Suspension and chassis design, and steering calculations for SAE BAJA All-Terrain Vehicle

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Abstract - *The purpose of this research paper is to provide an effective framework of design criterion, equations, & basis for design trade-offs to carry out suspension and steering calculations, suspension geometry design, and design decision-making for single-seater All-Terrain Vehicle for off-road racing specifically for student BAJA competitions.*

Following guidelines set by the BAJA Student rulebook, the ATV chassis was designed considering driver safety and ergonomics. A physical model of the chassis was created using PVC pipes for design verification. CAE validation of the chassis was done for the front, side, and rear crashes, torsional stability, and rollover, also the suspension wishbone A-arm deformation analysis was conducted.

Suspension and steering geometries were optimized using LOTUS software.

Keywords- Baja, Suspension, Steering, Design, CAE, Chassis, ATV

1. INTRODUCTION

BAJA SAE is a national level competition conducted annually by the Society of Automotive Engineers (SAEIndia) to design, make and race single-seating off-road cars. It has been running successfully for the previous 10 editions and our collegiate team '8 MILES' was participating in BAJA 2019.

All-Terrain Vehicle is a vehicle that travels on low-pressure tires and is designed to handle a wider variety of terrain. Since it is made to run on different types of terrain, thus stability, vehicle behavior, and driver comfortability in the vehicle are the foremost problems [5]. So the aim is to develop a suspension and steering system which gives good performance, and endurance and provides maximum directional control and stability to the vehicle. The steering knuckle is a disparaging component of any automobile. It also comes as the highest stress carrying part of the vehicle.

To ensure driver safety and standardize constraints for every team SAE BAJA provides an extensive set of guidelines in a rulebook [4]. You are supposed to adhere to it for the design and manufacturing practices of your BAJA Buggy. The rulebook also serves as design guide for the vehicle's roll cage and other sub-system's design. To keep the competition fair, BAJA bounds every participating team to use the same engine, Briggs & Stratton 1450 series 10 HP engine.

2. SUSPENSION AND WHEEL ALIGNMENT

2.1 Objective

The suspension sub-system play a pivotal role in the vehicle dynamics of an ATV as it helps the vehicle to perpetuate the rigorous environment of off-road racing. It also aids the vehicle to sustain the hard impact of bumps and ditches of the rough terrain. Student teams have faced difficulty in selecting suspensions, so it's always advisable to focus more on this part initially in vehicle design. A few factors involved in making an optimum suspension system for the vehicle are the roll center's height and its dynamic fluctuation and camber gain and scrub radius. A design engineer should carefully balance these factors considering on all the design trade-offs [2].

2.2 Design Contemplations

The design output of a suspension system should be to:

- Improve the vehicle handling and control.
- Provide sufficient ride height and total wheel travel.
- Have Sufficiently rigid and durable.
- Control movement at the wheels during vertical suspension travel and steering,
- Limit chassis' rolling during cornering, to prevent rollover, decrease roll camber, and therefore decrease steering reaction time.

2.3 Vehicle Specifications

Table -1: Wheel alignment angles and Suspension Results

Camber	3°	Enhances stability and cornering ability
Caster	7°	Enhances stability and aids in self-centering.
King Pin Inclination	31°	Return the ability of the wheel to a straight position
Roll Center Front	15.6''	More chassis rolls in turns
Suspension travel	6''	For Fox float 3 suspensions
Ground clearance	13 inches	-

2.4 Wishbones

The double-wishbone suspension system was chosen as it has the following advantages:

- It gives more flexibility in designing the suspension system i.e. we can control roll center variation and roll center height as per the requirements of the vehicle [6].
- It is sturdy and hence easily sustains the large bumps and frequent impacts that are desirable for the front suspension [6].

This system requires more physical space than other suspension systems (McPherson strut, trailing arm suspension systems). The vehicle Chassis was designed taking into account the extra space essential for double wishbones.

To start the suspension design one must begin by concluding on the front geometry of the vehicle. The design of the front geometry requires the following parameters [2]:

- Knuckle's length.
- Double A-arms' lengths.
- Inclination of kingpin.
- Vehicle's Jounce and Rebound.

The geometry optimization for suspension and steering was done using LOTUS suspension software. Suspension hard points are the areas where suspension connects to the chassis, they command the suspension kinematics. Coordinates of these points are taken as input in the software and the vehicle's dynamic motion during droops and bumps and steering motion is simulated.

Finer geometry optimizations were done using guidelines from Carroll Smith, "Tune to win" [2]. Graphs of Camber, caster, and toe angles versus droop/bump were extracted from LOTUS. Variations in their amplitudes were adjusted to be within desired values by changing hard points.

All-terrain high-performance tires were chosen with dimensions: 22 X 7 X 10: (external diameter x tire width x rim diameter) (in inches) after market research and understanding the experience of teams in previous competitions.

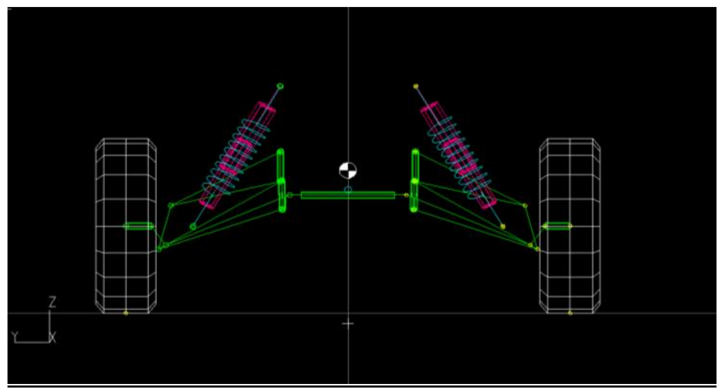

Figure 1: Suspension and Steering Geometry in LOTUS soft.

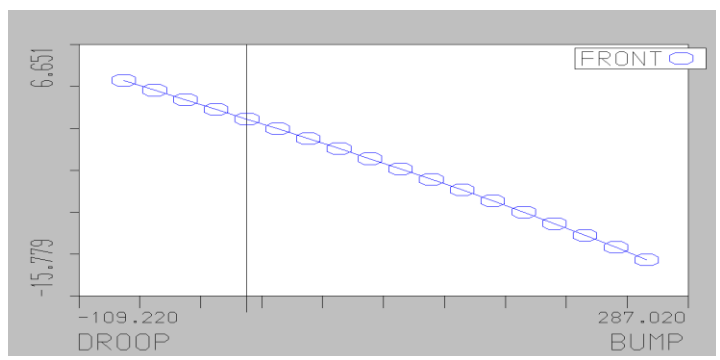

Figure 2: Camber

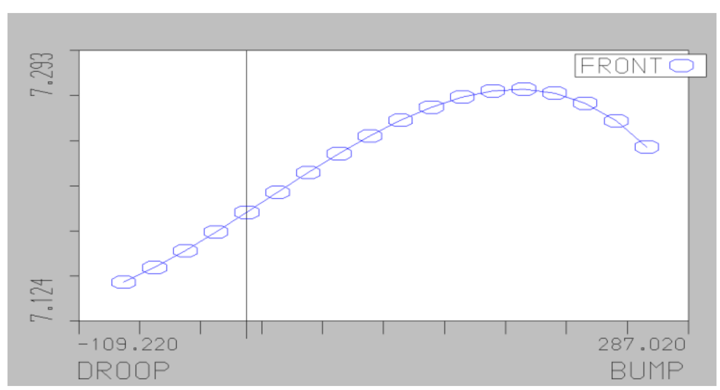

Figure 3: Castor angle

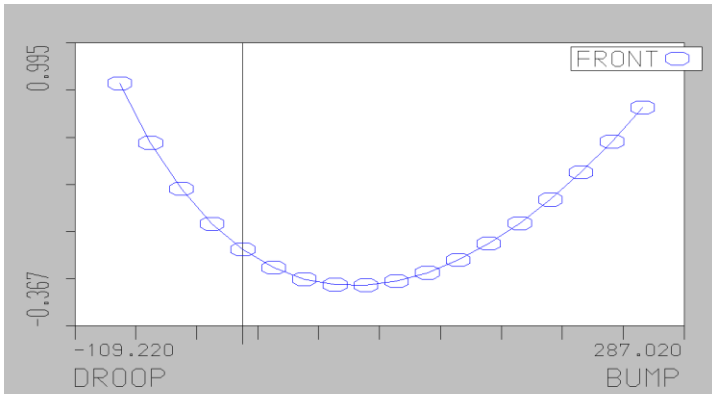

Figure 4: Toe angle

3. STEERING

3.1 Objective

- To provide directional stability to the vehicle, ease of moving and directing, comfortably stabilizing after turns, and maximum dispersion of road shocks [1].
- To facilitate straight-ahead recovery after completing a turn
- To keep the turning radius minimum in design
- To have excellent rolling of the tires about a sole point

3.2 Design decisions and computations

After a lot of research and study, it was decided that Ackerman steering geometry is the easiest to implement and has been tested all over the globe for BAJA vehicles.

Ackermann's steering mechanism is a 4-bar linkage mechanism. It consists of no sliding pairs. As there are only turning pairs, hence it minimizes the wear and tear of the mechanism. The mechanism has the following advantages [3]:

- It reduces the steering labor of the driver.
- It consumes minimum space.
- It involves less no. of very lightweight linkages.
- Due to the small no. of linkages probability of wear and tear of joints is lowest.

The steering wheel's rotational movement is transferred to the pinion through the use of universal joints. The rotary motion of the pinion is converted into reciprocal movement of the rack, this linear motion of the rack gets transferred to the ball joints and tie-rods and then to the wheels supposed to be steered.

After numerous iterations in LOTUS software, below mentioned values were chosen for their respective properties.

Table 2: Steering design parameters as results from LOTUS

PROPERTY	VALUE
Turning radius	2.528m
Steering angle	Inside-40 degrees Outside-25 degrees
No. of lock-to-lock turns	540
Rack length	4.25inch
Tie rod length	0.3683m

Figure 5: Assembly of the steering system

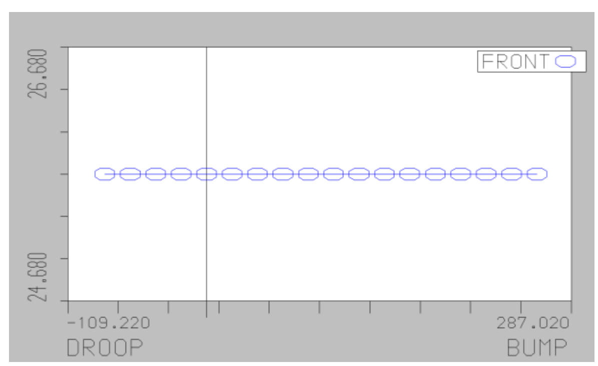

Figure 6: Bump-Steer graph

Table 3: Results from calculations

PROPERTY	VALUE
Ackerman percentage	83.9 %
Steering ratio	12:1
Scrub radius	0.0454m
Steering wheel diameter	9 inches
Steering wheel torque	4.134 Nm (static) 11.704 Nm (dynamic)

4. ROLL CAGE DESIGN

The roll cage is one of the most critical components for driver's protection in every vehicle. Principal aspects of the chassis focused on the design and implementation of the roll cage were driver safety, suspension and drivetrain integration, structural rigidity, weight, and operator ergonomics.

BAJA rulebook {was religiously followed to decide upon the size and orientation of every role cage pipe member.

The rear roll hoop's design was made for the safety of our driver considering the clearances and angles governed by the rulebook. Lateral Diagonal Bracing was determined during the PVC prototyping process with careful deliberation on the stability of the whole structure. The lateral side member was chosen such that the driver is able to steer the wheel comfortably and apply force to the brake and acceleration pedals with his feet to their limits. The slightly crouched sitting position of the driver was preferred keeping in mind the alertness and steadiness required in off-road racing.

4.1 Design considerations

- Easy manufacturing
- Durable and compact
- Lightweight and Ergonomic design
- Favor quick assembling and disassembling of vehicle components
- Driver safety

4.2 Pipe material and size selection for Roll Cage

The selection of the proper material for the building of a roll cage is very important as it provides the desired strength, reliability, safety, and endurance to the vehicle. The strategy behind selection of the material was weight, weldability, good bending stiffness, and maximum strength for the pipes. After a lot of market research we narrowed down the selection to AISI 1018 and AISI 4130 Steel materials. Based on the cost, availability, and properties of these two alloys we finalized AISI 1018 Steel.

Table 4: Properties of pipe materials

	MATERIAL	AISI 1018	AISI 4130
PHYSICAL PROPERTIES	Density (in kg/m3)	*7870*	*7850*
	Yield Strength (MPa)	*370*	*460*
	Tensile Strength (MPa)	*440*	*731*

According to the rulebook, the primary member should be circular steel piping with an externa diameter of 1.25 inches and a wall thickness of 0.067inch. As a constraint was provided on the selection of the size of secondary members, the minimum wall thickness must be 0.035inch and the minimum outside diameter must be 1 inch. The bending strength and ease of manufacturing were also taken into consideration while deciding the cross-section of the pipe.

4.3 Finite Element analysis of roll cage

The following results were obtained during different tests of roll cage:

Table 5*:* FEA analysis *results of Roll cage with* Factor of Safety

CASE	F.O.S
Front Impact	1.69
Rear Impact	1.46
Side Impact	1.01
Torsional Rigidity	1.54
Roll Over	1.13

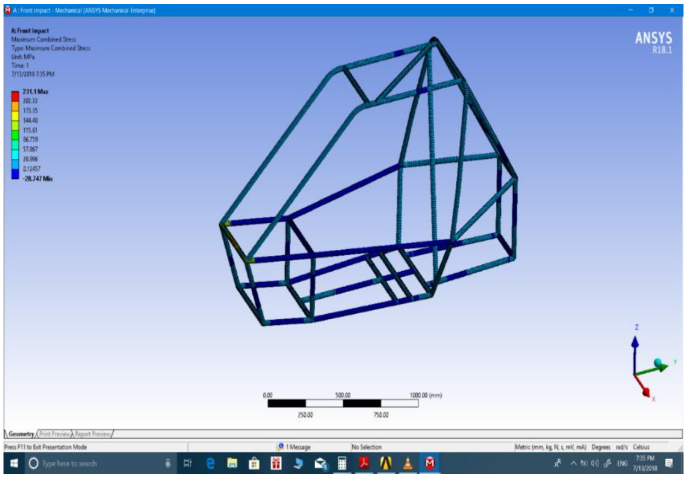

Figure 6: Equivalent stress plot for Front Impact

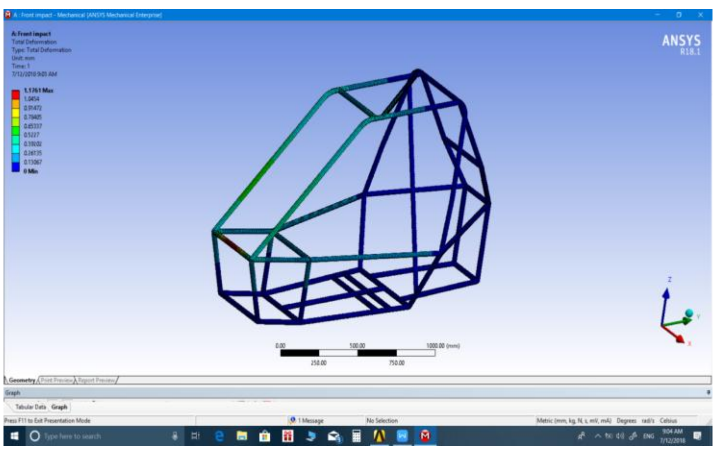

Figure 7: Deformation plot for Front Impact

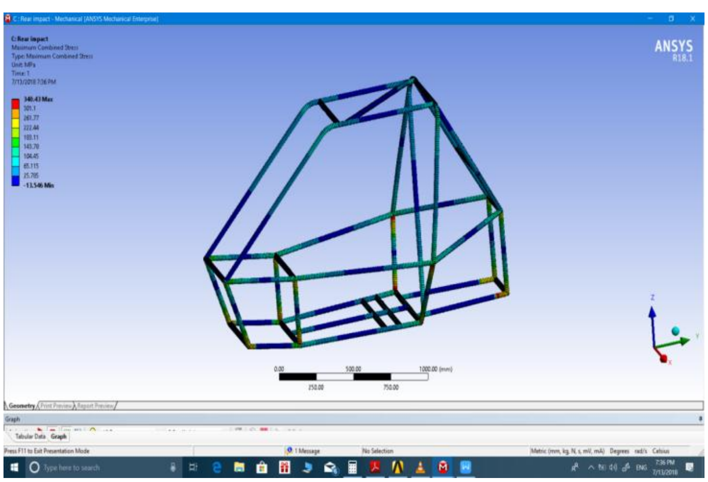

Figure 8: Equivalent stress plot for Rear Impact

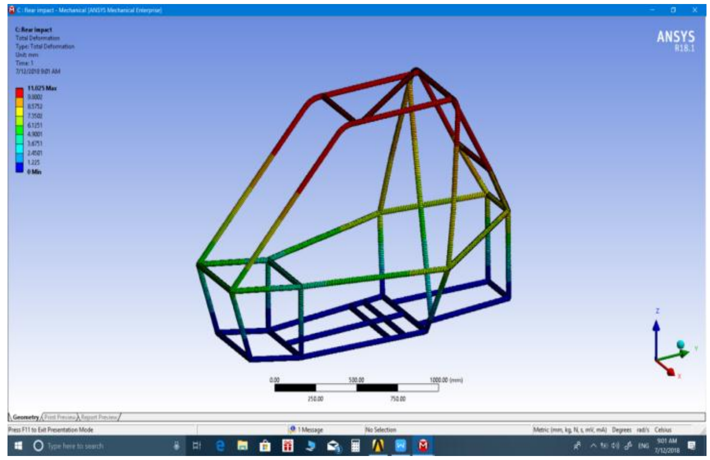

Figure 9: Deformation plot for Rear Impact

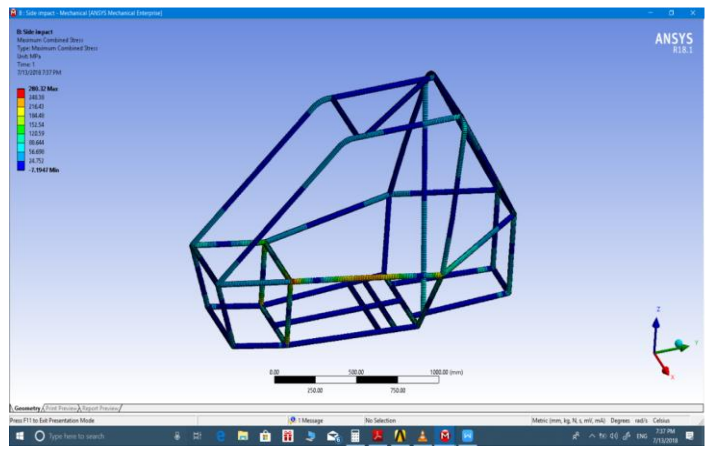

Figure 10: Equivalent plot for Side Impact

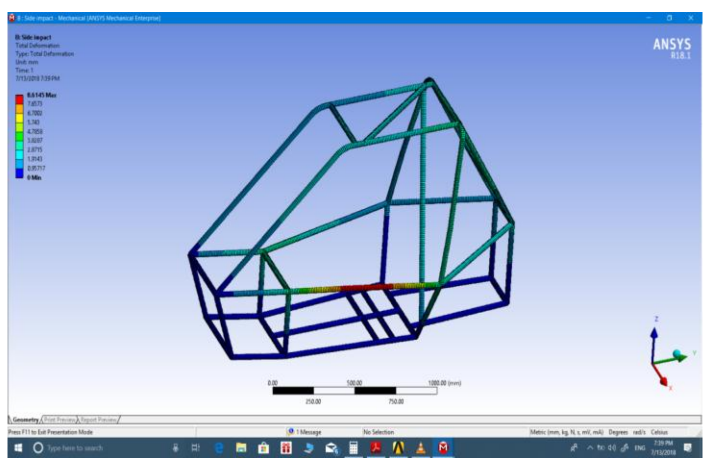

Figure 11: Deformation plot for Side Impact

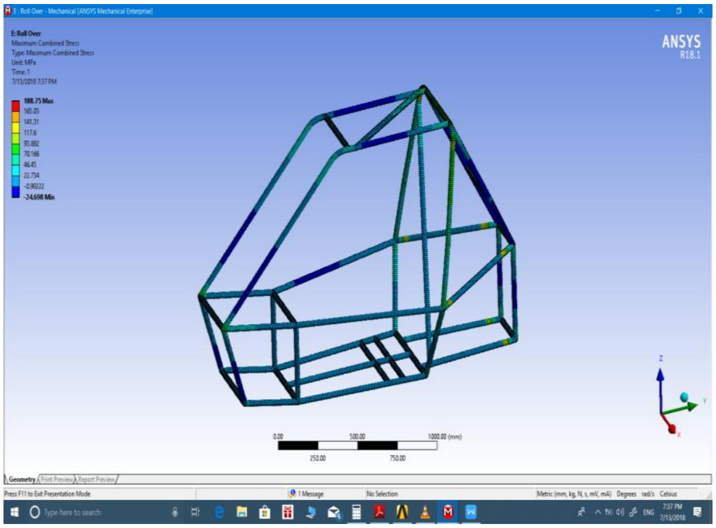

Figure 12: Equivalent stress plot for Roll Over

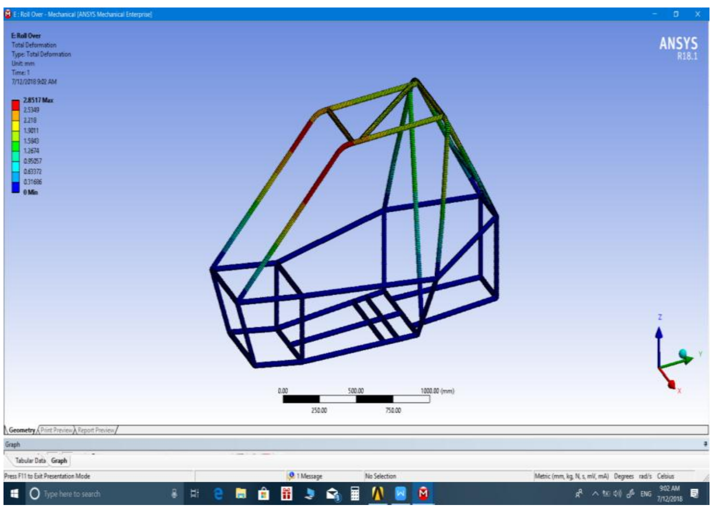

Figure 13: Deformation plot for Roll Over

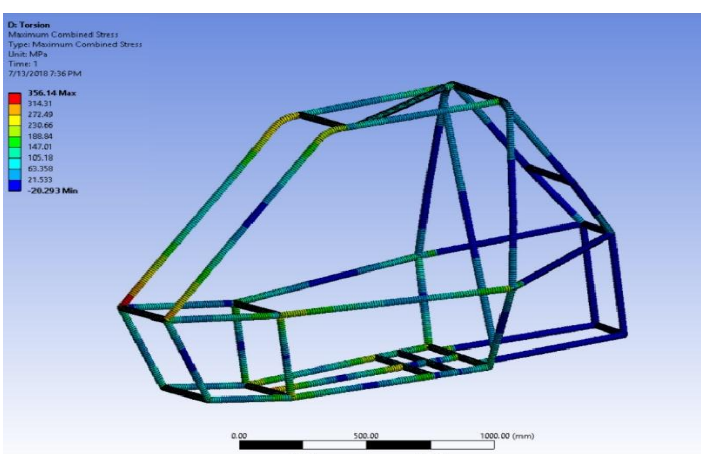

Figure 14: Equivalent stress plot for Torsion

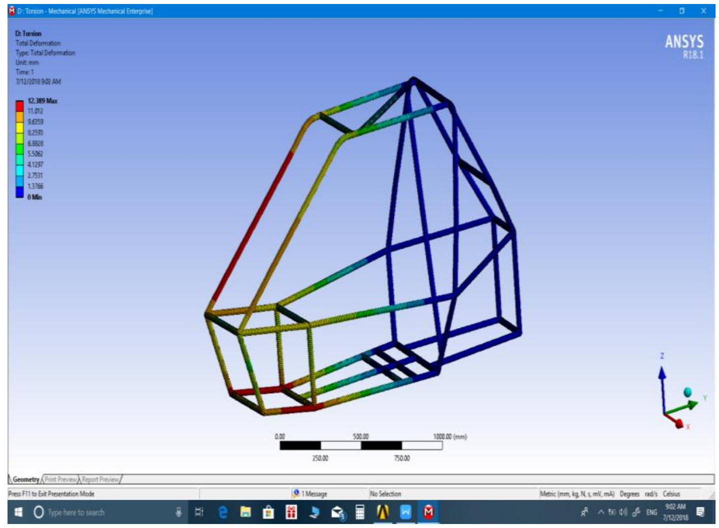

Figure 15: Deformation plot for Torsion

4.4 Driver Ergonomics

The following factors were considered in creating an ergonomically suited roll cage [4]:

- Seat inclination [4]
- Steering Wheel location [4]
- Designing of the foot box area [4]
- Driver Safety[4]
- Seat location [4]

CATIA V5 was used to do the human ergonomics test and a prototype model was prepared with PVC pipes.

Vehicle Ergonomics were decided based on the following features:

- Center of gravity of the vehicle
- Weight balancing
- The posture of the driver was decided so that any of its body parts do not interfere with the components
- Proper pedaling and its location for easy operation of the vehicle
- Seat and placement of the other components of the vehicle for safety and comfort.

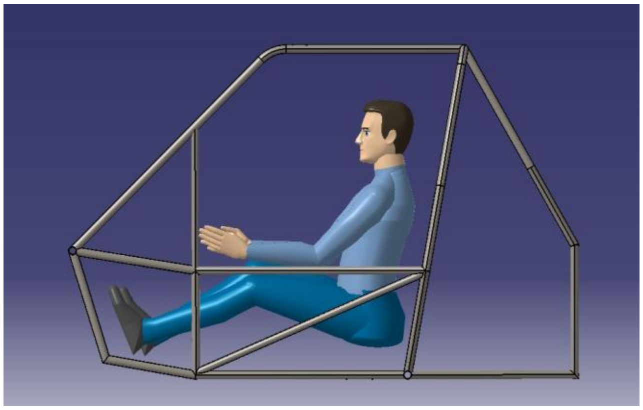

Figure 16: Side View of Chassis with a manikin

Figure 17: Front view of Chassis with manikin

Also, FEA analysis of critical components make the design fail proof and saves the cost of numerous cycles of prototyping.

6. ACKNOWLEDGMENT

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5. CONCLUSION

In conclusion we can say that designing and manufacturing an ATV for student competitions makes upcoming engineers well versed with every aspect of automobile engineering.

The use of LOTUS software is a very beneficial method to design the suspension and steering geometry. It allows use to test and trial different design parameters and optimize them to freeze on the final values.

7. REFERENCES

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