Research Paper

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Design and Simulation of Formula Vehicle: The Role of CAE

Engineering

KEYWORDS : Formula car, Simulation, Designing, ANSYS, CATIA, Ergonomics, CAE, Impact Analysis, Pre-Manufacturing Analysis, Vehicle Behavior, Finite Element Analysis

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ABSTRACT

Automobile sector is one of the most blooming sectors now-a-days. With the advent of computer assisted engineering and the blend of classic methodologies combined together to bring the most durable result about pre-manufacturing analysis and design optimization. This paper presents an overview of the role of Computer Assisted Engineering in the Design and Simulation of a Formula Vehicle.

Introduction

The concept of running on four wheels is as a worthy conjugation of technological human brain that has contributed in technological growth and human comfort. The time taken to cover the distance between any two junctions on the land is lowered to considerable extent with the inception of vehicles over the period of time.

1.1 A Brief History of Cars

The credit for the first car ever made – or for the invention of the first car is given to Karl Benz of the Benz car fame. He patented the first car ever made in 1886. However, the car's history goes back much further. Many attempts were made to build a vehicle that would propel itself – and it is said that around 150 BC there is such a reference where Hero of Alexandria thought about using steam power instead of horses. Further, more advance designs were developed, some based on steam engine, some on internal combustion engine working on fuels like petrol, diesel and alike. In 1908, the Ford Motor Company made the first people's car, the Model T, also fondly referred to as the Tin Lizzie. Henry Ford's aim was to make the car available to the common man since the rich were the ones who could afford to own automobiles.

Fig 1. Ford'sT-Model, First People's Car.

1.2 The passion for speed and Formula car

With the successful advent of technology over the period of time, various modification and amendments were observed in the field of automobiles, one crucial parameter to excel with was the speed of the vehicle in order to reduce the time taken as well as to enjoy the man created speed. Soon it became a passion to exhibit the skills and extent of taming the speed of one's vehicle can achieve and this gave birth to the concept of modern formula cars. In modern termology, car racing is a sport which incorporates speed, skill and high end technology blending with the human endeavor. The special car used in this segment is called a formula car and it may be defined as a single-seated, open cockpit, open-wheel racing car with substantial front and rear wings, and an engine positioned behind the driver, intended to be used in competition at Formula One racing events. The regulations governing the cars are unique to the championship.

1.3 A Brief History of Formula Sport

Formula One was first defined in 1946 by the Commission Sportive International (CSI) of the FIA, forerunner of FISA, as the premier single seater racing category in worldwide motorsport to become effective in 1948. It was initially known variously as Formula A, Formula I or Formula 1 with the corresponding "Voiturette" formula being titled Formula B, Formula II or Formula 2. When the 500c formula was internationally recognised as Formula 3 in 1950 it was never titled as "Formula C" so the three International Formulae were "officially" titled Formula 1, Formula 2 and Formula 3. Formula One racing is a testing ground where manufacturers can push automotive engineering to extreme limits in the hopes of achieving breakthroughs. Things like radial tires, traction control, anti-lock brakes and even steering-wheel-mounted paddle shifters then trickle down to cars in the consumer sector.

2.0 Modern Approach and Considerations of a Formula Car

An F1 car can be no more than 180 cm wide and 95 cm tall as described. Though there is no maximum length, other rules set indirect limits on these dimensions, and nearly every aspect of the car carries size regulations; consequently the various cars tend to be very close to the same size.

The car must only have four wheels mounted externally of the body work with only the front two steered and only the back two driven. There are minimum distances allowed between the wheels and the rear and front body work. The main chassis contains a "safety cell" which includes the cockpit, a structure designed to reduce impact directly in front of the cockpit, and the fuel cell directly behind the cockpit. Additionally, the car must contain roll structures behind and ahead of the driver. The driver must be able to enter and exit the cockpit without any adjustments other than removing the steering wheel.

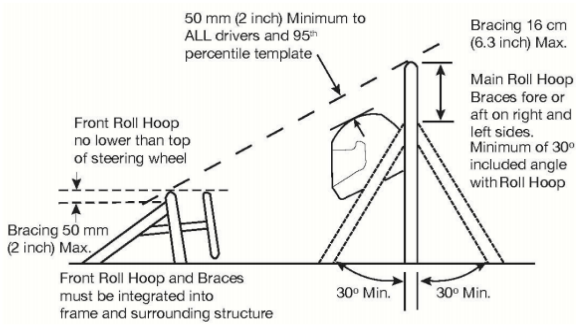

Fig 2. Deign Consideration of the vehicle cockpit.

There are also mandatory crash test standards. There is a 30 mph (48 km/h) head-on impact into a steel barrier; "average deceleration must not exceed 25g", with a maximum 60g for a minimum 3 milliseconds, with no damage to the chassis beyond the nose section. The same chassis must then sustain a rear impact from a sled travelling at 30 mph (48 km/h), with no damage in front of the rear axle. The roll hoop is not permitted to crush beyond 50 mm (2.0 in), and structural failure is only permitted in the top 100 mm (3.9 in) of the body. Side impacts by a 780 kg (1,720 lb) object at 10 m/s (22 mph) must be decelerated at less than 20g, and absorb no less than 15% and no more than 35% of the total energy; 80 kN (18,000 lb_f) cannot be exceeded more than 3 milliseconds. The steering wheel must survive the impact of an 8 kg (18 lb) 165 mm (6.5 in)-diameter object at 7 m/s (16 mph) with no deformation of the wheel or damage to the quick-release mechanism.

In addition, there are "squeeze tests" on the cockpit sides, fuel tank, and nosebox. The cockpit must survive a 25 kN (5,600 lb_f) pressure with no failure; for the fuel tank, 12.5 kN (2,800 lb_f) is applied. A maximum 3 mm (0.12 in) deformation is allowed. For the cockpit rim, the figures are 10 kN (2,200 lb_f) and 20 mm (0.79 in). The nosebox must withstand 40 kN (9,000 lb_f) for 30 seconds without failing.

2.1 Designing
The designing aspect of a formula car depends upon few parameters like the track width, the wheel base, the net permissible height, included with the consideration of adequate area for driver cockpit, engine mounting and passage to all electrical peripheries and mountings. One more crucial aspect that is followed while designing the rollcage, is the consideration of suitable three-dimensional trusses, safe designs like K-truss, Warren-truss, various rules governing the joint-member relation are kept in focus to avoid any tendency of design rupture or failure.

2.2 Simulation
Simulation is done to analyze the pre-manufacturing behavior of the subject like it's nature of rupture during an impact, its frequency behavior during run, various other analysis like torsional analysis, rollover analysis and desired check is implemented so as to achieve a safer design.

2.3 Ergonomics and Comfort Engineering
Safety in a race car is the art of protecting the human occupant, at whatever cost to the car. Designing the car to be damaged minimally while hindering driver safety is definitely the wrong approach, a few point that we have considered are enlisted here;

- Safety of the vehicle and driver has been the prime concern in the whole design process.
- Seat inclined at 20 deg from back and 18 deg from bottom to provide adequate back support.
- Thigh rest provided.
- Foot straight on ABC pedal that require minimum effort.
- Cushion done on back with a decreasing gradient from top to bottom.
- Removable Steering Wheel as in F-1 cars to provide low egress time and easy exit.
- 5- point driver harness is to be used.

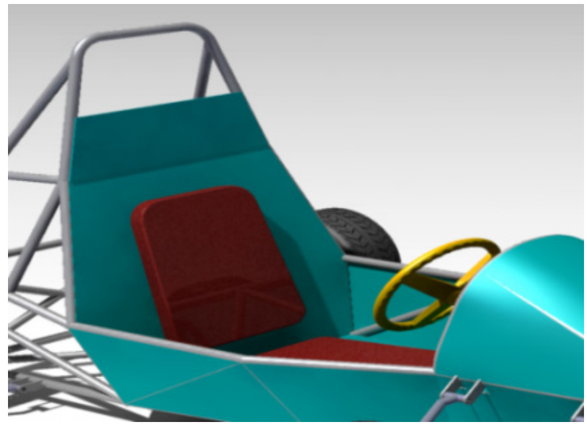

Fig 3. (a) Safe and ergonomic driver cockpit.

(b) Five point driver harness

Ergonomics, or the study of human-machine interfacing, is important to race cars because the ultimate control of the car belongs to the driver. Poorly placed controls mean the driver must lose concentration on the race, and instead focus on the cockpit. The ergonomics of a race car cockpit consist of several elements;

The driver's line of sight - Visibility is of prime importance. The goal in design is to ensure enough of the race track in front is visible, and enough of the action to left and right is visible, through peripheral vision. Of course, the driver also needs to see behind to watch for his/her competition. The mirrors should act as an extension of the visible field.

The steering wheel - The steering wheel is a tool of leverage. If a steering wheel is too far from the driver, the driver's arms will straighten, and ultimately limit the range of motion easily provided. If it doesn't stop the driver from driving properly, this situation will cause fatigue. If a steering wheel is too close, it will also limit the range of motion and perhaps cause interference with other cockpit controls or supports. The proper distance is largely a matter of comfort and clearance, and usually means the arms are bent at the elbows when driving straight, yet still comfortable when turning the wheel.

The gauges - The gauges act as vital signs for the car, and as such should be as close to the driver's normal line of sight when looking forward. Forcing the driver to look down at gauges removes concentration from the race. In Formula 1 (a particularly good example), the RPM is displayed with a series of LEDs (Light emitting diodes) that light as the redline is approached. This light sits almost at the very top of the cockpit, in line with the line of sight, allowing the driver to change gears without ever needing to look down. A technique frequently used in racing is to rotate the gauges so that all needles or indicators are pointed to the directly vertical position when operating normally. The driver does not need to consciously scan the gauges,

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but can instead use his/her peripheral vision to determine the state of the car.

The Pedals - The pedals, like the steering wheel are a leverage item. The driver's legs will tire if not given a position of leverage. Likewise, the driver's legs may tire anyway, due to an inappropriate leverage fulcrum in the actual pedal system. Assuming the pedals and levels are well designed, we can focus on the driver's legs. To be most effective the driver's legs should be bent slightly when the pedals are fully engaged, and should be bent somewhat more when the pedals are not engaged. The calf portion of the leg should probably not be at less than 120 degrees angle in relation to the thigh when the pedals are disengaged.

2.4 Safety in Engineering

Safety in race cars consists of optimizing the chassis and bodywork to provide maximum support for normal driving situations, and maximum protection and energy absorption in crash situations.

First, the driver needs to be supported, so movement under normal driving is very limited. This means a seat with lateral head support, a head rest, and good lower and upper body lateral support. Most racing seats provide these three elements.

Secondly, the car's chassis needs to hold the seat and driver in place, in all situations, driving and crashing. This is of course accomplished with a chassis mount for the seat, and a 5 or 6 point harness.

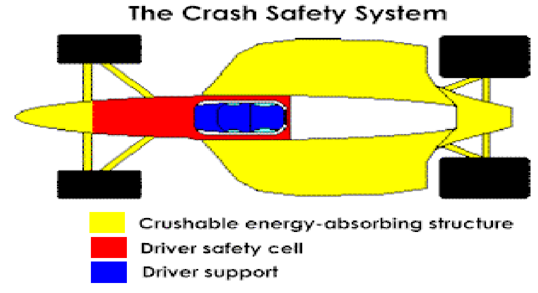


Fig 4. The Crash Safety System.

Thirdly, measures must be taken to prevent intrusion into or the crushing of the driver's limbs and extremities. On formula cars, the problem of suspension wishbones breaking and piercing the driver's legs is solved by anti-intrusion panels that prevent pieces of the car from intruding into the driver's cockpit. As well, the cockpit "Safety cell" needs to be very strong. The "Safety cell" is the last piece of material between danger and the driver, and so should be well constructed, and not prone to collapsing onto the driver.

Finally, the car needs to absorb the energy via structures that are crushable. As stated previously, the human body does not like to be decelerated from 80 or 100 km/h to 0 instantly. Therefore, we need to find a way that "quickly" decelerates the body. The only possibilities on a race car are the structures which surround the driver's safety cell. Designing these structures to collapse in an impact ensures that G levels are reduced because the car is literally decelerating over a small distance, instead of ZERO distance.

3.0 Design Paradigm

After focussing on all the considerations and constrains within which we are supposed to design our formula vehicle, we opt for a commercially available CAD Application software and perform the actual designing process. The designing is based on certain other parameters also like material consideration, vehicle's body aerodynamic and the performance it is supposed to provide.

3.1 Engine used for Designing

The various available engines at our disposal for designing the formula car are;

Solidworks
Catia
PRO-E, etc.

The designers according to their skill in each designing software or engines can select and make use of any of the above engines in order to give shape to the body of the car.

Here we have used **CATIA V5R19** as our preferred engine provided by Dassault Systems.

3.2 Creating a Line

With the lines, we can create a series of contiguous line segments, out of which, each line segment can be edited separately from the other line segment in the series. We can close a sequence of line segment so that the first and last segments are joined. In order to draw the line, we must specify the start point, either in terms of coordinates or cursor and complete the line by specifying the end point in the same manner. When we are finished with the operation, we can press ENTER or ESCAPE to end the continuation and thus a series of line segment is formed.

3.3 Ribbing

Rib is a special type of extruded feature created from open or closed sketched contours. It adds material of a specified thickness in a specified direction between the contour and an existing part. We can create a rib using single or multiple sketches. We can also create rib features with draft, or select a reference contour to draft .

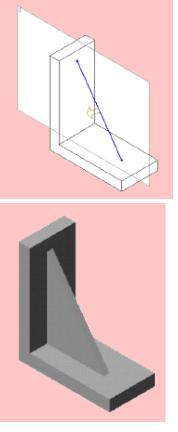


Fig 5. Ribbing of a design in CATIA V5R19.

3.4 Stages of Rollcage Design

The various stages of rollcage design would include drafting the design which is in our mind to paper with pen or pencil and then working along the outlines of the draft on our engine giving it a rough wireframe model and then further working out on the designs and dimensioning and then employing the designing engine CATIAV5R19. The method would flow as;

First of all we draw a rough outline of the vehicle using pencil and paper.

The second stage would be accurately defining the dimensions incorporating the various requirements.

In the third stage, we make the wire frame model of the rollcage using CATIA V5R19.

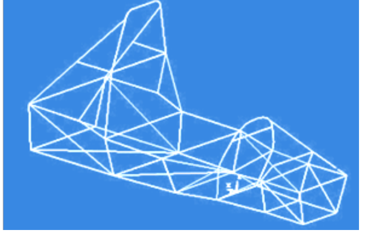


Fig 6. Final Wire Frame Model

In the fourth stage, we rib the wire frame model to get the actual model of rollcage along with the material properties.

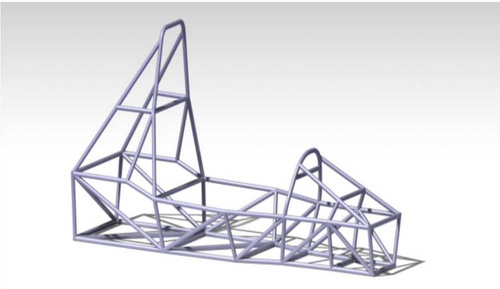


Fig 7. Final Ribbed Rollcage.

4.0 What is Mechanical Simulation?

Simulation of a design helps to predict the end performance, to optimize designs and to validate product behavior before the actual manufacturing; this is so done to minimize reliance on costly physical prototypes and shortens the total time of pre-manufacturing analysis.

4.1 Method

In formation of any engineering design project, we require an analysis which may yield in predictions of the behavior of the design. The analysis may involve stress-strain calculations, heat transfer computations, the use of differential equations to describe the dynamic behavior of the system being designed. The computer system is used to aid the whole process using some specific CAD based application software based on certain techniques. The two major techniques available easily are;

Analysis of Mass Properties
Finite Element Analysis Method

Out of them, the most powerful analysis feature available to any CAD based application software is Finite Element Analysis method. With this method, the object is divided into a large number of finite elements (usually rectangular or triangular shaped) which forms an interconnecting network of concentrated nodes. By using a computer with certain computational capabilities, the entire object can be analyzed for stress-strain and various other characteristics by calculating the behavior of each node as per the type of condition provided. Thus by determining the interrelating behavior of all the nodes in the system, the behavior of entire system can be assessed.

4.2 Formulation of a practical problem

If we talk about formulation of a practical situation in such way that it may be interpreted and acted upon by the CAD application software, we do it in this manner;

First of all we analyze the system and its surrounding, like the heating conditions, sound intensity conditions, magnetic field presence, vibration and various other characteristics.

Then we focus onto the various internal aspects affecting the system like the amplitude of driver and driven frequency, if the system is moving – whether it is balanced or not, if the system if utilizing energy in some format - the input is exploited in output and some permissible dissipation and nothing extra, etc.

Then we impose on the situation which is to be analyzed, like impact in terms of pressure on a particular end, frequency behavior at some particular constraining, immediate shift in system characteristics, such as the moving system stops suddenly, etc.

After defining the situation to be analyzed, we provide the actual constraining and system properties, like if there will be an impact, will it be of plastic type or elastic type? What material will constitute the design, what will be its dimensions and properties, like density, tensile stress, Poisson's ratio, etc.

Hence based on above figures, the CAD application software analyzes the practical problem and gives the nearest accurate solution.

4.3 Calculation of forces and other parameters

This is a special case that we have considered in this paper, and the data which we provided are closer to the extent possible for a general formula car. Let's say that we have a formula car which weighs 320 Kgs including a driver weighing about 85 Kgs. The maximum speed this vehicle can attain is about 120 Km/h on Indian roads and the material with which it's roll-cage, i.e., vehicle frame or chassis is made is AISI 4130 steel with mechanical properties like Ultimate tensile strength being 846 MPa, Yield stress being 685 MPa, Bending Stress being 545 Nm and density being 7865 Kg/(m^3).

Lets consider a case in which the vehicle is running in its full load, i.e., 320 Kgs with it's maximum speed of 120 Km/h and collides with another vehicle of identical features and for the sake of calculation, let's assume that the collision is perfectly plastic having time of impact around 0.2 seconds.

Therefore, from the impulse equation, the net force exerted and experienced by the vehicle will be calculated would be :

S_{Front} = (0.5 * Mass * (Change in Velocity)) / (Time of Impact),

Which in-turns gives $\boldsymbol{S_{Front}}$ = (0.5 * 320 * 33.34) / (0.2) = 26672 N ~ 27000 N = 27 kN. So, we can conclude that the amount of stress produced by the virtue of impact in any case would be equal to about 27 kN, so such parameters can be calculated mathematically using simple laws of physics.

4.4 Meshing

Dictionary says that meshing means a web-like pattern or construction the open spaces in the net or network resembles various nodes. So we can define the term meshing as creating a web-like pattern in the engineering design so as each member is divided uniformly into a particular number of nodes and the analysis of the impact or any condition imparted on it may easily be calculated through the nodes and overall behavior of the subject can be derived from the interrelation and behavior of the various nodes.

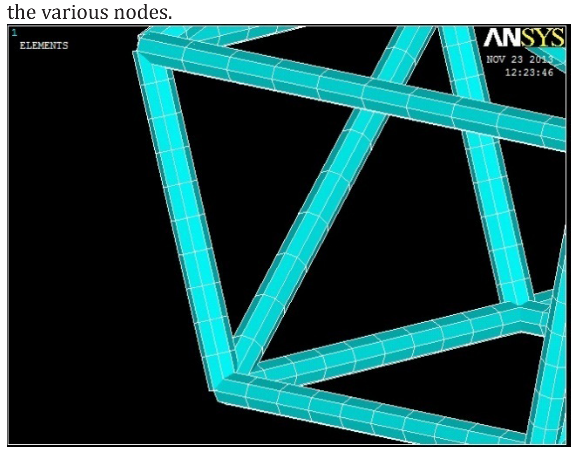


Fig 8. Magnified view of a part of meshed rollcage

4.5 Impact Analysis

As discussed earlier, one of the most crucial pre-manufacturing analyses is impact analysis under various conditions of collision and behavior of the design and possible rupture and extent of safety is estimated. The simulation engine we have used here is ANSYS 12, which is one of the most powerful FEA commercial software available in the market.

4.5.1 Front

In case of front impact, we consider the case that the vehicle is running at full load at its maximum speed and hits another vehicle under plastic conditions and the behavior of rupture is observed.

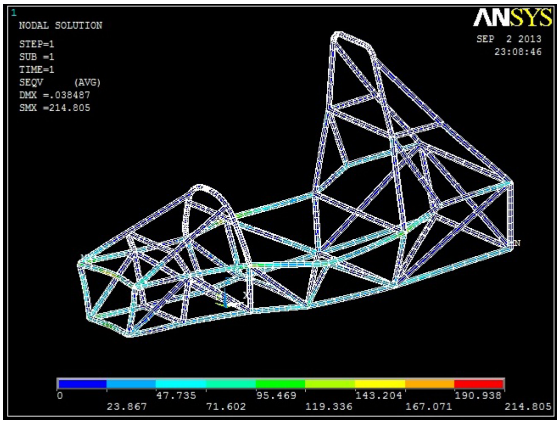


Fig 9. Frontal Impact : S_{max} = 214.805 MPa, D_{max} = 3.85 cm

4.5.2 Rear
In case of rear impact, we consider the case that an another identical vehicle is running at full load at its maximum speed and hits subject vehicle at the rear end under plastic conditions and the behavior of rupture is observed.

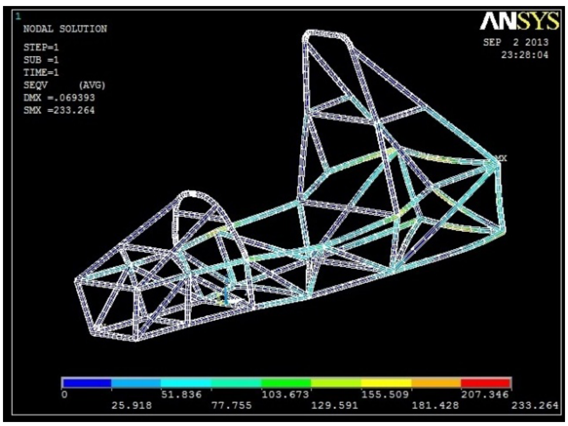


Fig 10. Rear Impact : S_{max} = 233.264 MPa, D_{max} = 6.94 cm

4.5.3 Side
In case of side impact, we consider the case that an another identical vehicle is running at full load at its maximum speed and hits with subject vehicle on either of its side under plastic conditions and the behavior of rupture is observed.

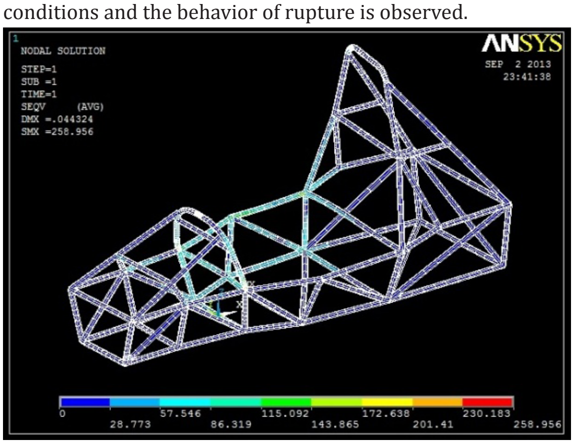


Fig 11. Side Impact : S_{max} = 258.956 MPa, D_{max} = 4.43 cm

4.5.4 Rollover
This is a special case we are considering, when due to certain bump on the track or due to imbalanced control, the vehicle topples sometimes and in such case, rollover impact is calculated. Here, again the vehicle is considered running with full load at its maximum velocity and the behavior of rupture is observed.

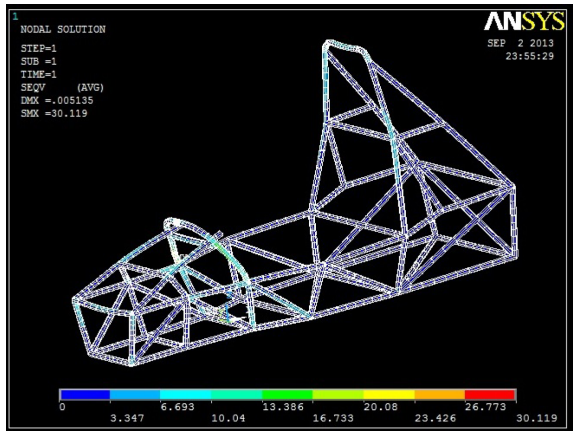


Fig 12. Rollover Impact : S_{max} = 30.119 MPa, D_{max} = 0.51 cm

4.6 Frequency Analysis (Modal Analysis)
It is said that in a mechanical system, there is a driver and there is a driven, so as per the understanding of the subject, here in a running formula car, the driver is off course the engine and driven is the car body, i.e., the rollcage along-with the various mountings and accessories. This analysis is so done to analyze if the natural frequency of the rollcage does not match with the operating frequency of the engine so as to avoid resonance, hence checking it for frequency rupture, if any.

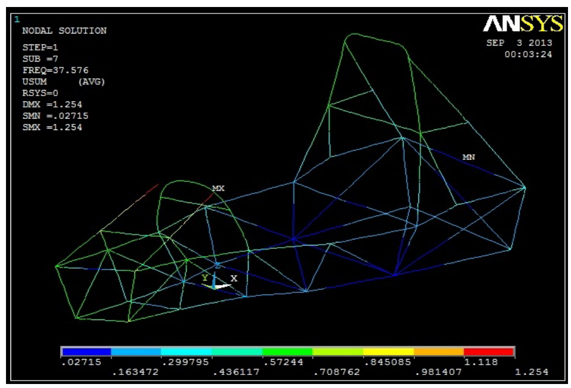


Fig 13. Modal (Frequency) Analysis : D_{max} = 12.54 cm

4.7 Torsional Analysis
Torsional analysis is a kind of spring test of the car rollcage, in which its stiffness is calculated so as to avoid breakage or rupture due to high stiffness and also to avoid too low stiffness that may result in failure of joint and welds.

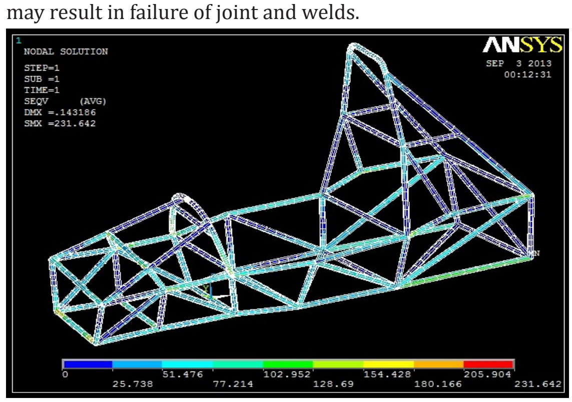
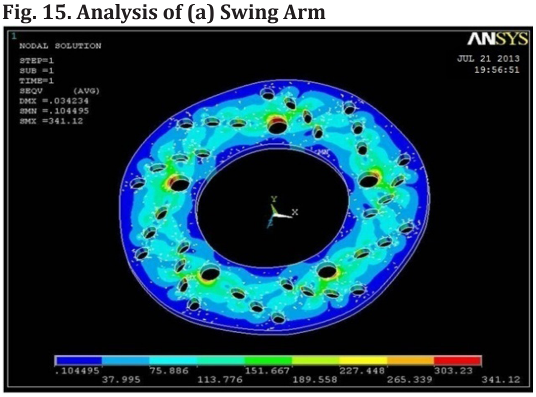


Fig 14. Torsional Analysis: S_{max} = 231.642 MPa, D_{max} = 1.43 cm

4.8 Analysis of various peripheries in action
There are various other peripheries mounted on the car like the disk brake (rotor), the arm (swing arm), which assists in play of

tyre during vehicle run. So, these peripheries are examined for ultimate conditions and rupture via FEA method.

Fig. 15. Analysis of (a) Swing Arm



(b) Rotor (Disc Brake)

The analysis of the rotor and the suspension arm was carried out, for all the analysis the weight of the vehicle is taken to be 310kgs including the overall weight of driver, engine and various mountings and accessories. This is so done to ensure that there is no rupture or material failure during play or course of extreme action.

5.0 Design review and evaluation

Once we are completed with all the analysis desired to attain the pre-manufacturing behavior of the subject, we are supposed to check whether the result we are arrived is positive or not or the vehicle is safe or not. So, in that regard, we check it for the factor of Safety for each case and Margin of safety for commercial usage. If we get the FOS > 1.5, we can say that the vehicle we have designed is safe and ready to manufacture and if it is 1.5 or below, we look for further optimization and performance of the design.

5.1 Estimation of various results and Factors of Safety (FOS)

Estimation of factor of safety is one of the most crucial parameter of pre-manufacturing analysis and study of the subject. It depicts, to what extent the design is safe under the provided conditions and to what extension of applied conditions, the system would undergo a change either in form of a rupture or failure. In the various cases observed, the FOSs are :

	Front	Rear	Side	Roll	Torsion
Velocity (kmph)	118.6	118.6	118.6	--	--
Time of Impact (s)	0.2	0.2	0.3	0.2	--
Force (KN)	26.5	26.5	17.5	3.2	9.2
G's	8.41	8.41	5.53	1.02	2.93
Results					
Max Eq. Stress (MPa)	241.8	233.2	258.9	30.1	231.64
Max Deformation (cm)	3.8	6.9	4.4	0.5	1.4
Factor of Safety	2.31	2.40	2.16	18.6	2.42
Margin of Safety	1.31	1.40	1.16	17.6	1.42

5.2 Estimation of result of Frequency (Modal) Analysis

Modes (#)	1, 2, 3	4	5	6	7	8
Frqs. (Hz)	0	3.017 e-2	1.040 e-2	4.140 e-1	37.57	73.74

Here, we can observe that in the working range, the frequency of vibration of an usual engine has the value from 14.16 Hz to 31.67 Hz (Lets for example we take Briggs & Stratton Engine, operating rpm: 1700 – 3800 Hz). After modal analysis, the result obtained is 0.41 Hz in 6th Mode and 37.57 Hz in 7th Mode. Thus the entire range of vibration of the engine lies between 6th and 7th mode natural frequencies of the roll cage and hence there is no resonance. Hence we can conclude that the Roll-cage is safe from frequency rupture.

5.3 Estimation of behavior of Peripheries

If we talk about the swing arm which aids suspension during vehicle play, we get the following result by conducting the analysis;

Material Used	Action	Velocity	Max. Eq. Stress (MPa)	Deformation (mm)	Factor of Safety
AISI 4130	To aid in suspension play.	-	245.23	0.38	2.79
Yield Strength of AISI 4130 : 685 Mpa					

As we can observe here, the FEA of suspension arm (or the swing arm), made by the same roll-cage material, i.e., AISI 4130 results in max eq. stress = 245.23 MPa, which in-turns results in FOS = 2.79, which again results into a safe design, also, the max deformation = 0.38 mm which can again be neglected. So we can again conclude that the suspension play will be safe and would not yield in rupture of the suspension arm.

If we talk about the rotor, i.e., the disc brake, we may infer the following result by conducting the analysis;

Material Used	Action	Velocity	Max. Eq. Stress (MPa)	Deformation (mm)	Factor of Safety
Mild Steel	Rapid braking of the vehicle.	59.4	341.12	0.03	1.42
Yield Strength of Mild Steel : 485 Mpa					

As we can observe here that the Disc Brake (Rotor) gives a **FOS** = 1.42 when the vehicle weighing 310Kgs, running at 59.4 km/h is brought under the action of disc brake. In this case, the net deformation observed is 0.03 mm which is negligible and when the vehicle comes at rest, the rotor regains its initial shape due to elastic its behavior. So, in this case we can conclude that adequate braking system functions effectively even at worst vehicle running conditions. Hence there is no rupture and material failure, hence the rotor is safe.

5.4 Addition of all Peripheries and Mountings

When we are done with all the pre-manufacturing analysis, and a confirmation that the design is safe to manufacture and to be launched in market, we attach the various mountings and peripheries on it, like the rotor, arms, springs, wheels, various other mechanical components electronically using the CAD engine CATIA V5R19.

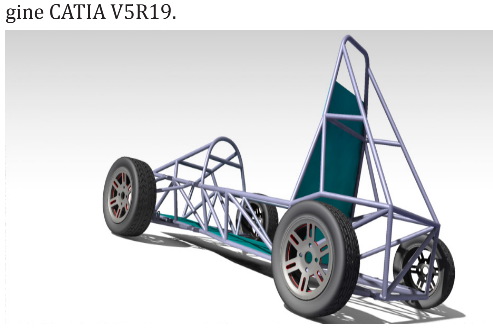


Fig 16. Addition of all peripheries to the vehicle.

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5.5 Surfacing

In course of design completion, the next step is surfacing. The term surfacing can be under in literal terms as creating surface. Like if we consider the practical case, in which we manufacture an automobile rollcage, then our next step is to provide with outer coating with the materials like GI Sheets or FRPs or some alike material. So, in the same way, we electronically generate surfaces on the designed chassis and provide it with mechanical properties and aesthetics.

5.4 Final Electronic Product Generation

When we are all done with the addition of all peripheries and surfacing of the vehicle, we are ready for its first electronic showcase and the result, i.e., product is an electronics prototype which resembles the final product in the exact and precise manner and much cheaper than the physical prototype generation.

Fig 17. Final Electronic product.

6.0 Conclusion

Towards the end looking at the variables which we have been able to showcase in this paper it has become quite clear that the idea of using the computer assisted designing softwares such as *CATIA, SOLIDWORKS* etc., and analysis softwares such as *ANSYS, HYPERMESH* etc, have been very useful and productive in order to produce and manufacture any vehicle. This is the reason all major automobile manufacturing industries make use of these softwares. The very same process has been used by our very own indigenous car manufacturer TATA MOTORS to design and manufacture TATA NANO which has earned the title for being the cheapest four wheel vehicle in the world. The designer's main aim in designing and manufacturing TATA NANO was to minimize all possible facets of cost and this very method has been very helpful for it to be possible. And as far as the end results are concerned, we have successfully designed a formula car and its pre-manufacturing analysis depicts that the whole vehicle roll-cage tested under impact conditions, frequency conditions and the analysis of the disc-brake rotor and suspension arm is safe from any kind of rupture and can be manufactured successfully.

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