Abstract - The presented work outlines the optimum methodologies to design an efficient Suspension system for a formula student vehicle. This report is the final output of the suspension design and analysis done for Supra SAE 2024. The work was performed under SUPRA SAE rulebook restrictions and guidelines for an efficient vehicle buildup that accompanied optimum speed and considered excellent ride comfort. The paper enlists various methodologies adopted for designing and analysing suspension systems, including control arms, damper springs, and knuckles. LOTUS software was used for static and dynamic analysis of suspension assembly considering various geometrical attributes such as Roll centre, Wheel travel, and wheel alignment angles such as Camber, caster, and toe angles. The 3D modelling of the system assembly was performed on SolidWorks, whereas the analysis was carried out on ANSYS workbench.

***Key Words*: Double Wishbone system, Suspension Damper & Spring, LOTUS software, ANSYS simulation software, Knuckle & Hub**

1. INTRODUCTION

The purpose of the car's suspension is to keep all four wheels in optimal contact with the ground under any conditions. A well-designed suspension must handle bumps, uneven surfaces, and dynamic cornering, braking, and acceleration. The FSAE car is a race car purpose-built for a prepared track, so performance and handling will be prioritized over smoothness and suspension travel. Generally, a system of shocks (dampers), springs, uprights, and arms keep a vehicle suspended above ground on its wheels. The primary components involved in the system include damper & springs, wishbones, knuckle/upright, and wheels. A Double wishbone suspension design was primarily used for its aerodynamic and adjustability advantages. The main requirement is a structure that will absorb the energy and transfer it to the frame without disturbing the system. The study of the forces at work acting on a moving car is called vehicle dynamics, and the concepts required for designing suspension systems are encapsulated further.

2. DESIGN METHODOLOGY

For the competition we used Double wishbone suspension system due to its high structural strength and its ease of track tuning. The main requirements for the suspension system are:

- It should have a minimum travel of 25 mm in both jounce and travel.
- The system must be responsive and also stable enough to give best performance in cornering and straight line.
- The system should be such that it should help maintain maximum tire contact patch for better friction.
- It must be structurally strong but also lightweight to maintain low unsprung mass. Following above assumptions after multiple iterations over LOTUS software the various basic parameters were decided & discussed upon and finally confirmed at requisite values:-

1. Wheel Base: 1621 mm
2. Front Track-width: 1135 mm
3. Rear Track-width: 1135 mm

4. Camber Angle: 0 in both front and rear
5. Caster Angle: 0 (front) & 0 (rear)
6. Toe Angle: 0 in front and 0 in rear
7. Kingpin Inclination: 0 in front and 0 in rear
8. Total Mass of Vehicle (with driver):350 kg
9. Sprung weight: 290 kg
10. Weight distribution: 42:58 (front: rear)

Load Calculations:

S.no	Quantities used in Calculations	Symbol	Values (in SI units)
1.	Wheel Base	W	1.621
2.	Track width	t	1.135
3.	Total Mass of Vehicle (with driver)	M	350
4.	Height of CG	h	0.419
5.	Longitudinal load transfer	W_L	
6.	Roll Angle	phi	0.0158
7.	Max Deacceleration(m/s^2)	d	6.725
8.	Lateral load transfer due to cornering (rear	LLTR	
9.	Cornering force rear axle(N) [y]	CFR	20300
10.	Cornering force Front axle(N) [y]	CFF	14700
11.	Roll Centre Height rear (m)	RCHR	0.07
12.	Roll Centre Height front (m)	RCHF	0.124
13.	Vehicle front roll stiffness (Nm/rad)	$K\phi f$	17391.0375
14.	Vehicle Rear roll stiffness (Nm/rad)	$K\phi r$	17391.0375
15.	Max tractive force (N)	$F_{x\ max}$	
16.	Friction Coefficient	u	0.7
17.	Front weight: Total Weight	W_f	0.42
18.	Rear Weight: Total Weight	W_r	0.58
19.	Rolling Resistance Force	F_r	
20.	Rolling friction coeff	f_r	0.05

1. **Longitudinal load transfer(N)**
   During braking, a dynamic load transfer from the rear to the front axle occurs, which is given by
   W_L (in N) = M*h*d/W

= 350*0.419*6.725/1.621
= 608.402992
This force is transferred to both front tyres.

2. Lateral load transfer due to cornering (N)

This is the force which is transferred to the outer wheel from the inside wheel during cornering and it is given by,

For rear,
LLTR = 2*(Kϕr *phi + CFR*RCHR)/t
= 2*(17391.0375*0.0158 + 20300*0.124)/1.135
= 2988.54 N

For Front,
LLTF = 2*(Kϕf*phi + CFF*RCHF)/t
= 2*(17391.0375*0.0158 + 20300*0.07)/1.135
= 3696.56 N

3. Max tractive force (N)

$F_{x\ max}$ **= (u*M*9.81* W_r)/(1-h/W*u)**
= (0.7*350*9.81*0.58)/(1-0.419/(350*0.7))
= 1700.21 N
This is force required on 4 wheels through the engine.

4. Rolling Resistance Force(N)

This is the force arises because of continuous elongation and compression of tyre at contact patch

F_r = M* f_r ***9.81**
= 350*0.05*9.81
=171.5 N

5. force on front tyre during braking(N)= 1223 N
6. force on rear tyre during braking(N) = 961 N

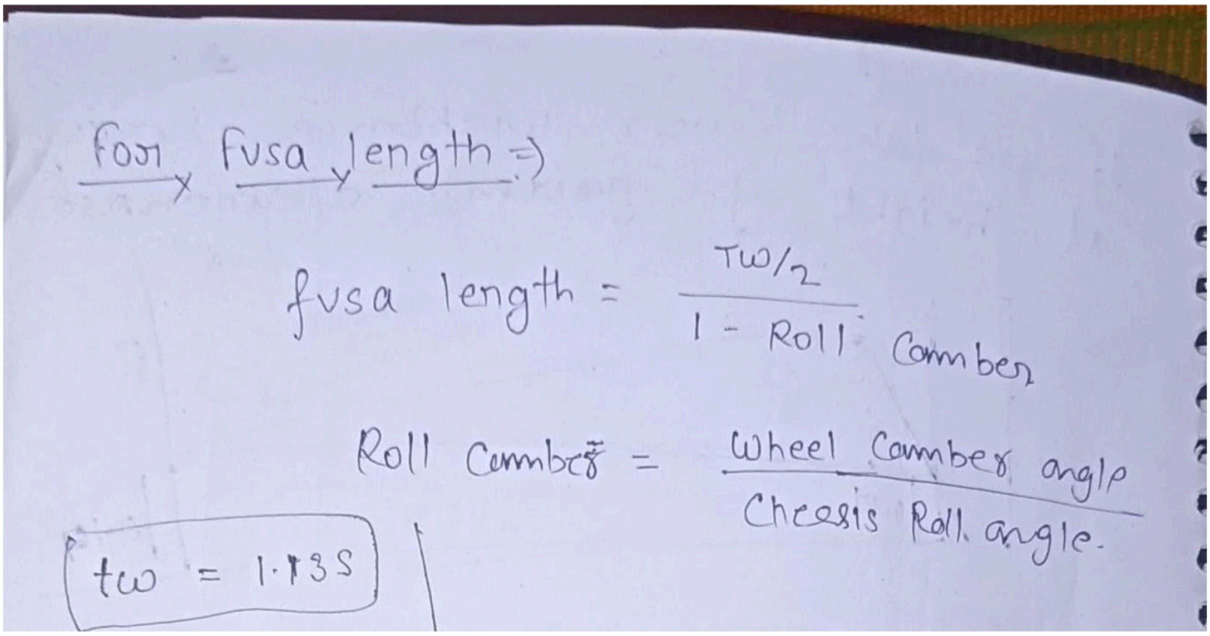
Design Procedure Followed

Mounting points of the Control Arms
↓
Design of the control arms
↓
Design of the Knuckle
↓
Tyre specifications
↓
Design of the Wheel Hub

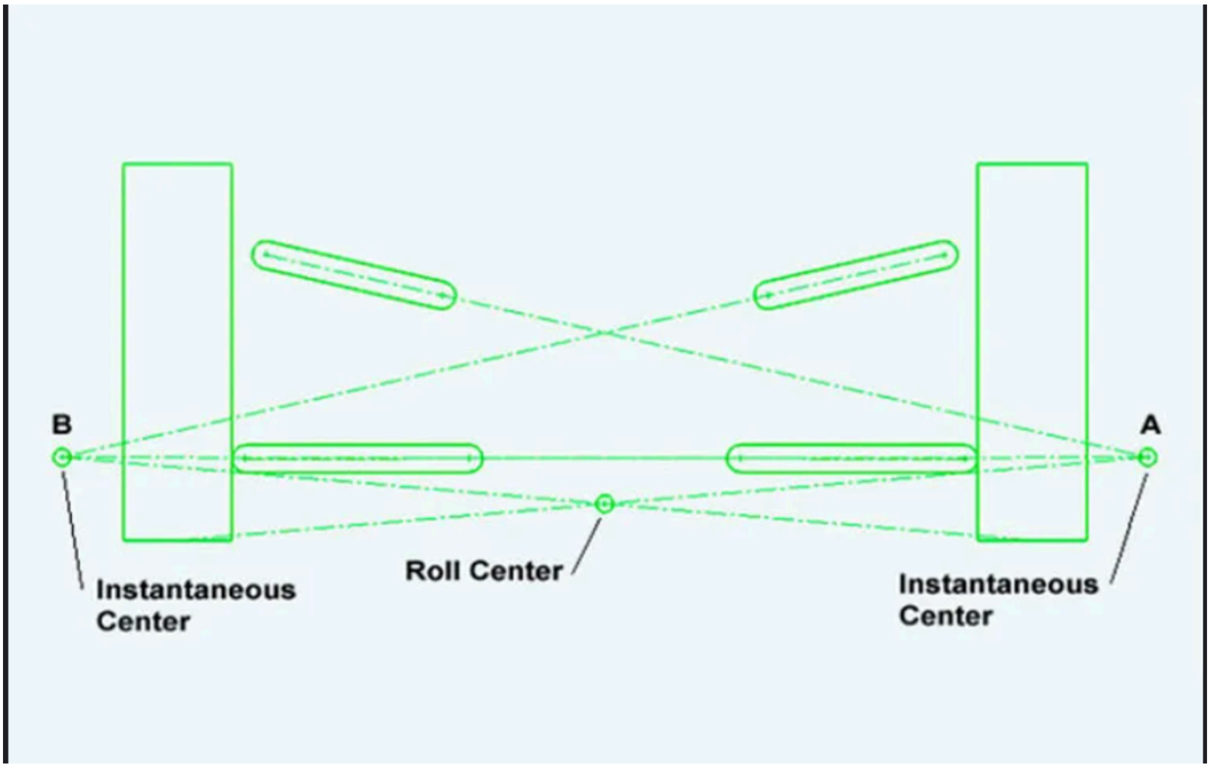
Calculation of Mounting points

After iterative analysis on MATLAB the **roll center height** was decided to be **50mm** below the CG of the vehicle.

The instantaneous center of rotation was calculated with the help of the FVSA (Front View Swing Arm) Length.



The FVSA is the distance between the Instantaneous center of rotation and the center of the Tyre.



Finally, the angles of the control arms were calculated by joining the upper and lower control arms mounts with the calculated ICOR.

Design of the Control Arms

After the calculation of the coordinates of the chassis mounts of the control arms following were the lengths of the control arms:

Front Upper Wishbone Lengths: 307.66mm and 299.04mm

Front Lower Wishbone Lengths: 382.06mm and 347.71mm

Rear Upper Wishbone Lengths: 451.96mm and 410.61mm

Rear Lower Wishbone Lengths: 454.06mm and 416.83mm

The Wishbones were designed on SolidWorks using 3D custom weldments.

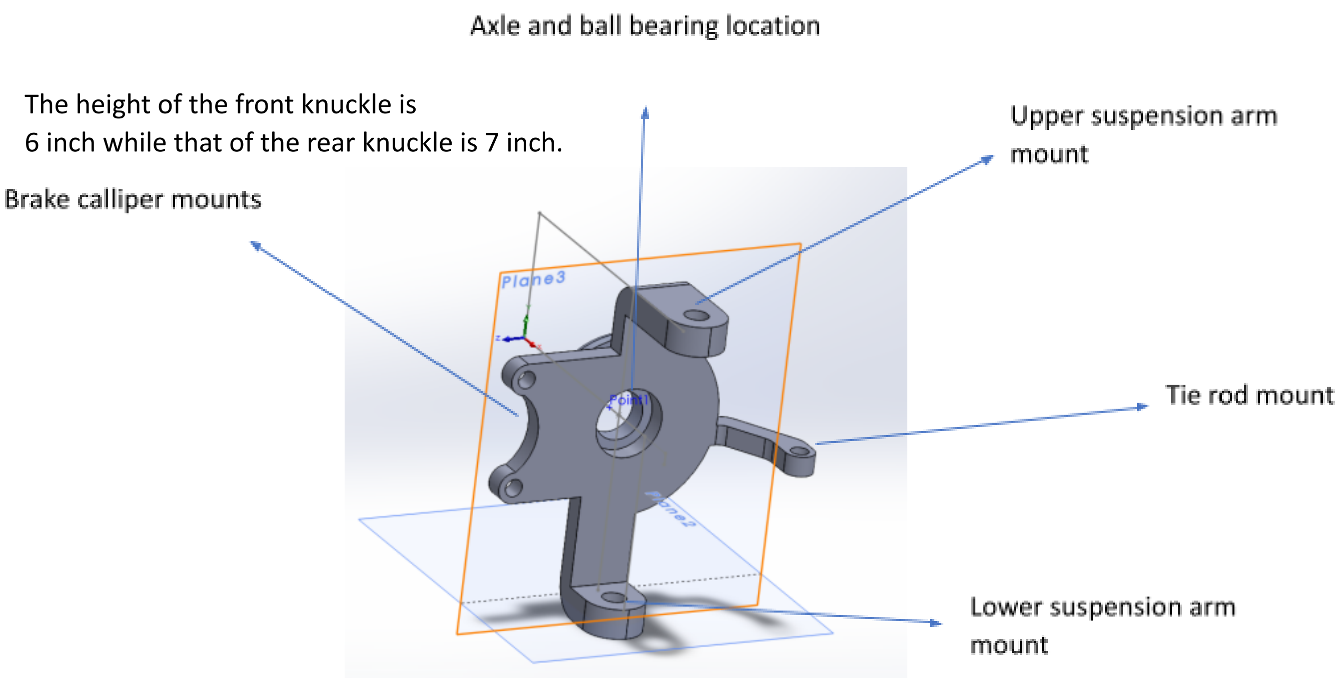
FRONT WISHBONE

REAR WISHBONE

Design of the Knuckle

CAD Model of the Knuckle was made on the 3D Modelling software SolidWorks. It consists of Tie rod mounting point, Brake Caliper mounting point, Suspension upper arm mounting and Suspension lower arm mounting. Knuckle geometry depends upon suspension and steering geometry. The design was prepared strictly following the FSAE rules and regulations. The material chosen was Aluminium 7076 T6 because of its more strength to weight ratio. It can bear a maximum load of 2808N with a deformation of less than 2mm. It has minimum FOS of 2.

The height of the front knuckle is 6 inch while that of the rear knuckle is 7 inch.



Tyre Specifications

Tyre Width -- 205mm

Aspect ratio – 50

Wheel Rim Size – 10 inch

The Wheel Rim size was finalised keeping in mind the weight of the corresponding wheel hub.

Design of the Wheel Hub

Wheel Hub is the mounting part for the wheels. It contains wheel bearings. It supports the vertical load on the vehicle and transfers load from the vehicle to the wheels.

Material Selection – Following are the properties of Al 7075 T6 which was chosen for the wheel hub

Property	Value	Unit
Density	2.81	g/cm^3
Young’s Modulus	71.7	GPa
Poisson’s ratio	0.33	
Tensile Yield Strength	503	MPa
Tensile Ultimate Strength	572	MPa

Outer Diameter of the Wheel Hub – 6 inch

Inner Diameter of the Wheel Hub – 2.5 inch

Diameter of the bolt holes – 8mm

Load Calculations for the Front Wheel Hub

Frame of reference – The -ve X direction is taken to be the direction of the weight. The -Y direction is taken to be opposite to the direction of cornering force when the vehicle is taking a left turn. The -Z direction is taken to be that of the traction force.

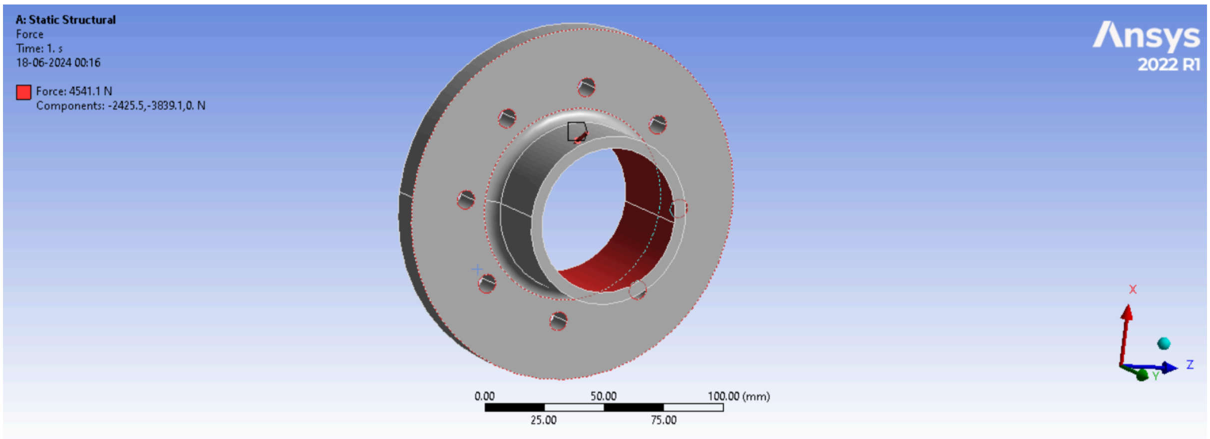
Load in -Z direction – 0.5*(Force due to front weight of the vehicle + Downforce + Longitudinal load transfer) + Lateral load transfer on the front

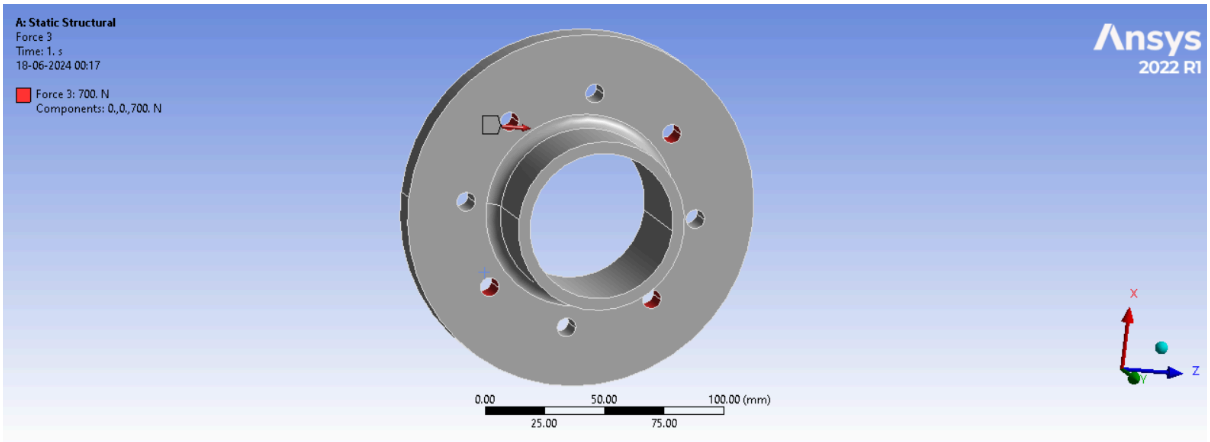
= 0.5*(147*9.8 + 260 + 608.4) + 3696.6 = **4851.1N**

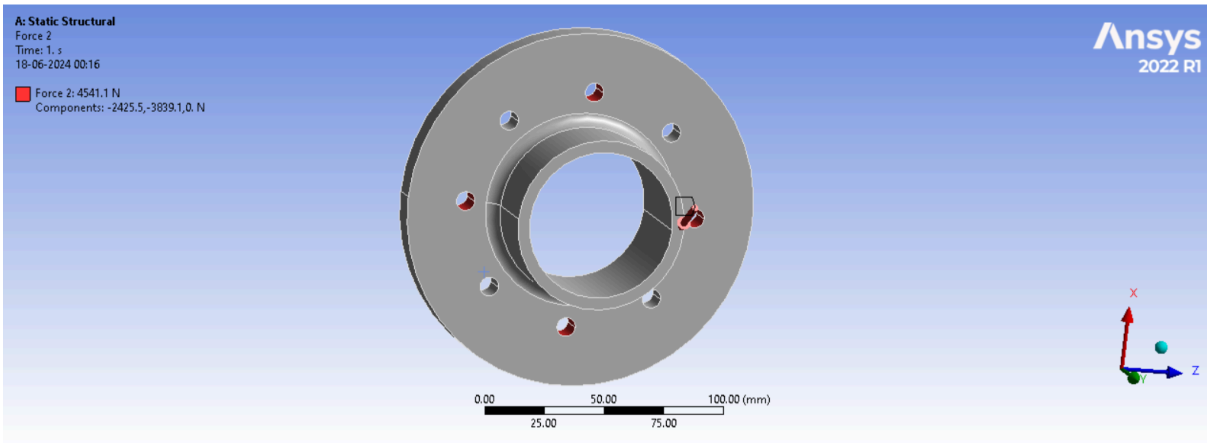
Load in -Y direction – Force due to lateral acceleration per tyre + 0.5*(Cornering force on front axle)

= 328.16 + 0.5*(14700) = **7678.16N**

Load in X direction – 0.5*(Braking force on Front tyre) = 0.5* 1400 = **700N**







Load Calculations on the Rear Wheel Hub

Frame of reference – The -ve X direction is taken to be the direction of the weight. The -Y direction is taken to be opposite to the direction of cornering force when the vehicle is taking a left turn. The -Z direction is taken to be that of the traction force.

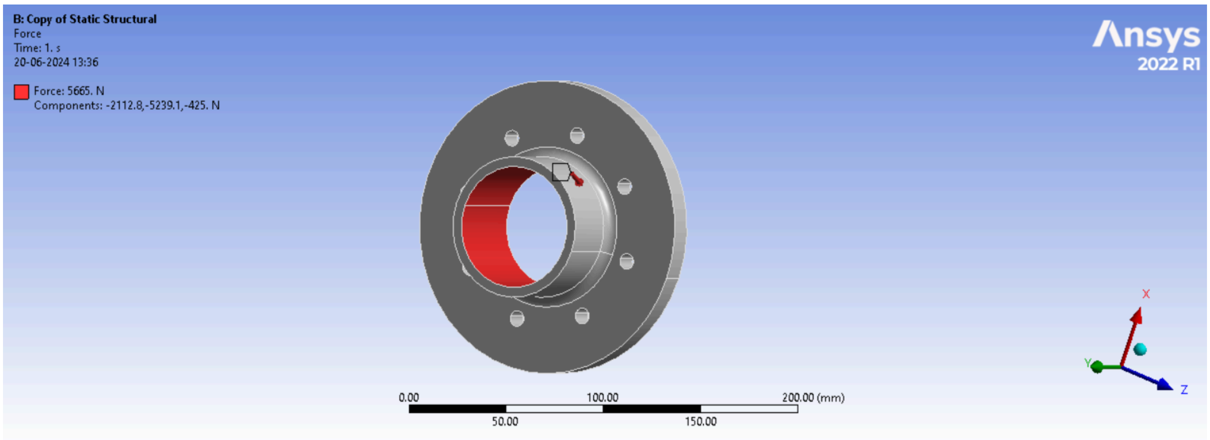
Load in -Z direction – 0.5*(Force due to Rear weight of the vehicle + Rear tyre lateral load transfer) + Lateral load transfer on the rear.

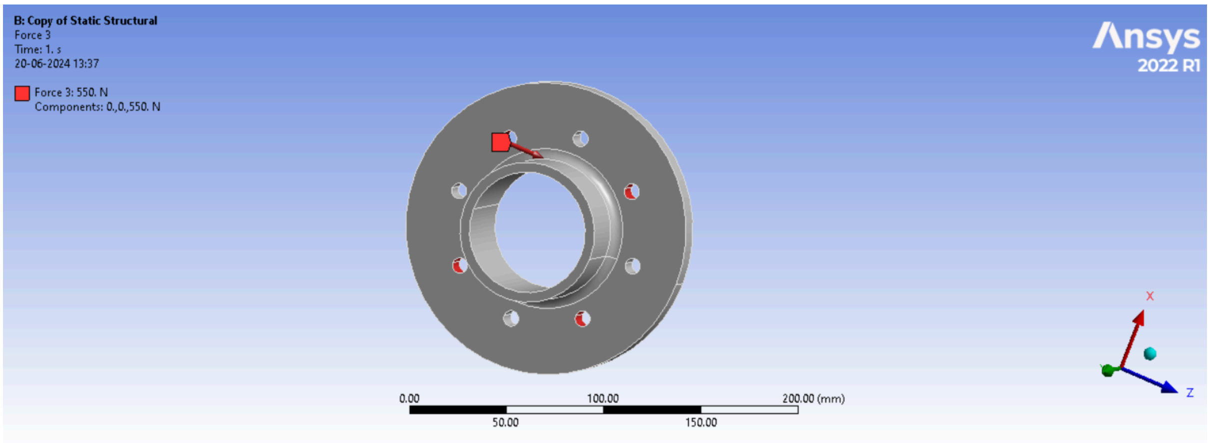
= 0.5*(203*9.8 + 242.3) + 2988.546 = **4104.396N**

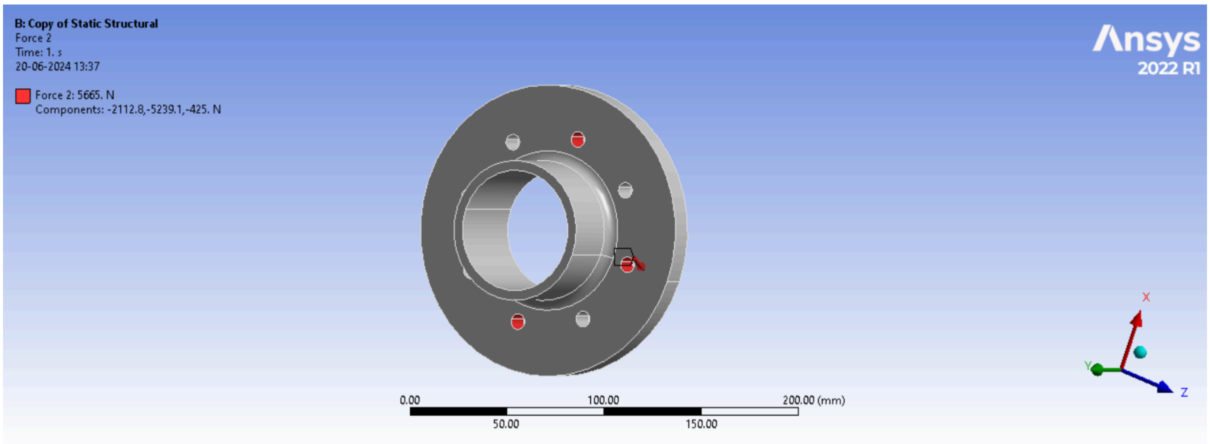
Load in -Y direction – Force due to lateral acceleration per tyre + 0.5*(Cornering force on rear axle)

= 328.16 + 0.5*(20300) = **10478.16N**

Load in X direction – 0.5*(Braking force on Rear tyre – Traction Force) = 0.5* (1100 – 1700) = **-300N**



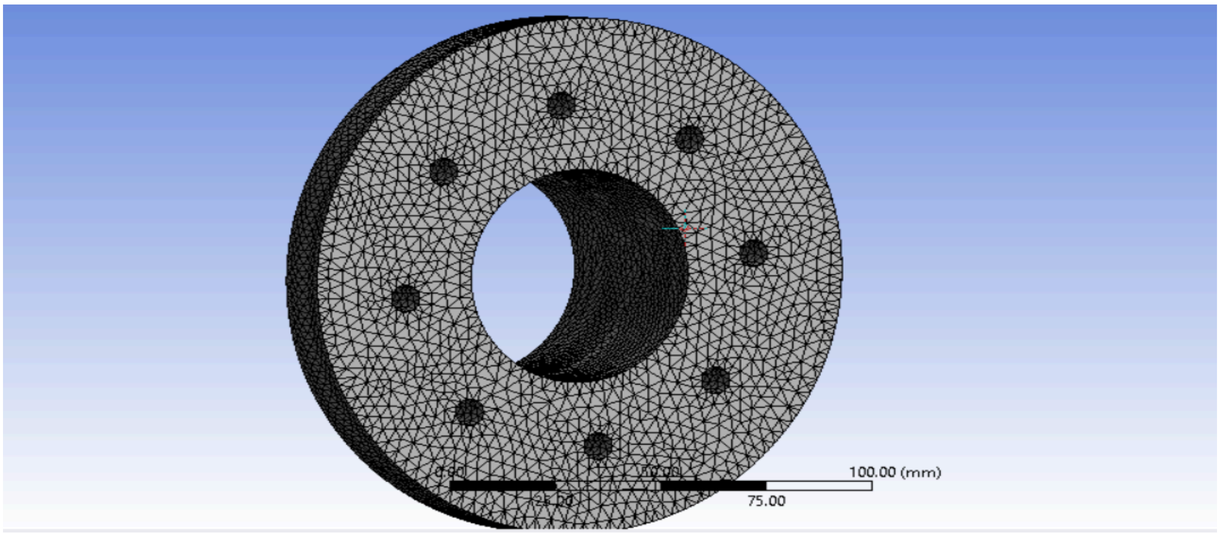




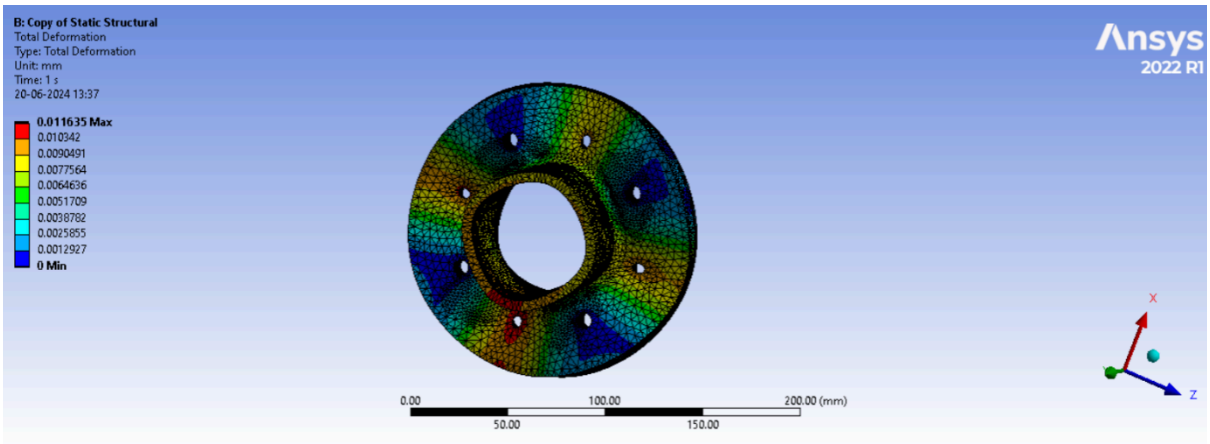
Meshing (

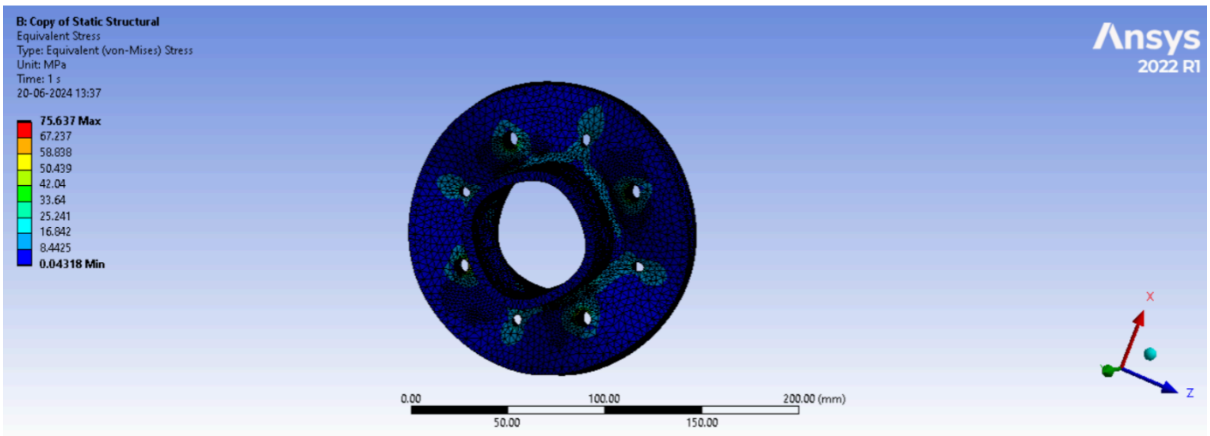
Number of Nodes	**72340**
Number of Elements	**40981**
Element Shapes	**Tetrahedral**

Type of Analysis	Static Structural

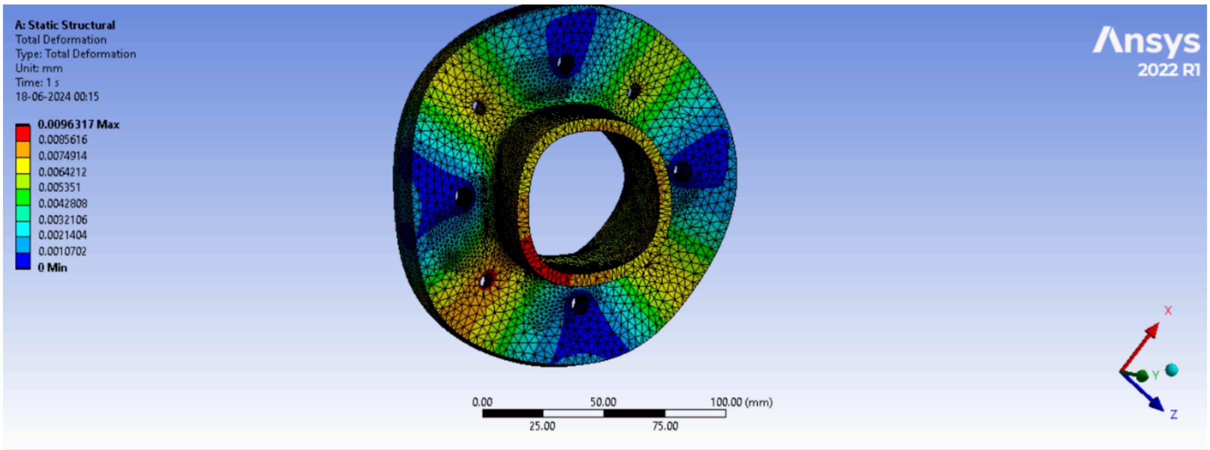


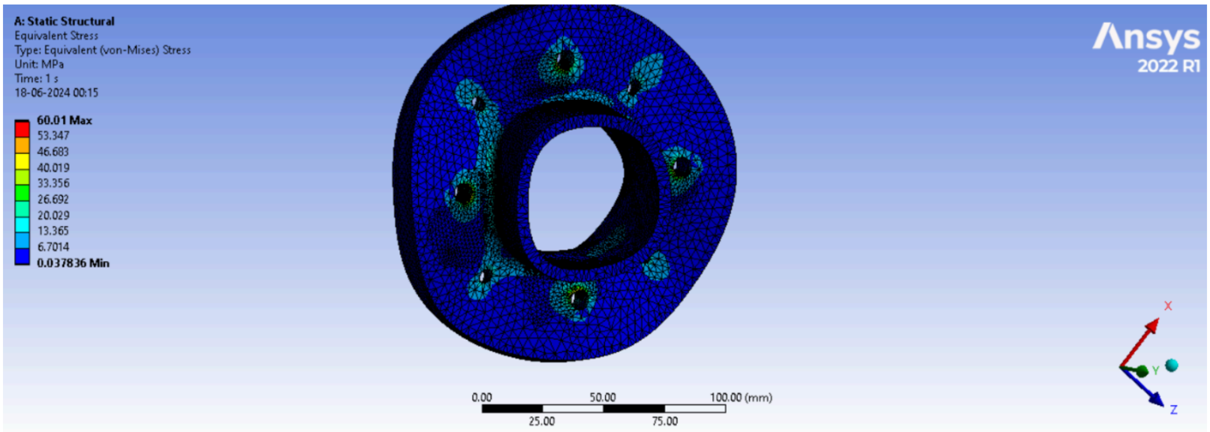
Results(Rear Wheel Hub)





Results (Front Wheel Hub)





Front Wishbone load calculations

Frame of reference – The +ve Z direction is taken to be the direction of the weight. The -Y direction is taken to be in the direction of cornering force when the vehicle is taking a left turn. The -X direction is taken to be that of the traction force.

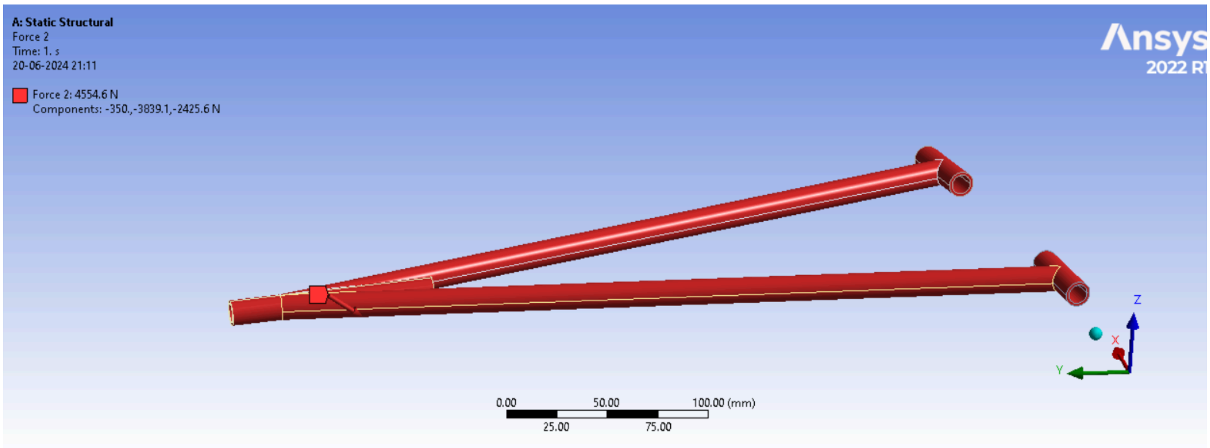
Load in +Z direction – 0.25*(Force due to front weight of the vehicle + Downforce + Longitudinal load transfer) + 0.5*(Lateral load transfer on the front)

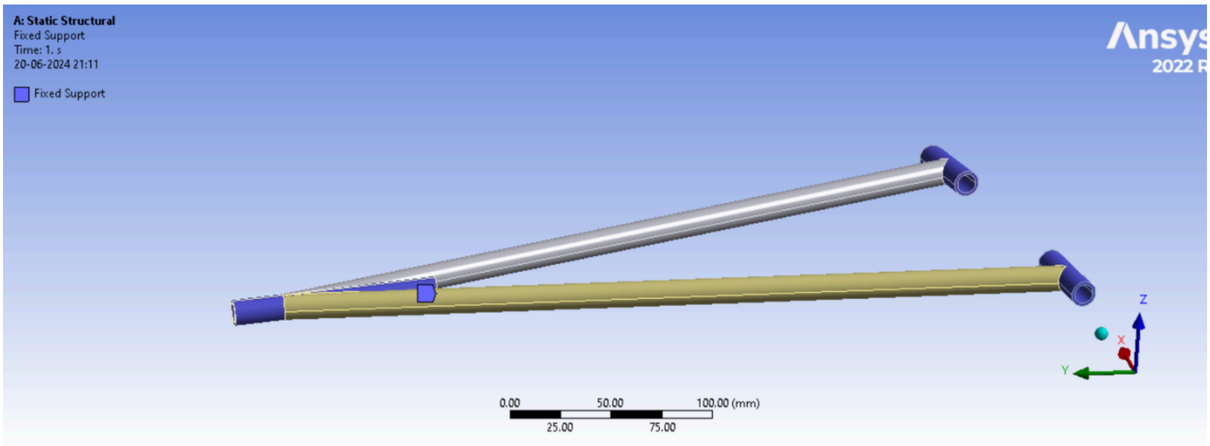
= 0.25*(147*9.8 + 260 + 608.4) + 0.5*(3696.6) = **2425.55N**

Load in -Y direction – 0.5*(Force due to lateral acceleration per tyre) + 0.25*(Cornering force on front axle)

= 0.5*(328.16) + 0.25*(14700) = **3839.08N**

Load in X direction – 0.25*(Braking force on Front tyre) = 0.25* 1400 = **350N**





Rear Wishbone Load Calculations

Frame of reference – The +ve Z direction is taken to be the direction of the weight. The -Y direction is taken to be in the direction of cornering force when the vehicle is taking a left turn. The -X direction is taken to be that of the traction force.

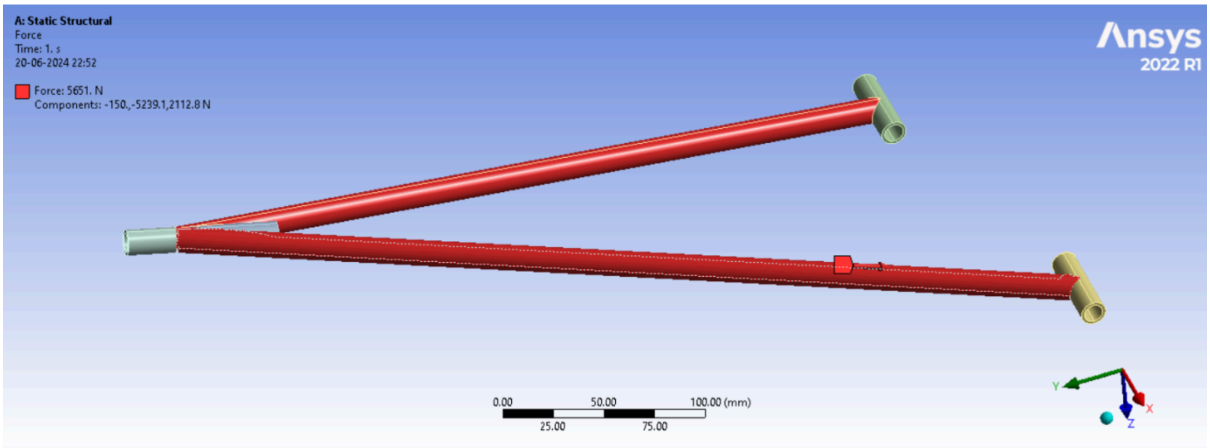
Load in -Z direction – 0.25*(Force due to Rear weight of the vehicle) + 0.5*(Rear tyre lateral load transfer + Lateral load transfer on the rear).

= 0.25*(203*9.8) + 0.5*(242.3 + 2988.546) = **2112.773N**

Load in -Y direction – 0.5*(Force due to lateral acceleration per tyre) + 0.25*(Cornering force on rear axle)

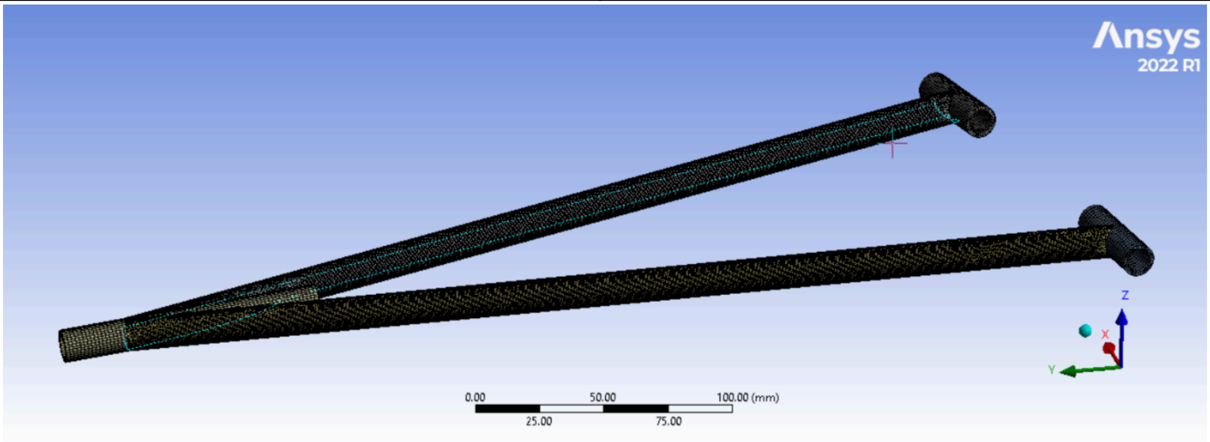
= 0.5*(328.16) + 0.25*(20300) = **5239.08N**

Load in X direction – 0.25*(Braking force on Rear tyre – Traction Force) = 0.25* (1100 – 1700) = **-150N**

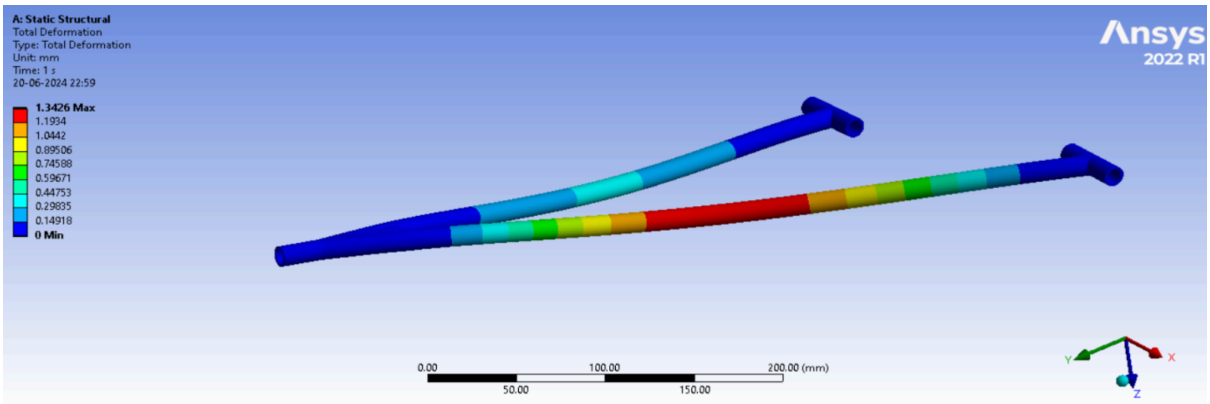


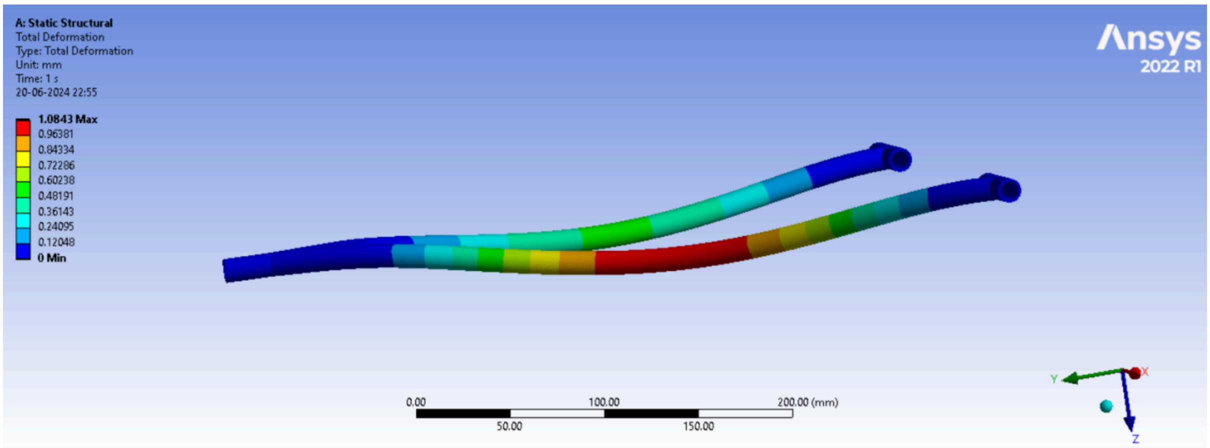
Meshing

Number of Nodes	**471347**
Number of Elements	**248986**
Element Shapes	**Tetrahedral and Regular sized**
Type of Analysis	**Static Structural**



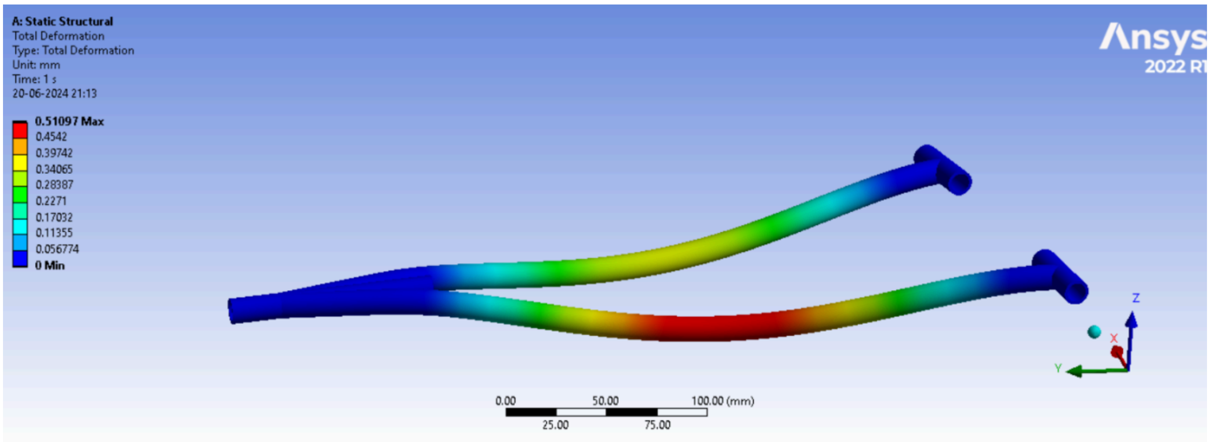
Results (Rear Wishbone)





Lower

Results (Front Wishbone)



Upper

Knuckle Design

Properties	front Knuckle	Rear Knuckle
Material	Aluminium 7075t6	Aluminium 7075t6
Density(g/cm^3)	3	3
Mass(g)	615.83	443
Total Height(in)	7	6

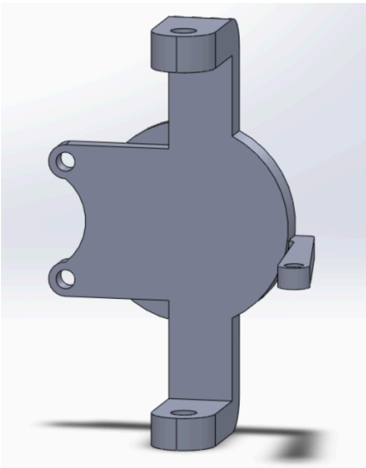


Fig. Front Knuckle

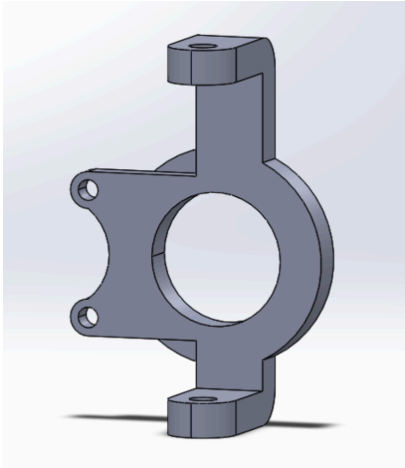
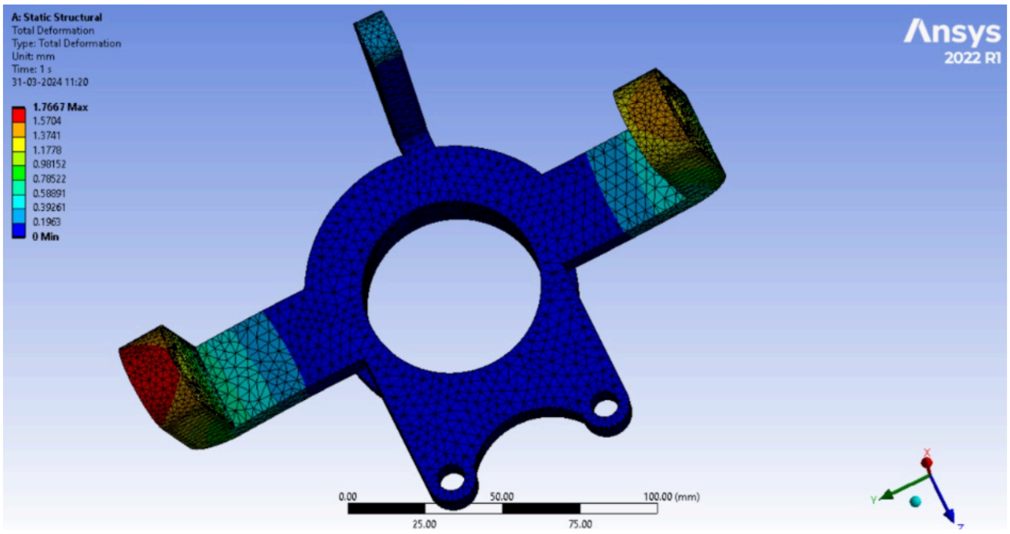
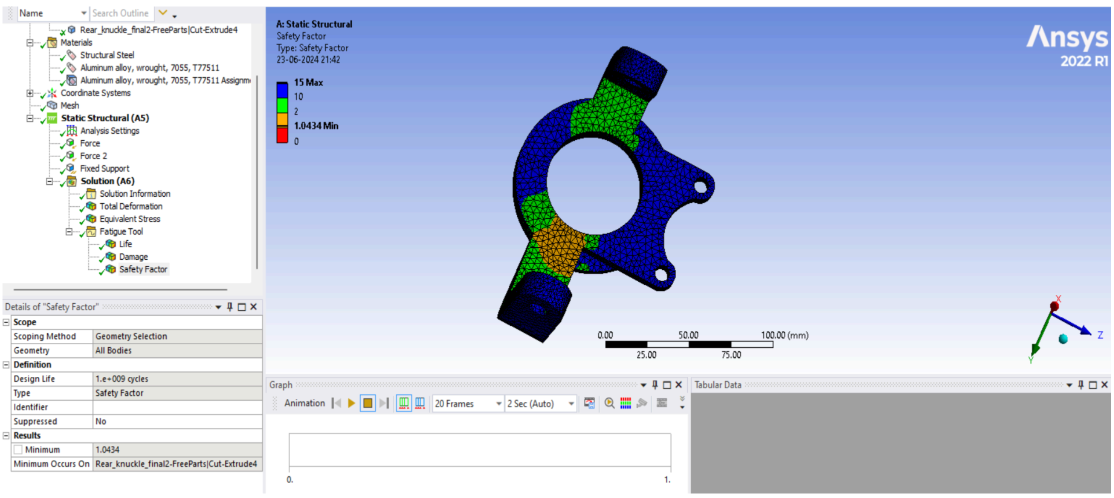


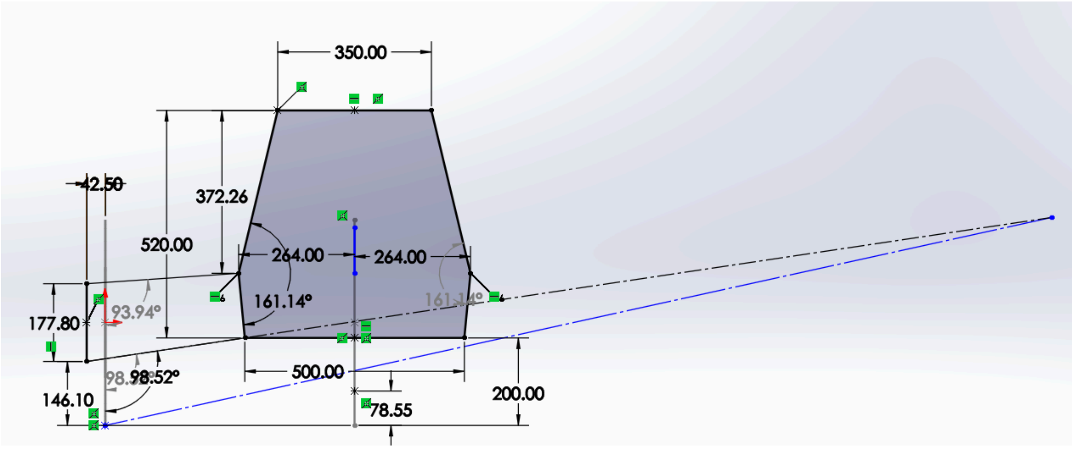
Fig. Rear Knuckle



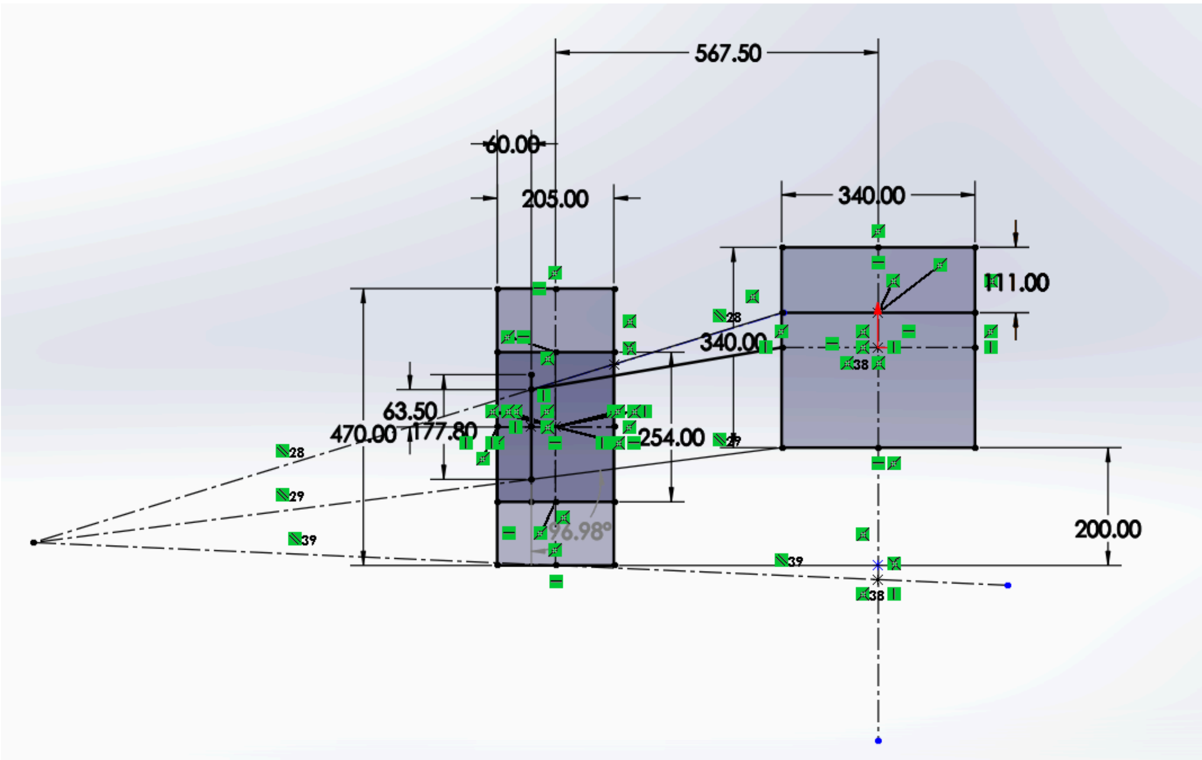
Front Knuckle Static Analysis



Rear Knuckle Static Analysis



Front 2D view



Rear 2D view