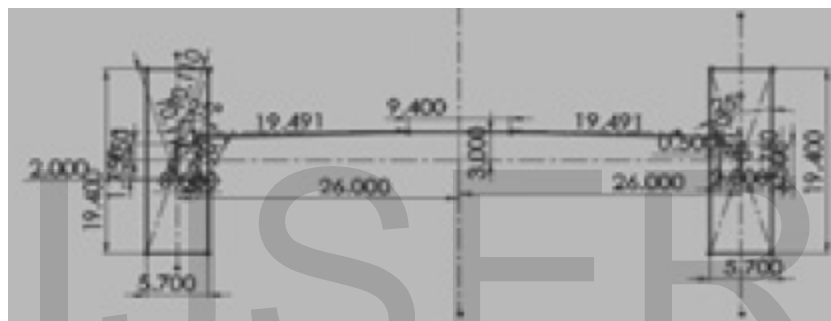

Fig 5: Kinematic model of steering mechanism

No. of teeth on pinion = 6
No. of teeth on rack = 24
Rack length = 137mm
Rack Gain = 34.1504mm
Placement of steering ahead of axle = 3 inches
Steering ratio = 8.2

d) Suspension
Weight distribution ratio = 60: 40(rear: front)
Front suspension = 74 kg approx. (each)
Rear suspension = 111kg. approx. (each)
Load will transfer on front suspension under dynamic conditions of braking and cornering.

Approximately both the springs will have to bear same loads under different driving cycles so both springs are designed under same constraints.

e) Frame Design Analysis
The analysis of the design is carried out in Solidworks to ascertain the safety of the frame when acted upon by the static forces. The stability of the Roll Cage was studied under the impact of

these forces. If deformation is under limit, then our design is safe. The results were in good agreement with Distortion Energy Theory (Von Mises stress theory) [6] .The changes were incorporated accordingly.

- The following tests were done on the frame:
- Front Impact
- Rear Impact
- Roll Over Impact
- Side Impact

Head On Collision; Front Impact

In Front impact test, it was assumed that two bodies of moving in opposite direction of each other collide head on. The force that calculated on the basis of conservation of momentum is

Force = 26244 N

Rear Impact

In this, the impact is acted on the back side of the frame and stresses are induced at the same. The impact forces are calculated on the basis of Conservation of momentum.

Force= 13122N

Rollover Impact

The force used for roll over analysis is dependent on the weight of the vehicle and centre of gravity location.

In analysis we have consider the 3g effect.

Force on front hoop = 8343 N

Force on main hoop = 13230 N

Side Impact

In this type of impact, a body will hit to the frame of the vehicle on its side. The force encountered will be:

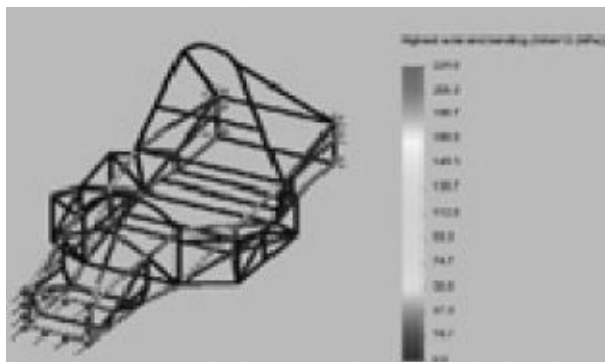Force = 13122 N

Front Impact

Max. Stress induced = 224 MPa   Maximum deformation = 1.5 mm
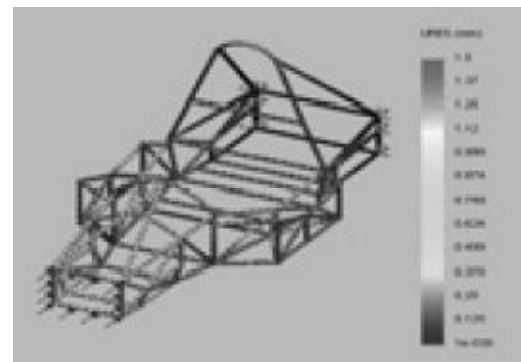

Fig 11: Max. Stress   **Fig 12: Maximum Displacement**

Side Impact

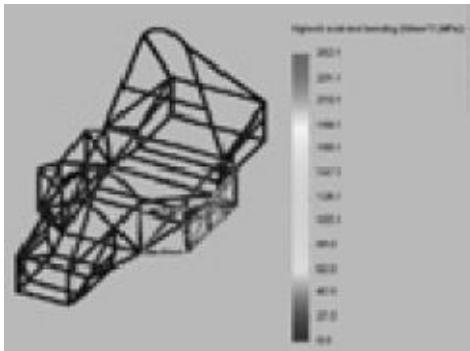Max. Stress induced = 252.1 MPa Maximum deformation = 2.53 mm
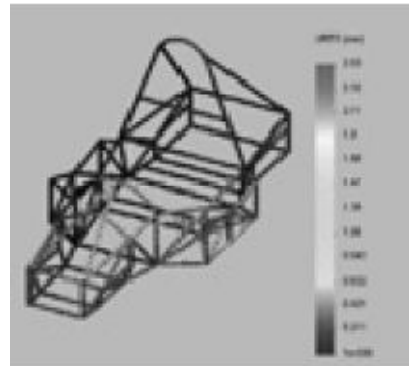
Fig 13: Max. Stress induced

Fig 14: Maximum Displacement

Rear Impact
Max. Stress induced = 248.514 MPa

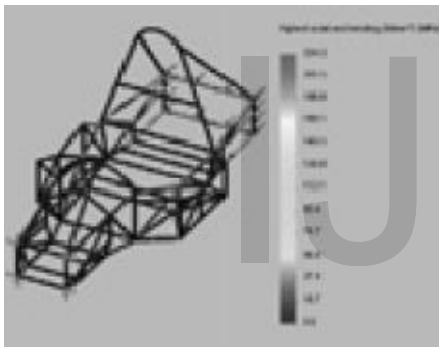**Maximum Deformation = 3.21 mm**

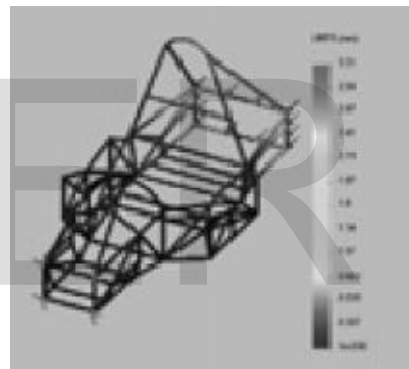**Fig 15: Max. Stress induced**

Fig 16: Maximum Displacement

Rollover Impact

Max. Stress induced = 353.4 MPa

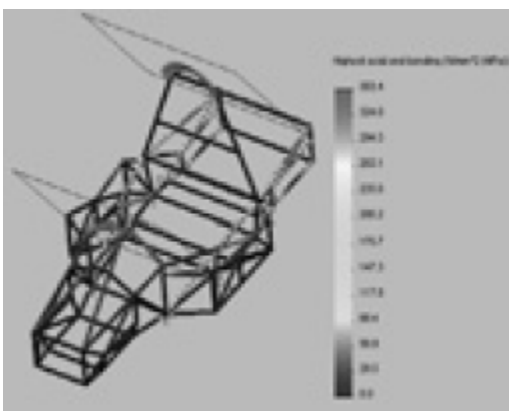Maximum deformation = 5.37 mm

Fig 17: Max. Stress induced
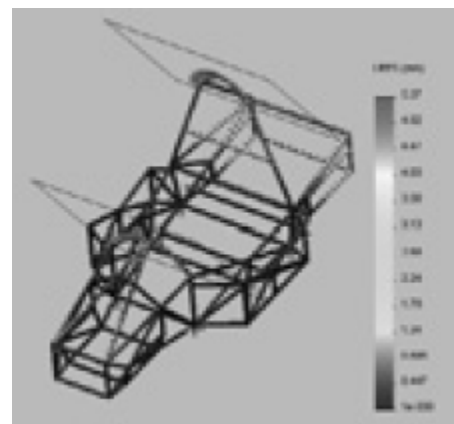**f) Airfoil Design And Analysis**

Fig 18: Maximum Deformation

We have chosen the length of airfoil on the basis of track width and chord length is decided on the basis of h/c ratio where

      h = distance of airfoil from ground

      c = chord length

Distance of airfoil from ground is calculated on the basis of h/c ratio from the Ansys results, we can conclude that drag coefficient is increasingly rapidly from 13 degree of angle of attack, so we have chosen angle of attack to 13 degree for best results.

Fig 19: Velocity Plot

Fig 20: Pressure Plot
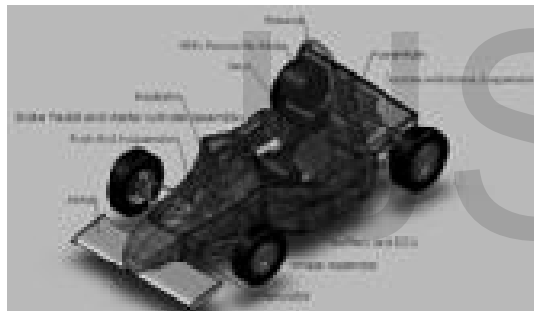
Detailed view of the Vehicle

Fig 21: Detailed View of the vehicle Fig 22: 3-D view of vehicle

1.5 References;

[1] Supra SAE 2018 rulebook

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[6] Strength of Materials by R.K. Rajput

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[10] An Introduction to Modern Vehicle Design, Chassis Design and Analysis………..pp 125-153,
suspension geometry………….pp 288-305

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