Design & Analysis of Suspension and Steering System for Formula Student Vehicle

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Abstract - The modern world is all about what can be done in the least amount of time, doing the most of every minute of every hour in a day. As the saying goes, time is money and we are in a modern capitalistic world, in which transportation is a key element of the economy, and vehicles are made into different types according to the uses and requirement of its task. Modern vehicles are very advanced compared to the firsts recorded in history, and it is far more complex than the previous technologies used in the previous models. But since the first apparition of the first vehicles, the one thing that haven't changed is the necessity of human control in its functioning. Driving a personal vehicle can be tiring and time consuming at times, and modern people have less and less time to lose. Autonomous vehicle is thought to be the solution to many problems in the modern industry of automobile, as it solves the problem of human labor by giving the task of path planning, vehicle management and driving, to a computer. The vehicle is controlled by a computer which perceive the environment around the vehicle by the use of sensors, and then will act according to the calculation to perform its task by the use of electronically controlled actuators.

Key Words: **Double Wishbone pushrod system, Steering system, Suspension Damper & Spring, Solid works software, ANSYS simulation software, Knuckle & Hub**

1. INTRODUCTION

Suspension is a very important component of any car as it should keep the tire in contact with the road while encountering forces acting on the tires. The type of suspension used decides how these forces are transferred from the tires to the chassis. Suspensions vary from simplistic leaf springs to complicated electromagnets to dampen the forces acting on the chassis. Pushrod suspension designs are used mostly among open wheel race cars because of the aerodynamic and adjustability advantages it gives. They consist of an inboard mounted spring a push rod and a bell crank assembly. As we are working on a national level project named SAE SUPRA in which the design and fabrication of a Formula student race car was to be done and for that we had the task to design a steering system that facilitated the driver to take sharp turns with less efforts or with less revolutions of steering wheel. To achieve this we decided to modify the conventional steering mechanism that is used in the normal road cars.

The design consists of a conventional rack and pinion steering with an extra idler gear between them. The diameter of both the gears has been increased from the conventional size due to which, improved sensitivity has been achieved. However, the extra idler gear caused steering reversal, which was avoided by mounting the tie rods on the front part of upright rather than mounting it at the rear end which is usually done in cars now a days.

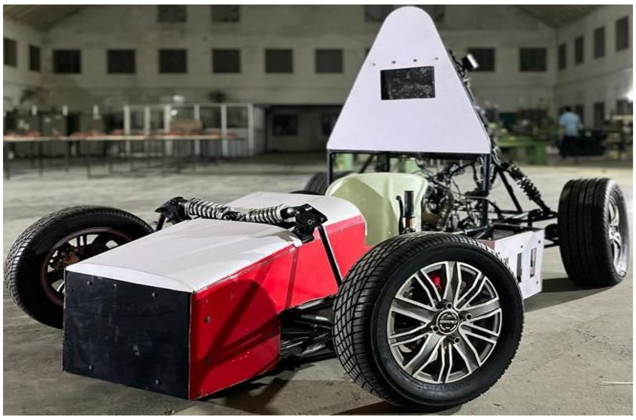


Figure 1: Picture of Complete vehicle

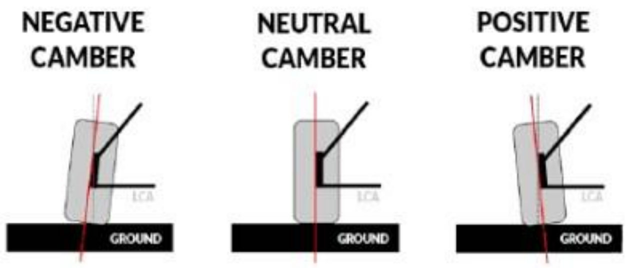
2. RESEARCH METHODOLOGY FOR SUSPENSION

This the very important factor by which a planned method from designing to manufacturing the final prototype. For designing purpose, use of basic hand calculations and research of design parameters referring design reports which are paper published and also certain figures to understand the basics by using internet and referring certain books like Carroll Smith's Tune to Win and Milliken & Milliken's Race car vehicle dynamics, etc. Drafting and CAD model designing is done on non-licensed CAD software's like Solid works, Catia, etc. FEA analysis is done on non-licensed version of ANSYS. Manufacturing is done by Major machining processes like laser cut, grinding, welding, lathe operations, etc. and assemblies were done by bolting and press fitting, etc. To simulate a vehicle the required subsystems are: • Front Suspension Subsystem • Rear Suspension Subsystem • Steering Subsystem • Front Wheel Subsystem • Rear Wheel Subsystem • Body Subsystem If a more detailed model is wanted, powertrains, brakes, anti-roll bars, and differentials etc. can be added to the vehicle model. There are several pre-made subsystems included and the opportunity to build your own subsystems. The subsystems interact with each other via communicators. There are input communicators that read information into a subsystem with data and output communicators that send information from a subsystem to another.

3. General Terms in Suspension System and Wheel Assembly

1 Camber Angle

Camber angle is the inclination of the vehicle tire with the vertical axis when viewed from the Front section. In case top of tire leans in towards the centre of the car this is the condition of negative camber. Positive camber is opposite of this.



2 Caster Angle

Caster angle is the angular displacement from the vertical axis of the suspension of a wheel in a car measured in longitudinal direction. In other words, it's a line joining the upper and the lower ball joint of the upright with respect to vertical axis drawn from the centre of the tire. The purpose of this is to provide a degree of Self – Centring for steering the wheel casters around so as to trail behind the axis of steering. This makes car easier to drive and improves its straight-line stability.

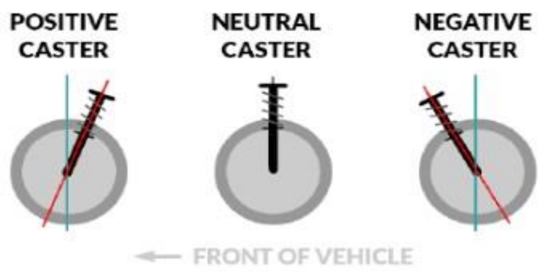
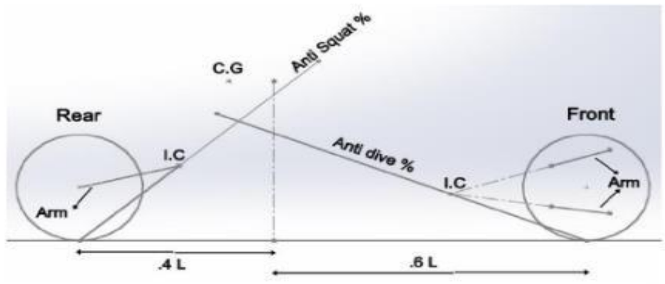


Fig.3.2different caster angle

3 Anti-Dive

Anti-dive describes the amount of front of the vehicle dives under braking. As the brakes are applied weight is transferred to the front and that forces the front to dive. Anti-dive is dependent on the vehicle centre of gravity (C.G), the percentage of braking force developed at the front tires vs. rear and the design of the front suspension.

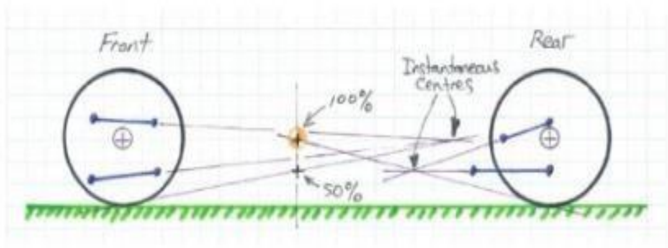
For the very common double A-Arm Suspension Anti-Dive is design to suspension based on the angle of the A-Arm mounting points when viewed from the side. If the intersection point of the extension lines for the mounting points is located above the neutral line, there is more than 100 % Anti-Dive. High Anti-Dive values require more complex suspension design and causes 'Rattling' type noise. Typical values are in range of 0 – 50%.



4 Anti-Squat

Squat is a term used to refer to the amount the car tips backwards under acceleration. Over 100% of anti-squat (AS) means suspension will extend under acceleration. With 100% AS suspension would neither extend nor compress. Under 100% AS means tendency to compress under acceleration.

The calculation of anti-squat is similar to that of anti-dive. Locate the rear Centres of the suspension from the vehicle's side view. Draw a line from the rear tire contact patch through the Instantaneous Centre. This is the tire force vector. Now draw a line straight down from the vehicle's centre of gravity. The Anti-squat is the ratio between the height of where the tire force vector crosses the centre of gravity plane expressed as a percentage.



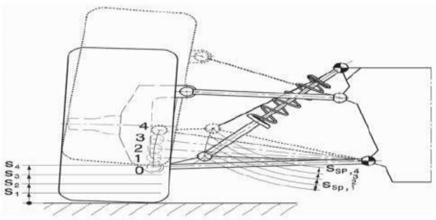
3.1 The double wishbone suspension

The double-wishbone suspension is also known as an A-arm suspension. It is a common type of independent suspension and is used in the most of the high performance cars and in every Formula car.

Figure 3.1.1 Double Wishbone suspension

While there are several different possible configurations, this design typically uses two wishbone-shaped arms to locate the wheel. Each wishbone, which has two mounting positions to the frame and one at the wheel, bears a shock absorber and a coil spring to absorb vibrations. But why is it the best to obtain the best car drivability?

All the advantages are based on the wide quantity of possibilities to design the suspension. By changing the angles, length and orientation of the arms we can obtain infinity of different geometries.



Double-wishbone suspensions allows for total control over the camber angle of the wheel, which describes the degree to which the wheels tilt in and out. This is decisive to obtain the best performance of the tires and improve the car handling. They also help minimize roll or sway and provide for a more consistent steering feel.

Because of these characteristics, the double-wishbone suspension is common on the large and racing cars.

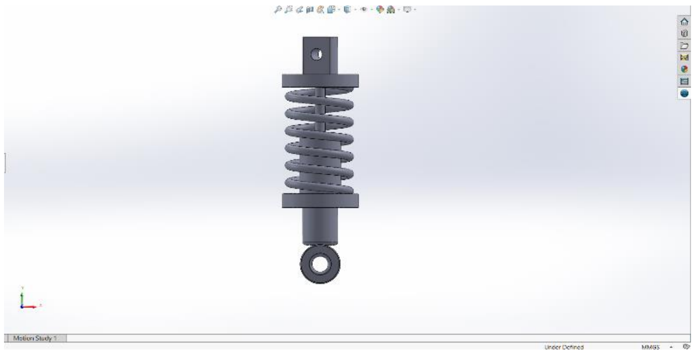
3.1.1 Front Suspension Modelling

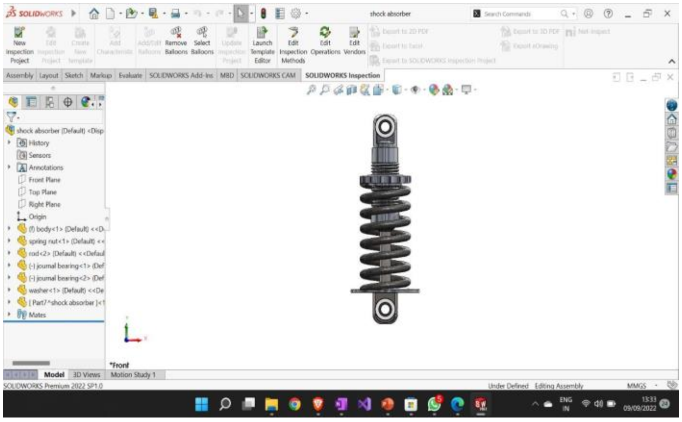
Front suspension design is of SLA type. The wheel is connected to the upright via a hub bearing which is a revolute joint. On the upright four control arms are connected with spherical joints, two lower ones and two upper ones. The other ends of these control arms are connected to the cars frame via revolute joints. On each upright there also is a tie rod connected with a spherical joint. The other end of the tie rod is to be connected to the steering rack via a spherical joint. Springs and dampers are connected to the uprights via pullrods with spherical joints. The pull-rods are connected to the rockers with hooked joints. The rockers are connected to the chassis with revolute joints and to the dampers with hooked joints. The communicators in the front suspension act between the front suspension and the body, the steering, the front anti-roll bar and the front wheels.

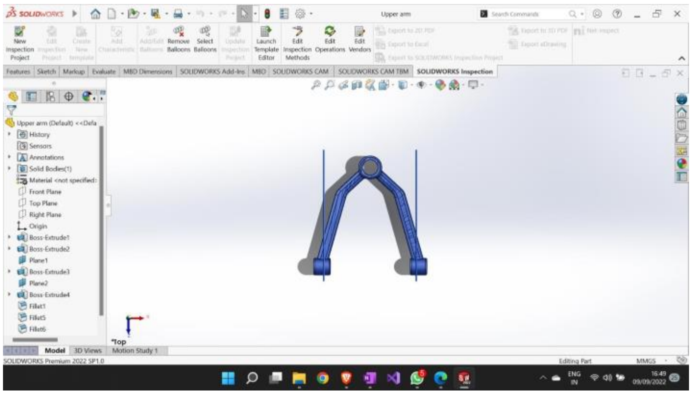
3.1.2 Rear Suspension Modelling

The rear suspension is also of SLA type. The model consists of uprights upon which the wheel hubs are connected with revolute joints. The control arms are connected to the upright with spherical joints. To the body the control arms are connected via revolute joints. The drive shafts are connected to the spindles with convel joints. The spindles are connected to the uprights with revolute joints. The drive shafts are also connected to the body with convel joints. The push rods are connected to the upright with spherical joints and to the rockers with hooke joints. The rockers are connected to the body with revolute joints and to the dampers with hooke joints. The toe linkage is connected to the uprights with spherical joints and with hooke joints to the lower control arms. The communicators in the rear suspension act between the rear suspension and the body, the steering, the rear anti-roll bar and the rear wheels.

4. DESIGN OF SUSPENSION

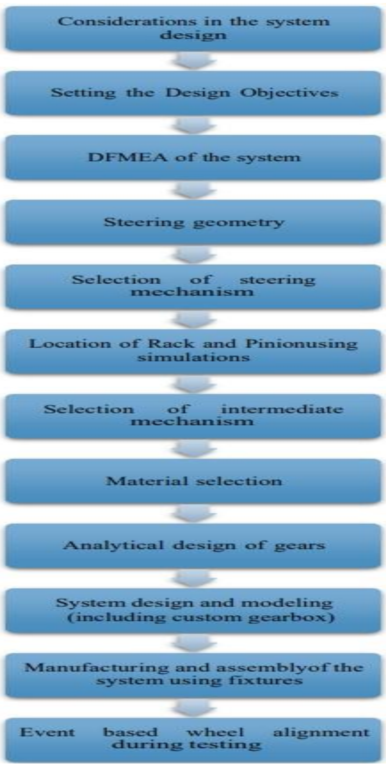






5 DESIGN METHODOLOGY

The methodology of design includes design procedure, calculations, modeling, and analysis as follows:



5.1 CALCULATION OF ACKERMAN ANGLE

Wheel Base = 1600mm

Track Width = 1350mm

For 80% Ackerman ,

Wheelbase = 0.8 x 1600mm

=1280mm

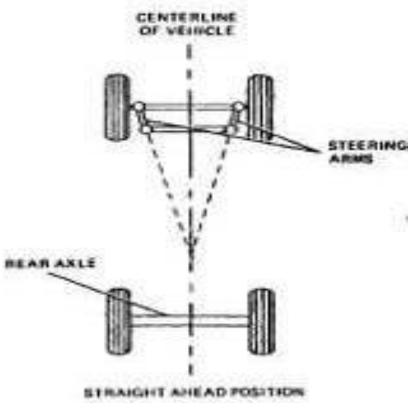
Half of track =1350 /2mm

=675mm

Hence,

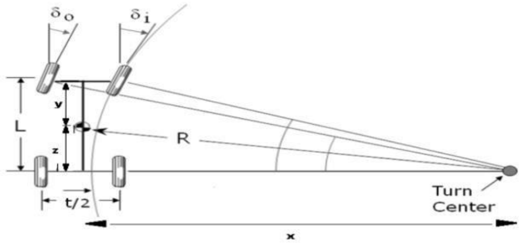
<u>Ackerman Angle</u> = $\tan^{-1}(675/1280)$

$=27.80^{0}$



5.2 TURNING RADIUS

Tight turning radius is required for the vehicle to maneuver around the sharp turns. Targetted turning radius is about 4 metres. As we know that the inner and the outer wheels rotate at different angles, the respective turning angles of the front wheels can be found out as shown below. Thus the amount of angle that the tires need to turn in order to turn the vehicle at 4 metres can be found out.



Calculation →

Wheel Base L = 1600mm

Required Turning Radius R = 4000mm

Track Width(Front) t =1350mm

Centre of Gravity(from front axle) y =960mm

Centre of gravity(from rear axle) z =L-y

=1600-960

=640mm

In Triangle EFO

Using Pythagoras Theorem

$$R^2 = z^2 + (t/2 + x)^2$$

$$(4000)^2 = (640)^2 + (1350/2 + x)^2$$

$16000000 - 409600 = (675 + x)^2$

$15590900 = (675 + x)^2$

X = 3273.4680

For outer wheel turning angle

$\tan \delta_0 = L/(t+x)$

$= 1600/4623.468$

$= 0.3460$

$\delta_0 = \tan^{-1}(.3460)$

$\delta_0 = 19.088^0$

For inner wheel turning angle

$\tan \delta_i = L/x$

$= 1600/3273.4680$

$= 0.4887$

$\delta_i = \tan^{-1}(.4887)$

$\delta_i = 26.248^0$

5.3 STEERING RATIO

Steering ratio is defined as the ratio of angle rotated at the steering wheel to the angle turned by the front wheels upon rotation. A tight turning ratio is required for the car driver to drive with the least movement of the steering wheel .This means that the wheels would be steered through an angle with comparatively less rotation of the steering wheel.
This is required considering the less space available for the hand and arm movement. Reducing the steering ratio , ie bringing it closer to 1 increases the effort required at the steering wheel.
Consider 90^o of steering wheel rotation

Rack travel in 270^o of steering wheel rotation
= 4 inch (specified in product)

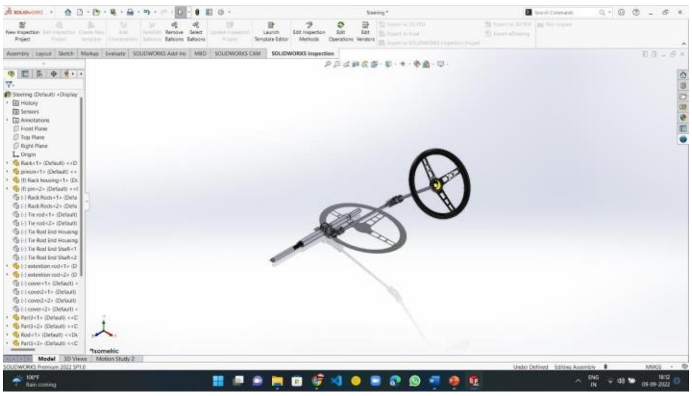
Rack travel in 90^o of steering wheel rotation
$=(4/270) \times 90$
$=1.334$ inch

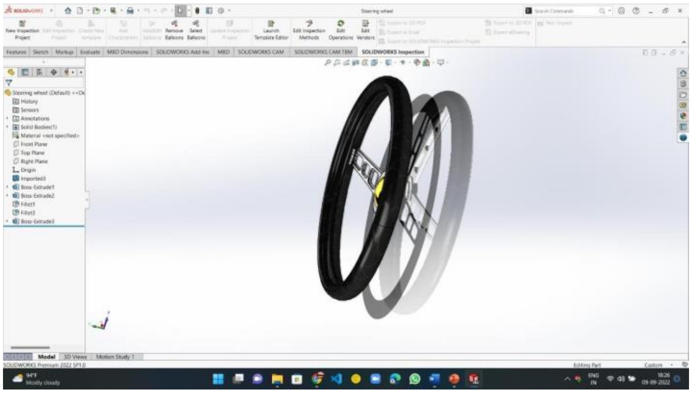
Length of steering arm =2.5 inch

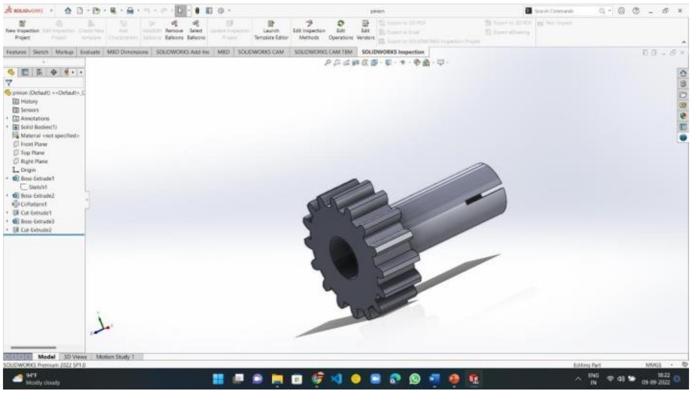
Steering arm rotated in 1.334 inch of rack travel
$=(1.334/2.5)(180/\pi)$
$=30.57^o$

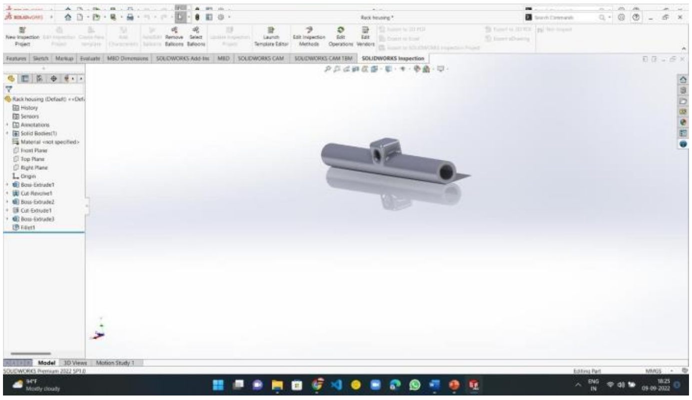
Hence steering ratio
$=90^o : 30.57^o$
$\approx 3 : 1$

6. CAD Design of steering system

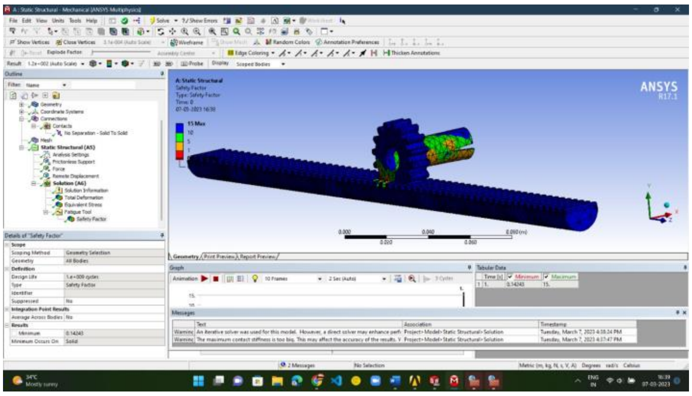


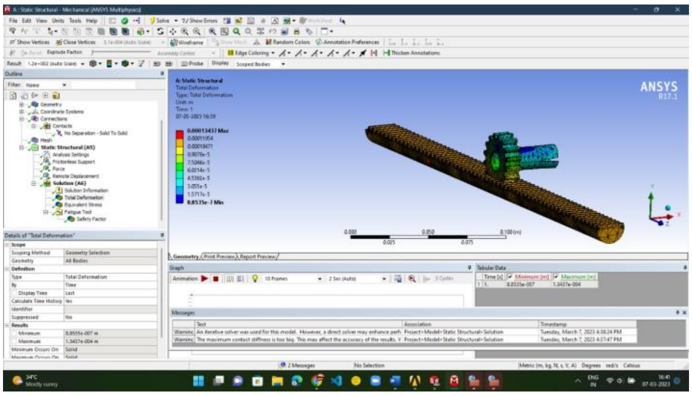


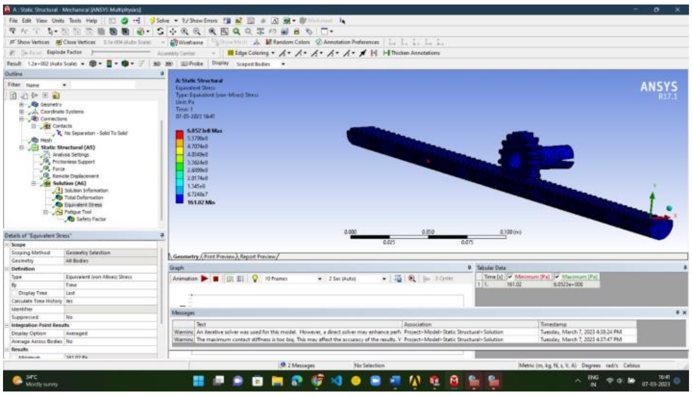




7. Analysis of steering system







4.CONCLUSIONS

This paper sums up the basic design and analytical concepts of the suspension and steering system used in student formula car. After designing wishbones, suspension damper, spring, steering rack, rack and pinion assembly and steering assembly 3D model built with the help of SOLID WORKS and analysis done on ANSYS workbench. Results obtained by simulation match with designed parameters. And after analyzing various suspension components, the paper lays down a methodology for analysis of different components. The FSAE guidelines have been thoroughly followed while working on this paper. Besides, it is to be noted that "Iteration is the key to perfection".

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