International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

# MODELLING AND ANALYSIS OF UPRIGHT AND HUB FOR FORMULA STUDENT VEHICLE

**Mr. A. Vijay Kumar, A Hemanth Reddy, D Jai Bharath Reddy, K Sachin**
[1]Assistant Professor, [2]Student, [3]Student, [4]Student
Mechanical Department
Guru Nanak Institute of Technology, Hyderabad, India.

***Abstract**:* The upright or knuckle attaches the wheel, brake rotor, hub, brake calliper, Steering arm, upper and lower control arm. The design of the upright or knuckle determines the geometry on the outboard side of the suspension. The mount points on the chassis and wishbones/links form the inboard side of the suspension, and provide their own contribution to the overall geometry of the suspension and that affects the dynamics of the vehicle. Initially suspension is designed using lotus shark software and by using that hard points upright is modelled using Solid works software. While modelling various parameters like hub diameter, brake calliper mounts, bolt size, rim spacing is taken into consideration. The model is meshed using ANSYS and analysed based on the loads calculated using analytical method using formulae of various manures possible.

The results from the analysis are taken and considered as input for the iterations on the model and the model which offers better factor of safety and less weight is considered for manufacturing.

**KEYWORDS:** Upright, Lotus shark, Solid Works, ANSYS.

## 1. INTRODUCTION

### 1.1. Suspension system

Suspension is the part of automobile that negates the most of the forces that the car gets from driving on the road making sure the cabin stays still. It can be small rocks on the road to big potholes, suspension deals with them all. This is a normal understanding we have that the job of a suspension is to only provide a cushion when a bump or a crack appears on the road. It does much more than that. It makes it easier to drive a car.

**Figure 1:** Suspension system

The suspension works on the principle of force dissipation which involves converting force into heat thus removing the impact that force would have made. It uses springs, dampers and struts to achieve this. A spring will hold the energy while a damper will convert into heat.

There are few important parts in the suspension system, discussed below.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

### 1.1.1. SPRING

The job of a spring in a suspension system is to store the energy that is generated when the car goes through a bump. A spring or a coil stores energy by compressing its size thus making any type of force into energy. The amount of energy spring can hold depends on a multitude of factors. Including and not limited to the length, the material of the spring and the coefficient of spring. The material is included because some springs might be able to hold more energy but with a non-durable material, the spring might falter.

There are two types of springs used for suspension a coil spring and a leaf spring. A coil spring is a common one which most you might have seen. A leaf spring is used on a solid axle so basically in trucks and has very high energy storing capacity compared to a coil spring.

Spring is good for providing a cushion however your car will keep on bouncing around giving you absolutely no control over it which is not a good thing. When you speed up your car or when you take a corner having only springs in your car will make it keep on moving back and forth.

**Figure 2:** Leaf spring


**Figure 3:** Coil spring

### 1.1.2. DAMPER

The energy stored by the springs need to go somewhere else it will be released by the springs again with some minor transfer loss and your car will keep on jumping around at every crack in the road. After the spring stores the energy, the dampers or shock Absorbers start working. Inside a damper is a piston with small holes in it and some Pressurised oil. When the spring transfers the energy to the damper the piston moves through the pressurised oil by using the energy of the spring. Passing through the oil generates heat, successfully converting the energy of the bump in the road into heat energy and negating any energy left which would have caused the car to jump.


**Figure 4:** Spring-damper setup

### 1.1.3. A-ARMS

In suspension, a A-arm, also known as control arm, is a hinged suspension upright or hub that carries the wheel. The inboard (chassis) end of the control arm is attached by a single pivot in double shear, usually bushings either rubber or steel ones. It can control the position of the outboard end in only single degree of freedom, the single bushing does not control the arm from moving back and forth. This motion is constrained by a separate link or radius rod.

**Figure 5:** Double wishbone setup

### 1.1.4. TYRES

Tyres is important for the suspension to keep the road wheel in contact with the road Surface as much as possible, because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension of a car may be different because of it effects the dynamics of the vehicle and basically the front tires are relatively smaller due this set up provides less roll centre.

### 1.1.5. ANTI-ROLL BAR

An anti-roll bar is a part of many automobile suspensions that helps reduce the body roll of a vehicle during the fast cornering or over road irregularities. It connects opposite (left/right) wheels together through short lever arms linked by a torsion spring. The A sway bar increases the suspension roll stiffness-its resistance to roll in turnsindependent of its spring rate in the vertical direction.

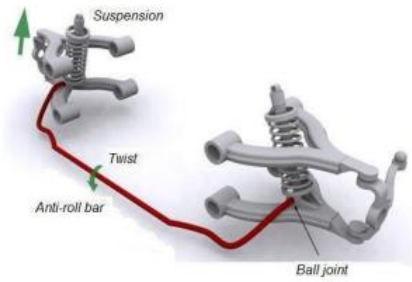



**Figure 6:** Anti-roll bar

### 1.1.6. UPRIGHT

The upright or knuckle attaches the wheel, brake rotor, hub, brake calliper and steering arm to the vehicle. The upright also locates these components in space.

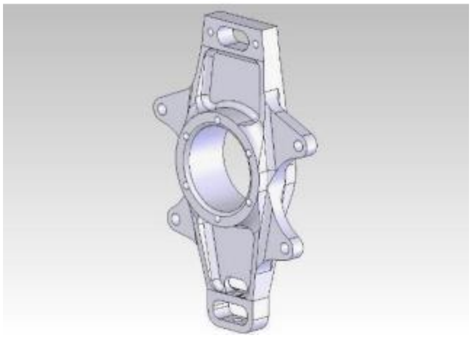


**Figure 7:** Upright of formula student vehicle

### 1.2. SUSPENSION USED IN FORMULA STUDENT VEHICLE

For formula student vehicle performance and handing are prioritized. The vehicle is expected to suffer large cornering forces and high –g cornering forces so the suspension plays a key role in keeping tire in contact with the ground. And the suspension must maintain the motion ratio (spring travel/wheel travel). So, the double wishbone suspension is not suitable for this purpose, because to maintain the motion ratio in 1:1 ratio the spring and damper must be aligned in 90 degrees which is not optimum for the formula student vehicle which causes ride height, mounting issues.

To maintain the motion ratio to 1, a pushrod and rocker arrangement is used. The push or pull rod is mounted on the upright and a rocker is mounted on the frame the push or pull rod actuates the rocker arm.

The pivot lengths of rockers are adjusted to produce the motion ratio to 1.

#### 1.2.1. DOUBLE WISHBONE – PUSH ROD SUSPENSION

In a push-rod suspension system, there is an upper and lower control arm, similar in design to a double-wishbone frame, which provides a structurally integral connection between the wheel hubs and the chassis. These arms are able to pivot inwards towards the centre of the vehicle, meaning that as the wheels experience shocks from the ground, they move up and down.

Between these two wishbone control arms, the wheel hubs connect to a rigid 'push rod'. Here, as the wheels move longitudinally, this rod will push upwards against an oscillating rocker arm, creating a see-sawing motion that transfers latitudinal forces from the ground into longitudinal forces inwards towards the chassis.

**Figure 8:** Double-wishbone pushrod suspension

### 1.3. SOFTWARES USED

Various soft wares are used for modelling and analysis, i.e.

1. Lotus shark for Designing of suspension.
2. Solid works for modelling of Modelling of upright.
3. Ansys for analysis and optimization of upright.
4. Ultimaker Cura for slicing of the upright.

#### 1.3.1. Solid works

Solid works is one of the most commonly used CAD programs today. It is a mechanical design automation application that lets designers create structural models quickly and precisely. When you want to sketch ideas, experiment with features and dimensions, and produce models and drawings. It lets you visualize how your design will look after manufacturing. Additionally, any changes you make to a part will reflect in all associated drawings. Solid works includes all familiar Windows functions, such as dragging and resizing windows in its interface for easier use. Many of the same icons, including open, save, cut and paste, and print is also included in the application. Solid works also allows collaboration between workspaces allowing other designers to see your progress and offer feedback.

### 1.3.2. Ansys

Ansys develops and markets finite element analysis software used to simulate engineering problems. The software creates simulated computer models of structures, electronics or machine components to the simulate strength, toughness, elasticity, temperature distribution. Electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys may simulate how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

### 1.3.3. Lotus shark

Lotus shark is suspension design software offered by Lotus Corporation. It consists pre- defined models that can be iterated according to our requirements. It offers different suspension parameters to iterate like camber, caster, toe, and king pin inclination.

### 1.3.4. Ultimaker cura

Ultimaker cura is open source 3d printing software. It provides integration of CAD, materials and 3d printer. The model can be uploaded in the Ultimaker cura and it is sliced for 3d printing and the G-codes are formed based on the slicing and geometry of the model and the G-codes are exported to 3D printer for printing of the model.

## 1.4. Suspension parameters

There are different parameters that are considered while designing suspension that affects the vehicle in dynamic condition and that also shapes the upright.

They are as follows.

### 1.4.1. Camber Angle

A wheel alignment adjustment of the inward or outward tilt on the top of the wheel when viewed from the front of the vehicle. Tipping the top of the wheel center line outward produces positive camber. Tipping the wheel Centre line inward at the top produces negative camber. When the camber is positive, the tops of the tires are further apart than the bottom. Correct camber improves handling and cuts tire wear.

Camber is of two types, positive camber and negative camber.

If the tire is viewed from the front, if the tire leans too much inwards then its negative camber. If the tire leans outwards then it is positive camber.

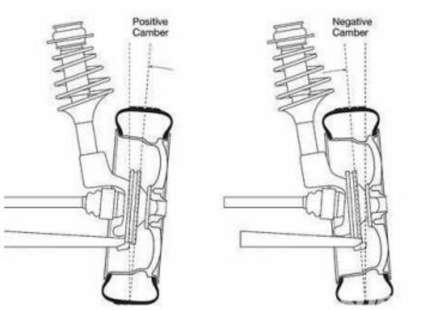



**Figure 9:** Positive and negative camber

### 1.4.2. Caster Angle

The caster angle or castor angle is the angular displacement of the steering axis from the Vertical axis of a steered wheel in a car, motorcycle, bicycle, other vehicle or a vessel, As seen from the side of the vehicle. The steering axis in a car with dual ball joint Suspension is an imaginary line that runs through the centre of the upper ball joint to the centre of the lower ball joint, or through the centre of the kingpin for vehicles having a Kingpin. Caster causes a wheel to align with the direction of travel, and can be accomplished Either by caster displacement or caster angle. Caster displacement moves the steering axis ahead of the axis of wheel rotation.

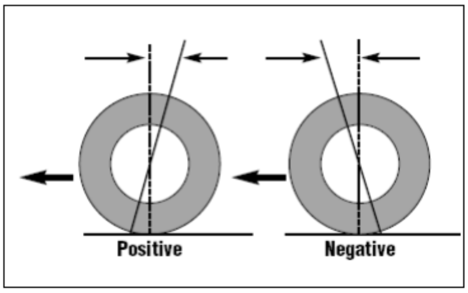



**Figure 10:** Caster Angle

**1.4.3. Kingpin Inclination Angle**

The kingpin inclination is the angle, measured in degrees, that forms the line passing through the kingpin and the perpendicular to the ground, looking at the vehicle from the front. The kingpin angle has an important effect on steering, making it tends to return to the straight ahead or centre position because the straight-ahead position is where the suspended body of the vehicle is at its lowest point. Thus, the weight of the vehicle tends to rotate the wheel about the kingpin back to this position. The kingpin inclination also contributes to the scrub radius of the steered wheel, the distance between the centre of the tire0 contact patch and where the kingpin axis intersects the ground. If these points coincide, the scrub radius is zero.

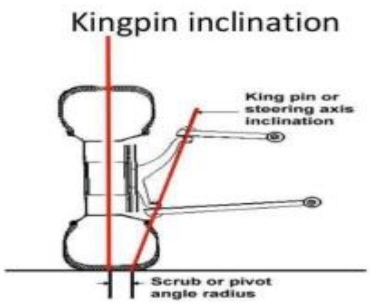



**Figure 11:** Kingpin Inclination Angle

**1.4.4. Toe in and Toe out Angles**

In automotive engineering, toe, also known as tracking is the symmetric angle that each wheel makes with the longitudinal axis of the vehicle, as a function of static geometry, and kinematic and compliant effects. This can be contrasted with steer, which is the ant symmetric angle, i.e. both wheels point to the left or right, in parallel (roughly).

Negative toe, or toe out, is the front of the wheel pointing away from the centreline of the vehicle. Positive toe, or toe in, is the front of the wheel pointing towards the centreline of the vehicle. Historically, and still commonly in the United States, toe was specified as the linear difference (Either inches or millimetres) of the distance between the two front-facing and rearfacing tire centrelines at the outer diameter and axle- height; since the toe angle in that case depends On the tire diameter, the linear dimension toe specification for a particular vehicle is for Specified tyres.

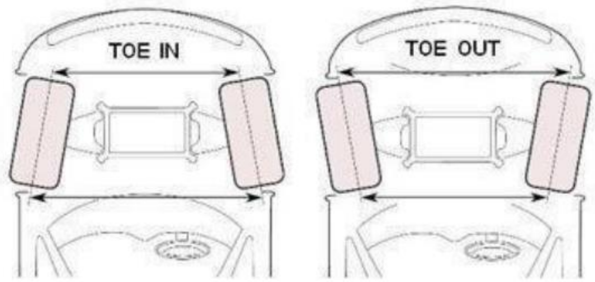



**Figure 12:** Toe-in and Toe-out

## 2. LITERATURE SURVEY

Tune to Win by Carroll Smith, 1978. [1] Covers the development and tuning of race car by clearly explaining the basic principles of vehicle dynamics and relating these principles to the input and control functions of the racing driver. It gives better insights in determining the important parameters like camber, caster, toe, king-pin etc. This book covers the concepts like lateral load transfer and longitudinal load transfer that helps in determining thetrack width and wheel base of the car. The book covers the dynamics of the suspension which directly affects the performance of the vehicle. Those parameters are taken into consideration in designing of the suspension system and steering.

Race Car Vehicle Dynamics by Douglas L. Milliken. [2] To find the load transfer and breakingcalculations in dynamic conditions this book contain experimental results and the book goesinto great detail about all aspects considered when building a race car. This book covers about the tyre dynamics, slip angles and g-g diagrams which give information about the tyreunder different conditions like roll, maximum cornering etc. that help in selecting the tyre to initiate the suspension design.

Fundamentals of Vehicle Dynamics by Thomas D. Gillespie. [3] This book provides a foundation of engineering principles and analytical methods to explain the performance of an automotive vehicle, with chapters focusing on acceleration performance, braking performance, aerodynamics and rolling resistance, ride, tires, steady state cornering, suspensions and steering systems and roll over. Acceleration, braking, Turning and ride areamong the most fundamentals properties of a motor vehicle. To understanding the vehicle as system, it is necessary to acquire knowledge of all these modes. Motion is the common denominator of these modes.

Anshul dhakar and rishav ranjan, [4] Forces are generated at the tire contact patch during variousmanoeuvres of the car and transferred to the chassis through the suspension links. Calculating the forces on every link is important to design the suspension system as all the forces from wheel to the chassis are transferred by the suspension linkages. These forces have been calculated for all the links of double wishbone suspension geometry. The load paths and FBD have been drawn and axial stress in the all the linkages are calculated that helps in choosing the right material and dimensions for the A-Arms.

Badih A. Jawad and Jason Baumann, 2002. [5] This paper will cover the suspension geometry and their component, which include the control arm, uprights, spindles, hubs, and pull rods and cover the key points in the design and analysis of different components and calculates the forces on uprights and calculation on the forces of the wishbones as that forces are transferred on the upright that are further used for the analysis of knuckle. This paper mainlyfocuses on the types of suspension geometries suitable for Formula student vehicles, thus helpsin choosing the vehicle suspension system.

Detailed design report of design of Upright and hubs, by Zubair, Karthik, 2016. [6] This researchpoints the important parameter for the designing of the upright and hubs of the automobile like Material, Load paths etc. This paper gives a brief idea about the designing of the Hubs and upright and considerations while designing the wheel assembly system. This paper alsoconcentrates on the fatigue analysis of the upright in cyclic loadings. This paper guided us in analysis of the upright and the application of the static forces on the upright.

Design and optimization of Formula SAE suspension system, by Ashish Avinash Vadhe, 2018. [7] This research paper discusses about the types of suspension systems suitable for the FSAE vehicle and compares the pushrod and pull rod suspension system. This paper contains the details analytical calculations on the force on the wishbones by resolving the forces form vehicle and upright thus helps in analysis of the upright and it also concentrate on the calculation of forces on the bolts on the upper and lower ball joints of the Upright thus helps in determining the suitable bolts for the upright.

Design of Suspension system for a Formula Student race car, Y. Sumanth Saurabh, SantoshKumar, 2016. [8] In this work, presented in detail the design procedure of the front double A- arm push rod suspension system for a formula student race car. The type of suspension systems used generally is reviewed. The CAD models of the components in the suspensionsystem are made using Solid works.

Car Suspension design. [9] This gives insights on the suspension parts and how to design suspension in consideration to the external parts and also gives the overview of the wheel assembly and focuses on the design of knuckle including determining the different values like camber angle, caster angle etc.

Abhijeet das et al., [10] The purpose of an upright assembly is to provide a physical mounting and links from the suspension arms to the hub and wheel assembly, as well as carrying brake components. It is a load-bearing member of the suspension system and is constantly moving with the motion of the wheel. For the use on a high-performance vehicle, the design objective for the upright is to provide a stiff, compliance-free design and installation, as well as achieving lower weight to maximize the performance to weight ratio of the vehicle. This is the goal for the optimization process. In this thesis a virtual prototype of Upright assembly is created by using SOLIDWORKS CAD tool.

Shubham Kumar Verma et al., [11] conventionally used uprights are made of cast-iron, which has more weight for required strength or FOS but by analyzing the upright using Al 6061-T6, we can conclude that our upright is light weighted along with the required strength and parameters. It makes the vehicle to perform well in rough terrain.

Umesh S. Sangle et al., [12] the purpose of this paper is not only to design and manufacture the upright assemblies for the car, but also to provide an in-depth study in the process taken to arrive at the final design. With all the project work presented above it can be concluded that the project work has been successfully completed along with completion of all the objectives. In today's era mass or weight reduction is becoming a core highlighted issue in automobile manufacturing industry to improve fuel efficiency thereby reducing emissions. Weight reduction has been achieved through advances in materials, improved design and analysis methods, fabrication processes and optimization techniques, etc.

M Azmeer et al., shape optimization had been performed and the mass of the upright was reduced by 21%. [13] Maximum stress and deformation are within control. The shape optimization gives small change in deformation when several loads are applied, which means that change of volume and shapes does not influence significantly to stiffness of the structure. Therefore, the total weight of the vehicle has been reduced, as well as, costs and materials used. This will improve the fuel efficiency, handling and carbon emission.

Rohit B Pawar1 et al., [14] adding composite material on the stainless steel (carbon fiber Kevlar), result is increasing the stress capacity of wheel hub model. Also increase the onemises stress & shear stress of wheel hub model. Reduce upspring mass by using or adding composite material for manufacturing the wheel hub.

The Finite element analysis of the components is done using ANSYS Workbench. [15] Both kinematic and dynamic analysis of the designed suspension system is performed. The resultsof vibration or ride analysis and roll steer analysis are also presented for the designed suspension system. The method for spring design is elucidated. This work emphasizes the method for designing and analyzing the suspension system for a race car in various aspects.

V.Sivananth et al. [16] Simulation and analysis of components are executed in automobile plant, so as to cut back the quantity of prototype during experimental validation. During this study, CAD model of steering knuckle was developed using modeling package SOLIDWORKS. While vehicle in a motion, the load generated at tire road contact patch would be transferred to the knuckle and its surrounded parts. The load transfer varies relation to various driving condition such as cornering, acceleration, braking, bump, static pot hole etc. will severely affect its fatigue life. It's been noticed from knuckle manufacturers that material and geometric optimization is that the real need for the automobile industry to reduce weight of the knuckle without affecting the performance. Static analysis was performed on three load cases and the results were compared for SG iron and Al alloy.

Saksham Bhardwaj et al. [17] Steering upright is a part of suspension system which contains the wheel hub, and attaches to the suspension components. It is the pivot point of steering and suspension aggregate, which allows the front wheels to turn. Considering it for double wishbone suspension geometry, lightweight & low fuel consumption are fundamental requirements for vehicle, especially for racing car. This paper focus on design optimization of steering upright/ knuckle target to induce weight reduction with required strength and stiffness. Our project provides two paths to realize identical goals of weight reduction, one which needs only a few resources and hence the other requires several resources. First approach of intuition shall be used for low budget study by compromising a bit on the burden and increasing the target Factor of safety.

Ayush Garg et al., [18] analysis Formula racing car components experience immense mechanical loads which keep varying all through the life span of the components. It is essential to know the life of a component and replace it in time to ensure performance, reliability and durability of the vehicle. This paper addresses the fatigue life analysis of the Uprights for a Formula SAE vehicle and optimization of the design based on the results to increase the life.

Mahesh P. Sharma et al. [19] In this paper Steering knuckle is one of the important components which connects to steering, suspension and brake to chassis of auto. It undergoes different loading under various conditions. In this paper static analysis of steering knuckle was done. Knuckle was designed which accommodates twin caliper mountings to improve braking efficiency & reduce stopping distance of a car. During this investigation, steering knuckle was used as component for study. Main design and functionality of steering knuckle depends on variety of suspension implemented. Additional factors like brake caliper, steering sub-system rod mounting also effects knuckle design. To result maximum stress and deformation of steering knuckle when different forces like braking force, load transfer during acceleration and braking etc. are applied thereon static analysis is performed. Structural optimization tools like topology and shape optimization alongside manufacturing simulation have gotten attractive tools in product design process. These tools also help to reduce development time. Shape optimization gives the optimum fillets and thus the optimum outer dimensions.

Mahendra L. Shelar et al. [20] In this journal it presents the foremost important issue in vehicle industry is that the existence of differences within the physical properties and manufacturing methodologies. Deterministic approaches are incapable to into account these variability's without leading to oversized structures. The requirement of assessing the robustness of a particular design requires a method supported strength and elegance optimization through probabilistic models of design variables (DOE). Generally, it's identified the steering knuckle which is one amongst the critical components of auto which links suspension, steering system, wheel hub and brake to the chassis. In these journal author has identified the above problem strategy of optimizing the planning employing a strategy supported durability and elegance optimization through probabilistic models of design variables (DOE). When comparing the optimized model with the initial version, 9.19% weight has been reduced with acceptable stress and deflection change and not crossing the project target limits.

## 3. DESIGN

Design of upright starts by designing of suspension in lotus shark software.

### 3.1 Design of Suspension in Lotus Shark

Lotus shark is suspension design software offered by Lotus Corporation. It consists pre-defined models that can be iterated according to our requirements. It offers different suspension parameters to iterate like camber, caster, toe, and king pin inclination. This is the widely used software in Formula student teams for designing of the suspension and the steering systems.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

For designing of suspension, initially the wheel base and track width are constrained as of rule book the wheel base must be of minimum of 60 inches (i.e., 1524 cm) and one of the track widths must be 75% of the wheel base. Track width does have an effect on the lateral load transfer and Influence the cornering stability of the vehicle the larger the front track width there will be less load transfer on the outside tires and that offers better stability while cornering. Hence a track width of 48inches (i.e., 1219.2) is considered at the front.

Then the wishbones are projected between the upright and the chassis of mounting while designing the suspension the wheel parameters like camber angle, caster angle, king pin inclination, scrub radius are defined. Negative camber is preferred in racing application because it allows the full contact path on outer tyre while cornering so a camber is set as -1.5 degrees. Caster is used to stabilize the wheels in running conditions and also self-centering effect a positive camber is preferred about 5 degrees is installed at the front wheels. King pin inclination the purpose of the KPI is to produce vertical displacement of the vehicle in during steering in an upward direction. The larger the KPI, the larger the effect. This lifting effect produces a self-centering torque similar to that of caster. The KPI also generates scrub radius. Hence a positive king-pin inclination of 6 degrees is preferred.

The roll centre is along the centre plane and above the ground that offer less roll moment and reduce the load transfer and improve the cornering stability.

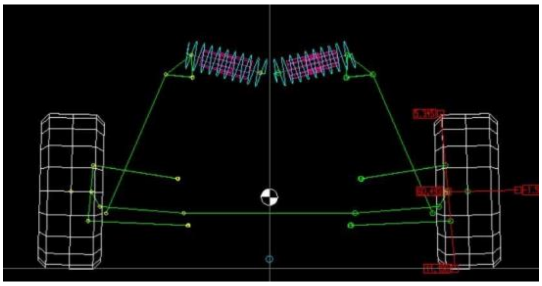


**Figure 13:** Suspension design front view

The wishbones geometry determines the roll centre position so after fixing the roll centre position the wishbones are drawn along the axis.

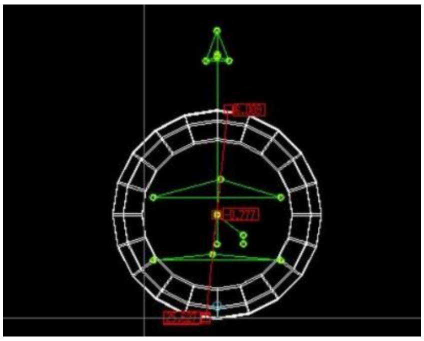


**Figure 14:** Side view of the suspension

The upper and lower ball joints form suspension is designed and the obtained hard points (the pivot points of the suspension) are exported to the Solid works for the modelling of the upright.

### 3.2 Modelling of The Upright in Solid Works.

Solid works is one of the most commonly used CAD programs today. It is a mechanical design automation application that lets designers create structural models quickly and precisely. When you want to sketch ideas, experiment with features and dimensions, and produce models and drawings. It lets you visualize how your design will look after manufacturing. Additionally, any changes you make to a part will reflect in all associated drawings. Solid works includes all familiar Windows functions, such as dragging and resizing windows in its interface for easier use. Many of the same icons, including open, save, cut and paste, and print is also included in the application. Solid works also allows collaboration between workspaces allowing other designers to see your progress and offer feedback.

First the Inner ball joints and outer ball joints are defined in the 3D sketch and the sketch looks as follows.

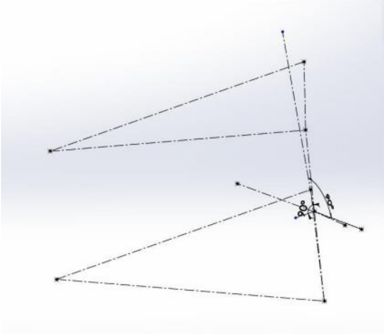


**Figure 15:** Wishbone 2-D drawing in solid works.

Then different planes are defined on the sketch and each plane is used for the modelling of the different bodies. 4 planes are created for modelling of steering arm, Spindle, Upper pivots and Lower pivots.

1) Plane 1 is used to model spindle it is perpendicular to rim axis that is coincident to z-axis.
2) Plane 2 is used created on pivot axis from center to upper pivot points.
3) Plane 3 is used created on pivot axis from center to lower pivot points.

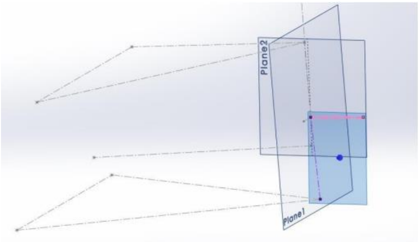



**Figure 16:** Plane view

After creation of planes Bodies are drawn on their respective panes and Dimensions. The bodies are created in the upright that is designed should fit in the rim with sufficient clearance.

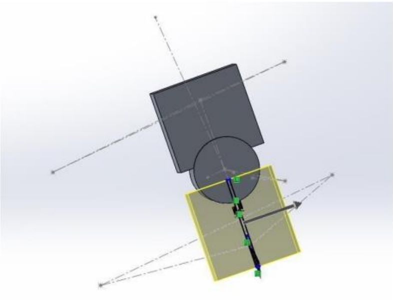


**Figure 17:** Bodies sketch on the planes.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

After creation of bodies the extra material is removed from the bodies other than mounting points, spindle bearing accumulation is removed by using the cut extrude tool. This is done to reduce the weight of the weight of material thus reducing the unspring mass of the vehicle.

The spindle is chosen as 70mm according to calculations of hub and spindle analysis.

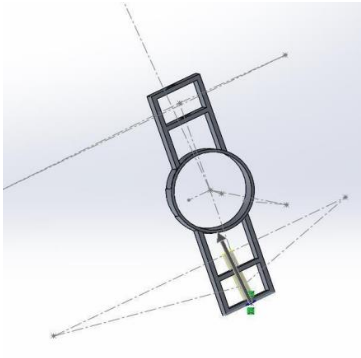


**Figure 18:** After removing excess material

Then a plane is created for modelling the steering arm along the outer ball joints. After creating the steering arm the excess portion, the excess portion is removed using cut extrude.

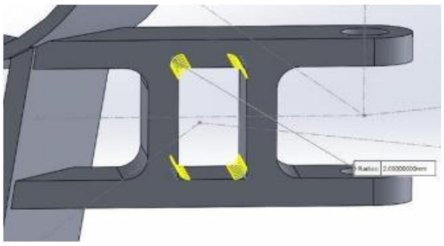


**Figure 19:** Steering arm

After creating the steering arm, Fillets are created along the edges and corners of the upright. Because the fillets have following advantages.

Stress concentration is a problem of load-bearing mechanical parts which is reduced by employing fillets on points and lines of expected high stress. The fillets distribute the stress over a broader area and effectively make the parts more durable and capable of bearing larger loads.

- For manufacturing, concave corners are sometimes filleted to allow the use of round-tipped end mills to cut out an area of a material. This has a cycle time benefit if the round mill is simultaneously being used to mill complex curved surfaces.
- Radii are used to eliminate sharp edges that can be easily damaged or that can cause injury when the part is handled.

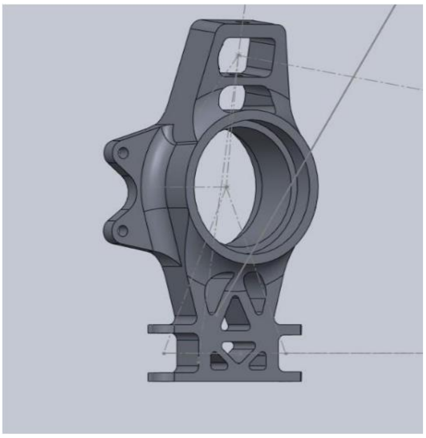


**Figure 20:** Isometric view of upright

This upright provides good clearance between the upright and the rim. After creating this part, the break mounts are created. The mounts are created for the housing of the calliper. The position of housing of calliper is along the driver side that actually improvers the polar moment of inertia calliper is along the After creation of break mounts, the holes for the bolt are cut so that the outer ends of the A-arms can be fit in the upright.

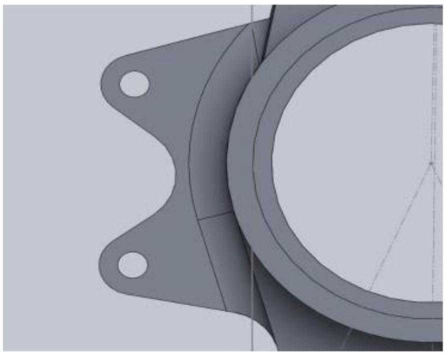


**Figure 21:** Brake mounts

There are certain rules for the bolts provided in the rule book.

- T 10.1.2 All threaded critical fasteners must be at least of either 4 mm in diameter or of the diameter specified in the referencing rule, whichever is labelled.
- T 10.1.3 all threaded critical fasteners must meet or exceed metric grade 8.8 or equivalent.
- T 10.2.3 a minimum of two full threads must project from any lock nut.

After comparing and analysing the different bots the bolt size of 8mm is considered for A-arm and steering pivots and 4mm for break pivots (As the Calliper has 4mm pivots) Metric hole of 8.8mm grade of 8mm is cut at their respective points using Hole Tool.

The Final model is as follows.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

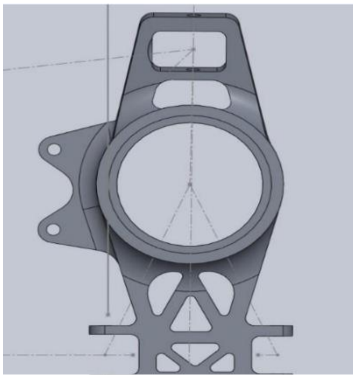


**Figure 22:** Upright final model

## 4. Calculations

During the manoeuvring, Vehicle undergoes different load transfers under different situations like braking, Cornering, Bump etc. During each phase load is transferred between inner and outer wheels and from rear axle to front axle o vice versa. The load transfer depends on various parameters like vertical centre of gravity, overall weight of vehicle, weight distribution between front and rear axle, roll centre, speed of vehicle etc. the weight transferred acts on the tire which indirectly acts on the upright.

The following load transfers are calculated

- Lateral load transfer
- Longitudinal load transfer

### a) Lateral Load Transfer

Lateral load transfer or lateral weight transfer, is the amount of change on the vertical loads of the tires due to the lateral acceleration imposed on the centre of gravity (CG) of the car. In other words, it is the amount ΔW by which vertical load is increased on the outer tires and reduced from the inner tires when the car is cornering.

The total lateral load transfer on the car can be calculated from its free body diagram, in the image, the car is looked from the rear in a right-hand turn. Here, Ay is the lateral acceleration in G units, W is the weight of the car, h is the CG height, t is the track width and Wl and Wr are the vertical loads on the left and right tires, respectively.

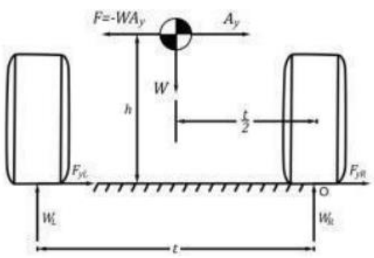



**Figure 23:** Lateral load transfer

Ay is lateral acceleration, it depends on radius of curve, and linear acceleration of the car.

It is given by the formula,

$$Ay=V^2/R$$

Taking moment equilibrium about point0, of the tyre, we can see that:

W*Ay*h – WL*t + W*(T/2)

Solving further

ΔW = (W * Ay * h)/t

According to our parameters,

weight of the vehicle (W) = 300kg

centre of gravity height = 250 mm

front track width = 1219.2 mm

**i) Lateral acceleration**

Lateral acceleration is calculated using the formula V^2/R. according to the testing the maximum lateral acceleration occurs at skid pad. It is a dynamic event in which the vehicle moves in a circular path of a radius of 7.125 m this is the largest curve a formula student vehicle undergoes during the event. The maximum velocity possible according to our engine data at this event is 45kmph.

So,

V=45*5/18 = 12.5m/s

R=7.125

Ay = (12.5) ^2 / 7.125

Ay=1.75 g

**ii) Total lateral load transfer**

ΔW = (W * Ay * h)/t

= 300*9.81*1.75*0.25/1.219

Δ W = 1100 N

Hence, there is a load transfer of 1100N from inside tire to outside tire. The total weight on the single wheel is weight transferred + weight of outside wheel Therefore the weight on the single wheel = 1600. 6 N, and that weight acts on the upright.

**b) Longitudinal Load Transfer**

When a car is acceleration or braking, a reaction force is generated similar to that of cornering. This reaction force is Wax. The reaction force is in g force similar to that of lateral load transfer. The g force value is Ax. In This scenario the weight will transferred from Front axle to rear axle and vice versa depends on the type of longitudinal load transfer. If the load transfer is due to braking then the weight will be transferred from rear to front and if due to acceleration the weight will be transferred from front axle to rear axle.

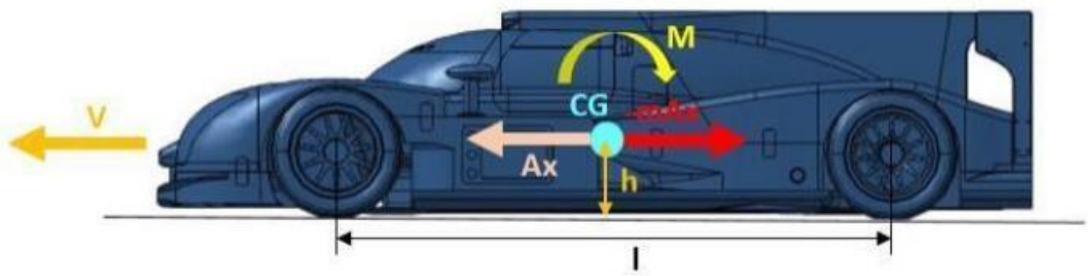



**Figure 24:** Longitudinal load transfer

The weight is transferred along the centre of gravity and the amount transfer depends on centre of gravity height, Weight distribution, Overall weight, Accelerations or deceleration of the car, wheel base.

The load transfer is given by the formula.

$$\Delta Wx = W*Ax*h/l$$

W=Weight of the Car.

Ax=longitudinal acceleration.

h=Centre of gravity height.

l=wheel base.

**i) Longitudinal acceleration**

This is the linear acceleration this is +ve if the moving accelerating and –ve if the vehicle is braking. During braking the weight of the vehicle transfers from the rear axle to front axle.

After calculating the Deceleration, the weight transfer can be calculated by given that weight of the vehicle (including the weight of the driver) =300 kg

$$Ax = -2.2\ g$$

Wheel base = 1524 mm

Centre of gravity = 0.25 m

$$\Delta Wx = 300*-2.7*0.25/1.524$$

$$\Delta W = 132 * 9.81 + \text{weight on the single front wheel}$$

$$\Delta Wx=2000N$$

Therefore, a weight of 2000 N acts in down ward direction on the front upright.

**c) Combined Lateral and Longitudinal Load Transfer**

This is the extreme case; it causes the maximum loading on the wheel. This is due to combined weight transfer of longitudinal or lateral load transfer. When the Driver apply breaks and takes a turn at the corner at the same time then the rear inside wheel lifts off the ground and the maximum weight is transferred to the outside front wheel of the vehicle. This case is considered in the Analysis of the upright.

$$\Delta Wxy = \Delta Wx + \Delta Wy$$

Consider the deceleration of the vehicle to be 2.2g and the vehicle is cornering at the radius of 5m with a velocity of 45Kmph then the lateral acceleration is 2.5g.

First the longitudinal load transfer is calculated.

$$\Delta Wx = 103\ kg$$

Then the weight is added with front axle weight and longitudinal load transfer is calculated.

$$\Delta Wy=103*9.81*2.5*0.25/1.2$$

Therefore, the weight of 2500N acts on the upright acts on this scenario.

## 5. MATERIALS USED

The material that is being chosen for formula student upright must possess few properties

1. High strength to weight ratio
2. Minimal weight
3. Maximum stiffness

For 3d printing 3 types of material forms are available, solids, liquid, and powder. Based on the type of application and required properties powder based rapid prototyping is chosen and different materials are available and different materials are considered for our application and compared.

They are.

1. Alsi10mg
2. Ti6Al4V ELI
3. 316L
4. Maraging steel M300

These materials are compared based on few parameter Density, yield strength, Availability, powder price.

The table below shows the comparison between materials

| S. No | MATERIAL | Density (g/cc) | Yield strength (M PA) | COST (per 10 kg in rupees) | Modulus of elasticity (GPA) |
|---|---|---|---|---|---|
| 1) | Alsi10mg | 2.7 | 200-266 | 51000 | 66-76 |
| 2) | Ti6Al4V ELI | 4.4 | 923-947 | 2,31,200 | 125-130 |
| 3) | 316L | 8.0 | 190-197 | 47000 | 190-197 |
| 4) | Maraging steel | 8.1 | 999-1016 | 62000 | 160-162 |

**Table 1:** Materials comparison

Few interpretations can be drawn from the above point

1) Maraging steel possess highest yield strength and good modulus elasticity and reasonable cost but it has high density which adds more weight to the vehicle which increase the un-sprung mass of the vehicle. Although it possesses better mechanical properties marging steel is not considered because of its weight.
2) 316L have considerably good mechanical properties which include better strength and modulus of elasticity and it is relatively cheaper when compared to other materials but it has low strength to weight ratio (density 8.0). Which adds more weight with less strength hence? It is not chosen for upright.
3) Ti6Al4V ELI is a titanium alloy, which possess among all the materials considered it has high yield strength, less dense than Maraging steel and 316L and it has good modulus elasticity index but it is very expensive and it must be imported from other places so availability issues.
4) Alsi10mg has good strength and it is bit inexpensive and has less modulus of elasticity but it is less dense 2.7, hence it has higher strength to weight ratio, it doesn't add much weight to the upright and increases strength of the upright. Hence ALSI10MG is considered for manufacturing of upright.

Properties of ALSI10MG

| Mechanical Properties | Test Method | As Built | Heat Treated |
|---|---|---|---|
| Tensile strength | ISO 6892-1:2009(B) Annex D | 460 ± 20 MPa | 350 ± 10 MPa |
| Yield Strength (Rp 0.2%) | ISO 6892-1:2009(B) Annex D | 260 ± 20 MPa | 230 ± 15 MPa |
| Elongation at Break | ISO 6892-1:2009(B) Annex D | 6 ± 2% | 6 ± 2% |
| Young's modulus | - | 75 ± 10 GPa | 75 ± 10 GPa |
| Hardness | DIN EN ISO 6506-1 | 120 ± 5 HBW | 120 ± 5 HBW |

| Thermal Properties | Test Method | As Built | Heat Treated |
|---|---|---|---|
| Thermal conductivity | ASTM E1461-13 | 110 ± 5 W/m°C | 170 ± 5 W/m°C |
| Specific heat capacity | ASTM E1461-13 | 910 ± 50 J/Kg°C | 890 ± 50 J/Kg°C |

**Figure 25:** Material properties of ALSI10MG

Aluminium AlSi10Mg is a typical casting alloy with good casting properties and it's typically used for cast parts with thin walls and complex geometry. It offers good strength, hardness and dynamic properties and is therefore also used for parts subject to high loads. Parts in Aluminium AlSi10Mg are ideal for applications which require a combination of good thermal properties and low weight. The part can be machined, spark-eroded, welded, micro shot-peened, polished and coated if required. Conventionally cast components in this type of aluminium alloy are often heat treated to improve the mechanical properties, for example using the T6 cycle of solution annealing, quenching and age hardening.

The laser-sintering process is characterized by extremely rapid melting and re-solidification. This produces a metallurgy and corresponding mechanical properties in the as-built condition which is similar to T6 heat-treated cast parts.

The chemical composition of ALSI10MG

| Chemical Composition and Physical Properties | | |
|---|---|---|
| Chemical composition | Al<br>Si<br>Fe<br>Cu<br>Mn<br>Mg<br>Ni<br>Zn<br>Pb<br>Sn<br>Ti | Balance<br>9 - 11%<br>0 - 0,055%<br>0 - 0,1%<br>0 - 0,45 %<br>0,20 - 0,45 %<br>0 - 0,05 %<br>0 - 0,10 %<br>0 - 0,05 %<br>0 - 0,05 %<br>0 - 0,15 % |
| Physical Properties | Relative density | Approx. 99,85 % |
| | Density | 2,67 g/cm$^3$ |

**Figure 26:** Chemical composition of ALSI10MG

## 6. ANALYSIS

Analysis is carried in Ansys software. The analytical calculations are used in analysing of the Upright.

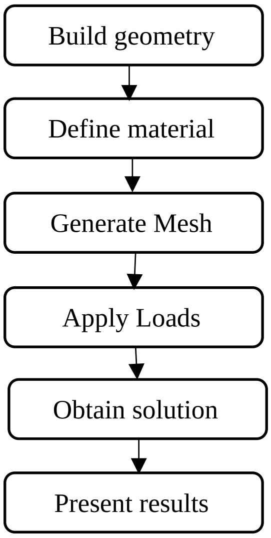
### 6.1 Ansys Software

Ansys develops and markets finite element analysis software used to simulate engineering problems. The software creates simulated computer models of structures, electronics or machine components to the simulate strength, toughness, elasticity, temperature distribution. Electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. For example, Ansys may simulate

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

how a bridge will hold up after years of traffic, how to best process salmon in a cannery to reduce waste, or how to design a slide that uses less material without sacrificing safety.

### 6.2 Steps in Ansys




#### 6.2.1 Geometry

The geometry is already modelled in Solid works and the process is mentioned in the section

#### 6.2.2 Engineering Data

In this section the material properties are to be defined in the Ansys workbench I.e. the properties of ALSI10MG should be defined the important mechanical properties Like density, young’s modulus, Modulus of rigidity, Yield strength are to be defined.

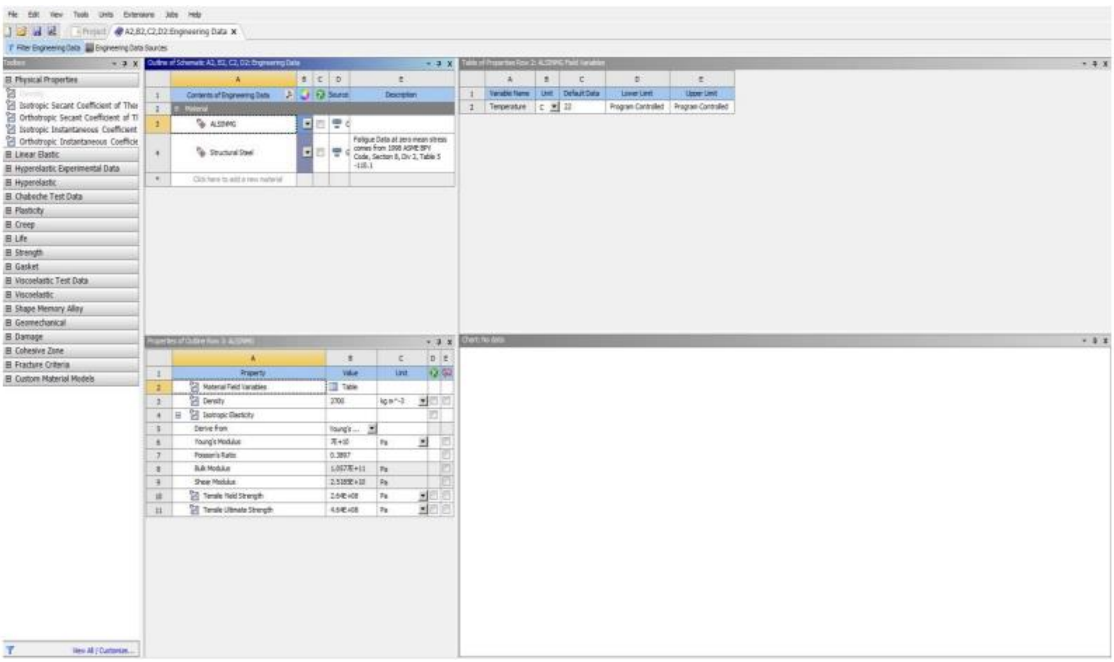


**Figure 27:** Engineering Data

#### 6.2.3 Mesh

Meshing is a process of dividing the body into number of elements that are used to solve the mathematical equations involved in the calculations. Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation. Furthermore, since meshing typically consumes a significant portion of the time it takes to get simulation results, the better and more automated the meshing tools, the faster and more accurate the solution. Elements are of two types structured and unstructured elements. Structured mesh follows a uniform path whereas the unstructured elements form a non-uniform pattern.

There are different types of meshes available in Ansys.

1. 2D meshing: this meshing is basically used in analysing of the 2d geometry's and static thermal analysing. Different 2D meshing's available are Triangle mesh and Quadrilateral mesh and a polygon.
2. 3D meshing: 3d meshing is used in solving complex bodies and 3d structures. Various types of mesh elements are available in Ansys. Such as tetrahedron, prism with quadrilateral base, polyhedron, Pyramid, Prism with polyhedral base. Tetrahedron mesh: A tetrahedron has 4 vertices, 6 edges, and is bounded by 4 triangular faces. In most cases a tetrahedral volume mesh can be generated automatically.

Pyramid: A quadrilateral-based pyramid has 5 vertices, 8 edges, bounded by 4 triangular and 1 quadrilateral face. These are effectively used as transition elements between square and triangular faced elements and other in hybrid meshes and grids.

Triangular prism: A Triangular prism has 6 vertices, 9 edges, bounded by 2 triangular and 3 quadrilateral faces. The advantage with this type of layer is that it resolves boundary layer efficiently.

Hexahedron: A hexahedron, a topological cube, has 8 vertices, 12 edges, bounded by 6 quadrilateral faces. It is also called a hex or a brick. For the same cell amount, the accuracy of solutions in hexahedral meshes is the highest. The pyramid and triangular prism zones can be considered computationally as degenerate hexahedrons, where some edges have been reduced to zero. Other degenerate forms of a hexahedron may also be represented.

From the available meshes the Tetrahedral and Hexahedral provide better results and for static structural application the Tetrahedral is chosen for its feasibility to mesh in instructed bodies and provide optimum results in less possible time.

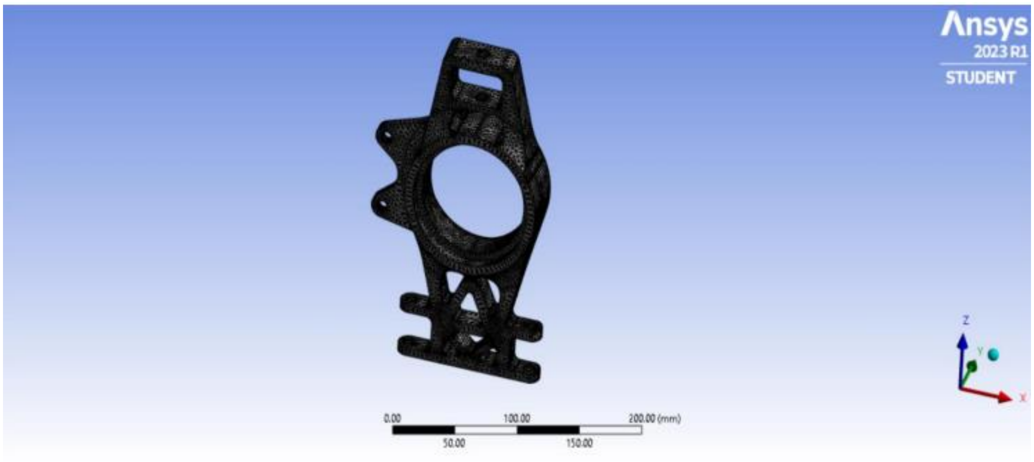



**Figure 28:** Mesh of upright

### 6.2.4 Loads

Loads are applied on the upright form the analytical load transfer calculations.

### 6.2.5 Solutions

Solutions are applied by applying the global meshes and local mesh co-ordinates and the solutions get generated. Total deformation, Equivalent stress, Factor of safety is then calculated.

## 6.3 Load Cases

Different load cases ae applied on the upright in Ansys according to the calculations.

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

### 6.3.1 Load On Upright

When vehicle is maneuvering on the track there is possibility of the vehicle will encounter the bump. Which means sudden dip in the front nose on to road. The load will be acted on the upright. After defining the model in Ansys workspace then the mesh is generated and in local mesh settings the size and the type of mesh is defined. The size of the mesh can be of any number the smaller the mesh size the better and the accurate are the results at the cost of computation time and it depends on the graphics and Ram of the computer. The mesh size of 0.3mm is selected and the no. of elements are generated are approx. 1, 30,000. Then the boundary conditions are fixed.

There are two types of boundary conditions exist

1. Structural boundary condition
2. Displacement boundary condition.

The displacement boundary condition used in this analysis is a fixed support. This is applied at the cylindrical centre at the faces of the bearing.

And the displacements boundaries are placed at the application of forces and the direction of the force is along the direction of force. For bump condition the load will be applied on the bottom faces of the mounts, (i.e. the bump and reaction force will directly act on the mounts) in +z direction. After solving the model, the equivalent stress, Factor of safety and Deformation are calculated after solving the model. Factor of safety is defined as the ratio of a structure's absolute strength (structural capability) to actual applied load.

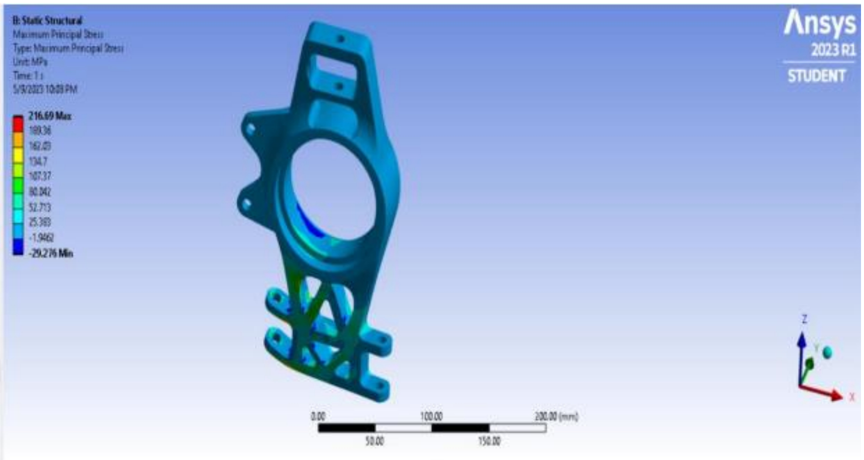



**Figure 29:** Equivalent stress

It is observed that the maximum stress that is acting on the upright When the applied load is 3000N is 216.69 MPA.

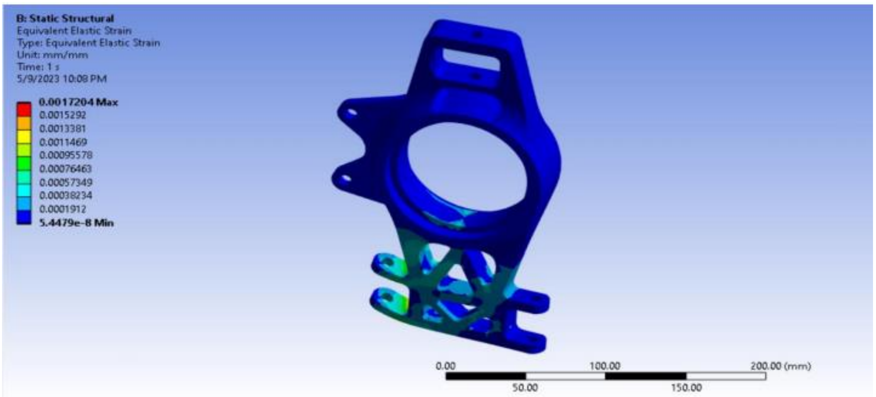



**Figure 30:** Equivalent strain

The strain that is acting on the upright is 0.001720 at the base of the upright.

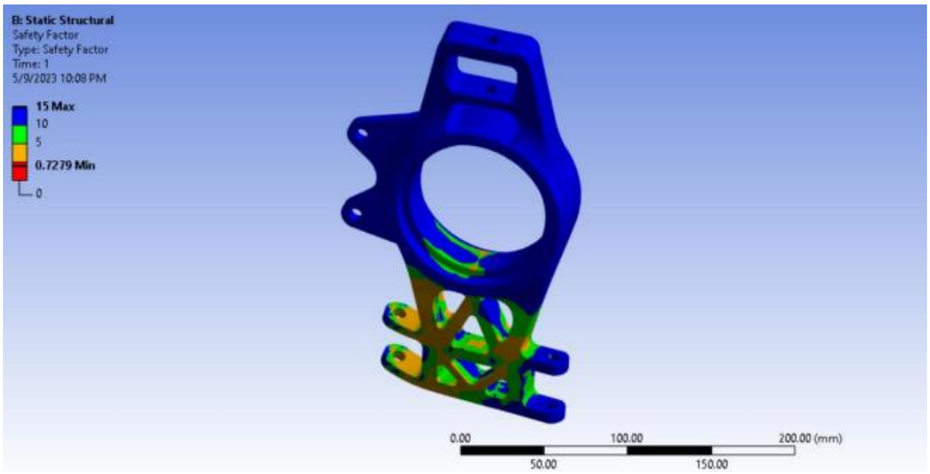



**Figure 31:** Factor of safety

A minimum factor of safety of 5.148 is observed.

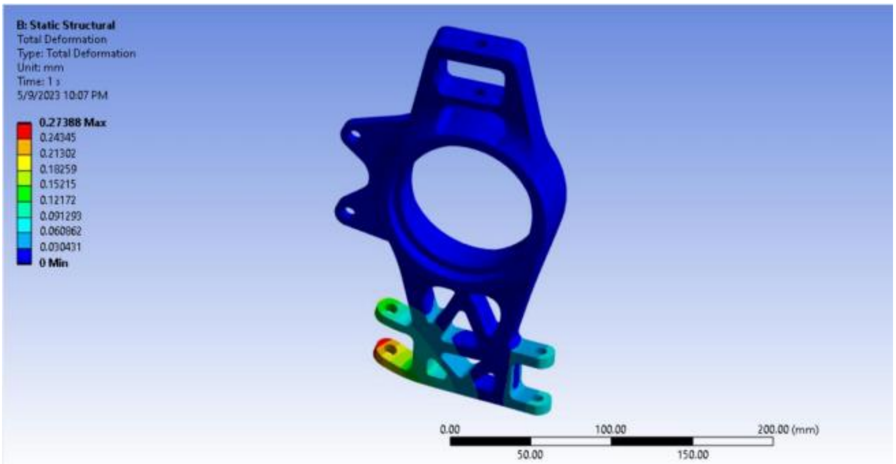



**Figure 32:** Deformation

A deformation of 0.27388mm is observed at the base of the upright.

### 6.4 Load On Hub

This type of loading condition basically occurs during braking or acceleration.

From the calculations load transfer of 2500N is acting on the HUB.

This load is applied on the mounts of the upright in the Z direction.

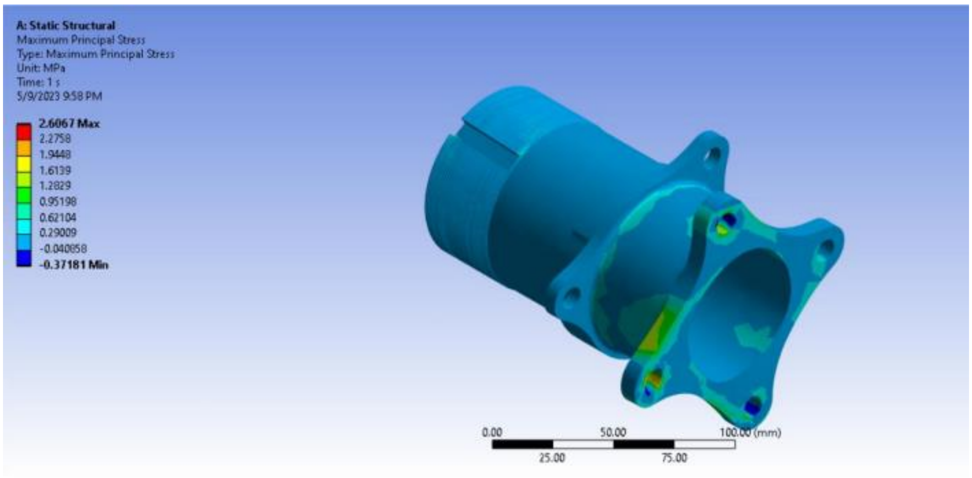



**Figure 33:** Equivalent stress

It is observed that the maximum stress that is acting on the Hub When the applied load is 2500N is 2.606 MPA.

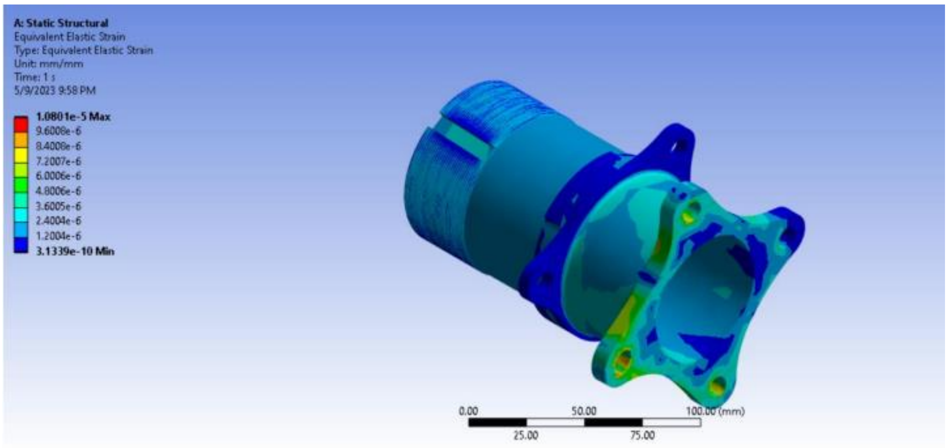



**Figure 34:** Equivalent strain

A stress of 66.72MPA is observed on the application of load 2500N with a strain of 0.0801

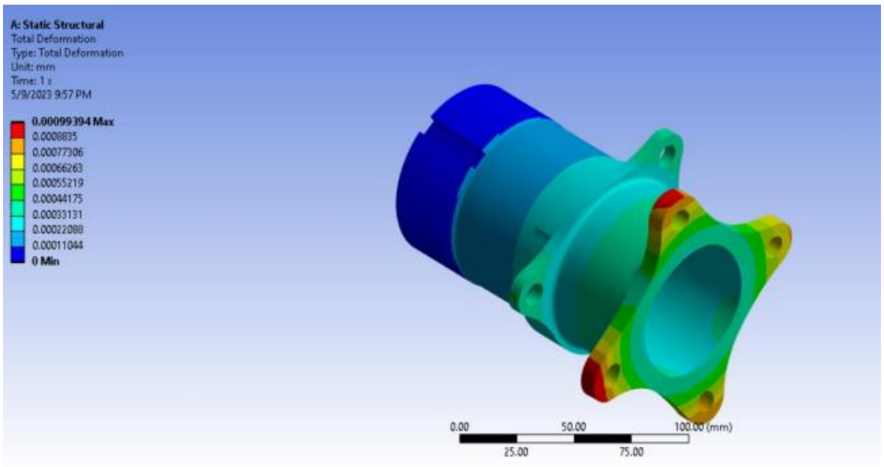



**Figure 35:** Deformation

A deformation of 0.0723mm is observed at the base of the upright.

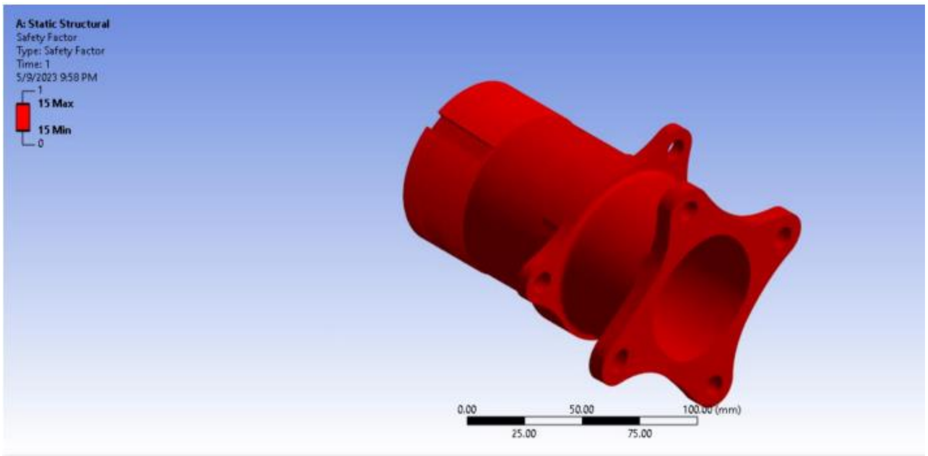



**Figure 36:** FOS (Factor of safety)

A maximum deformation of 0.045mm and a factor of safety of 8.63 is observed on the hub on the application of load 2500N. From the analysis it is observed that the

| S.no | Type of loading | Equivalent stress (MPA) | Deformation (mm) | Factor of safety (FOS) |
|---|---|---|---|---|
| 1. | upright | 216.69 | 0.273 | 5.1 |
| 2. | hub | 22.606 | 0.0723 | 8.63 |

**Table 2:** Analysis results

- From The above table it is evident that the upright and hub are able to withstand all load conditions with less deformation.
- Considering the objective to design an optimum upright for a formula student car Keeping rules in mind. The design goals are achieved by iterating several models and analysed with the load transfer calculations.
- It is observed that the upright can sustain any kind of loading and provides a Factor of safety of around 2.5 which is preferable for the mechanical components
- The upright does fit in the rim space provided clearance between rim and the upright. And there is negligible deformation is observed in the upright under different Loading condition.

## 7. Results and Discussions

- The model is developed in solid works using the points extracted in lotus shark.
- The weight of the model (obtained from CAD data) is relatively less than the previous model which is modelled using AL-6061. The weight of the material is got reduced by around 20%.
- The upright is able to sustain the given loading condition and has good factor of safety.
- Considering the objective to design an optimum upright for a formula student car keeping rules in mind. The design goals are achieved by iterating several models and analysed with the load transfer calculations. It is observed that the upright can sustain any kind of loading and provides a factor of safety of around 2.5 which is preferable for the mechanical components and the upright does fit in the rim space provided clearances between rim and the upright. And there is negligible deformation is observed in the upright under different loading condition.

## 8. References

[1] Carroll Smith book on race car engineering. *"Tune to win"* 1978

[2] Thomas D. Glipse *"Fundamentals of vehicle dynamics"* Book about vehicle Dynamics.

[3] William F. Milliken. "*Race car vehicle dynamics*" Book ondesigning formula Car.

[4] Anshul dhakar and rishav ranjan. "*Force calculation inupright of a FSAE Car" IEEE* Technical paper,2018

[5] Norbe, J. P., "The Car and its Wheels, A Guide to Modern Suspension Systems", TAB Books Inc, 1980.

[6] Badih A. Jawed and Jason Baumann. "*Design of SAE suspensionsystem"* SAE Technical paper, 2002.

[7] Zubair, Karthik. "*Detailed design report of design of suspension and hubs"* IEEE paper. 2018.

[8] Ashish Avinash. *"Design and optimization of SAE Suspension system"*

[9] Abhijeet Das- International Journal of Mechanical and Industrial Technology, Vol. 2, Issue 2, pp: (79- 86).

[10] Y. Sumanth Saurabh, Santosh Kumar. "Design of Suspension system for a Formula student vehicle". IEEEpaper 2018.

[11] Mat web provides the material data

[12] Comprehensive View on Racing Car Upright Design and Manufacturing

[13] Rapid prototyping techniques and classification and comparison, Dharipalli Hyndhavi, S. Bhanu Murthy.

[14] Design and analysis of upright in All Terrain Vehicles Shubham Kumar Verma, Amit Kumar Sinha and Ankush Anand, International Journal of Advance Research and Innovation Volume 5 Issue 3 (2017) 341-342.

[15] Design & fabrication of Front Wheel Upright Assembly for an ATV, Umesh S. Sangle, International Research Journal of Engineering and Technology (IRJET) Volume: 05 Issue: 04 Apr-2018.

[16] Saksham Bhardwaj, Ashok B, Uma Shankar Lath, and Aman Agarwal, "Design and Optimization of Steering Upright to Reduce the Weight Using FEA" SAE Technical Paper 2018-28-0081, 2018, doi:10.4271/2018-28-0081.

[17] Mr. V. Sivananth, Dr. S. Vijayarangan, Mr. R. Aswathaman, "Fatigue and Impact Analysis of Automotive Steering Knuckle under Operating Load Cases".

[18] Ayush Garg- International Journal of Science and Research (IJSR), 2015.

[19] Mahesh P. Sharma, Denish S. Mevawala, Harsh Joshi, Devendra A. Patel, "Static Analysis of Steering Knuckle and Its Shape Optimization", eISSN: 2278-1684, p-ISSN: 2320-334X PP 34-38.

[20] Mahendra L. Shelar, Prof. H. P. Khairnar, "Design Analysis and Optimization of Steering Knuckle Using Numerical Methods and Design of Experiments", 2014 IJEDR | Volume 2, Issue 3 | ISSN: 2321-9939.