Virtual Prototype of Upright Assembly of A Race Car for SUPRA SAEINDIA Competition

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Abstract: **SUPRA SAEINDIA is an annual national level competition organized by the Society of Automotive Engineers India. From all over India, the selected Under Graduate & Post Graduate Engineering Student teams are asked to design, model, fabricate and compete with a small open-wheel, open cockpit type race car. The purpose for this thesis project is to design and manufacture the SUPRA SAEINDIA race car Front and Rear Upright Assemblies. 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.**

Keywords: **SUPRA SAEINDIA, Formula SAE, Solid works, Hub, Upright.**

I. INTRODUCTION

SUPRA SAEINDIA is a national level student competition, organized by Society of Automobile Engineers India, wherein students are asked to design, manufacture and run a prototype of open wheel racing car. This competition is conducted annually in India and about 180 colleges participate every year from all over India. The purpose of the thesis is to design and manufacture the front and rear wheel upright assemblies to be used in SUPRA SAEINDIA race car. The goal is to produce a lighter and simpler design without sacrificing performance in stiffness. The function of a vehicle upright assembly is to provide a physical connection from the wheels to the suspension links, and to provide mounting and installation for brake calliper. The main advantage in this design is that the front and rear uprights can be used in left and right wheel assemblies.

For the purpose of the application on a high performance racing car, it has to meet the following criteria:

• Lightweight to maintain good performance to weight ratio of the race car.

• Optimum stiffness to ensure low system compliance and maintaining designed suspension geometries.

• Ease of maintenance for enhancing serviceability and setup repeatability.

II. DYNAMICS AND COMMON TERMS

The uprights are critical to locating different suspension geometries including the outer most control arm points as well as the tie rod connections. The location of these points relative to the mounting locations on the chassis determines caster, camber, toe, and Ackerman. The following section will briefly outline these concepts so they can be referenced throughout the report.

- **Caster:** Caster is the angle of the steering axis relative to vertical. This causes a restorative force felt by the driver which returns the steering wheel to centre, just as the caster wheels on a shopping cart naturally roll in a specific direction. Positive camber is accomplished when the top steering pivot point is located rearward of the lower steering pivot point. The greater this angle, the greater the straight line stability of the car, and the greater force required to turn the steering wheel.

- **Camber:** Camber is the relative angle of the wheel with respect to vertical. Negative camber is defined as the configuration when the top of the wheel is leaned in towards the centre of the car. Positive camber is the opposite in which the top of the wheel is leaned away from centre. The amount of camber that is necessary is determined by analysing tire temperatures from practice data.
- **Toe:** Toe is the angle created between the front tires when pointed directly forward. There are two possible toe conditions, toe in and toe out. Typically, a very small amount of toe out is desired in a race car for faster steering response. The toe adjustment is most commonly made by shortening or lengthening the tie rod links.
- **Ackerman:** Ackerman is the amount of steering angle the inside wheel experiences in relation to the outside wheel when a steering input is applied. Ackerman is most commonly adjustable at the upright by moving the toe link connection point forward or back. This adjustment is commonly utilized on race cars to help reduce tire scrub during cornering and increase grip.
- **Bump Steer:** Bump steer is the amount of toe that is gained or lost during the full travel of the vehicle suspension. As the suspension travels, the caster, and camber can cause the toe to change slightly. Reducing this effect can reduce tire wear and allow the driver a more consistent feel of the car. To adjust this, the relative heights of the inside tie rod point and outside tie rod point is adjusted.

III. DESIGN DEVELOPMENT

A. Design consideration:

Being a race-car, the primary goal is to achieve the best performance to weight ratio. The reduction of weight in any area will allow for better vehicle performance overall. From basic Newtonian Physics, mass = force x acceleration, by reducing mass with a given amount of force capable to be exerted from the vehicle, the acceleration can be maximized. There is a finite amount of cornering grip available from any given tire, it is just as important to reduce the vehicle weight to better exploit the available grip from the tire to achieve maximum amount of cornering acceleration possible. As such, weight is inevitably a key constraint in designing any component in the race-car.

Weight is also an important consideration for any components in the wheel assembly of the vehicle. As this part of the vehicle weight is defined as “unsprung weight”. The importance of unsprung weight lies in the fact that it dictates the response of the suspension system to any given handling input. The higher the unsprung weight, and more inertia there is in the given suspension system, and thereby increasing its difficulty to change direction. If the inertia of the wheel assembly is high, it will take more time for the system to recover from a disturbance such as a bump on the track, and thereby not allowing driver to exploit the performance from the vehicle.

Aside from unsprung weight and inertia, another important aspect in designing any suspension components is its stiffness. The only way for the vehicle to stay true to its design intent is to ensure that all the key variables that the designer wants to get translated and dynamically maintained in the final product. In the case of the suspension system that means the geometries on paper has to be maintained by the components in the real world when great loads are applied to them. If there is excessive amount of deflection, then all the key geometries will not be there where the designer intended them to be in a given situation. This is crucially important especially when dealing with various adjustable parameters available on the race-car. If the stiffness is not there then the desired results cannot be obtained, as the system will not be in the state where the engineer expects it to be.

With the above points in mind, the design goal for the vehicle suspension upright assemblies then have to achieve an optimized stiffness to weight ratio. Such that the unsprung weight in the assemblies will keep its effect to the wheel movement to a minimum and that adequate stiffness is present in the system so that vehicle behaviour remains predictable and repeatable in the vehicle development process.

B. Design Constraints:

As with any design, there are a number of constraints that limits the physical layout, material choice, and manufacturability of the upright. The constraints are highlighted in the following section:

- **Physical Limits:** As the upright assembly exists entirely enveloped by the wheel, its size obviously cannot be bigger than that of the space available in the wheel. Also, the primary driving factors of the upright layout are the designed layout and geometries of the suspension system. The upright has to incorporate all the pivots needed by the suspension and allows the system to move within its designed range of travel without obstructions and cause binding. Other physical limitation includes the choice of the bearing sizes and the amount of suspension adjustments needed to be built-in to the design. The finalized design needs to be within these limits while maintaining the functional requirements of the upright.

- **Material Choice:** With the current trend of advancements in material and manufacturing processes, the designer have complete liberty to choose whatever material that is suitable and fits his/her needs. However the competition have a clear outline as to the cost of the vehicle, as well as SUPRA SAEINDIA team's budgetary constraint, material choice is not as free. For the purpose, the only materials that are realistically being considered are Aluminium and Alloy Steel. This is due to their mechanical properties, availability and cost. 6061 T6 Aluminium was chosen in this project as it excels all the required factors of material choice.

- **Manufacturability:** There are lot of options for manufacturing components of wheel assembly, but as earlier mentioned SUPRA SAEINDIA teams are always limited in budget, machining the component with a 3 axis CNC Vertical Machining will be a wiser choice. Machining in 3axis CNC is not much economical but is better for complex designs and there could be a chance to get the desired stiffness. It is advised not to make the design much complex as it will increase the overall cost for machining. While utilizing sponsorship resources, the turnaround time for complicated parts is bound to be excessive, and as such may limit the overall vehicle progress.

C. Prerequisite Information:

To design upright and other components of wheel assembly certain data are needed to calculate or assumed technically. The data which are required pre-hand are camber, caster angle, suspension geometry, wheel size etc. This section will cover the details for some of the data that is required:

- **Suspension Kinematics/geometries:** As the upright being the primary suspension component at the wheel side, its key geometries is driven by the vehicle suspension parameters. As such, the geometric layout of the suspension system is the first thing in the design process to be completed for the design of the upright assembly. In designing the suspension geometries of a high performance vehicle, the first thing to be considered is the tire performance. The goal for designing the suspension kinematics is to maintain the tires in their preferred position as the vehicle experiences roll, pitch and yaw movement as it is being driven around the track. Through iterative design process with the help of Susprog3D (a free open source Suspension Analysis software), the kinematics of each iteration can be analysed in terms of their positioning of the tire throughout the ranges of travel of the wheel, the amount of vehicle roll and the amount of steering input.

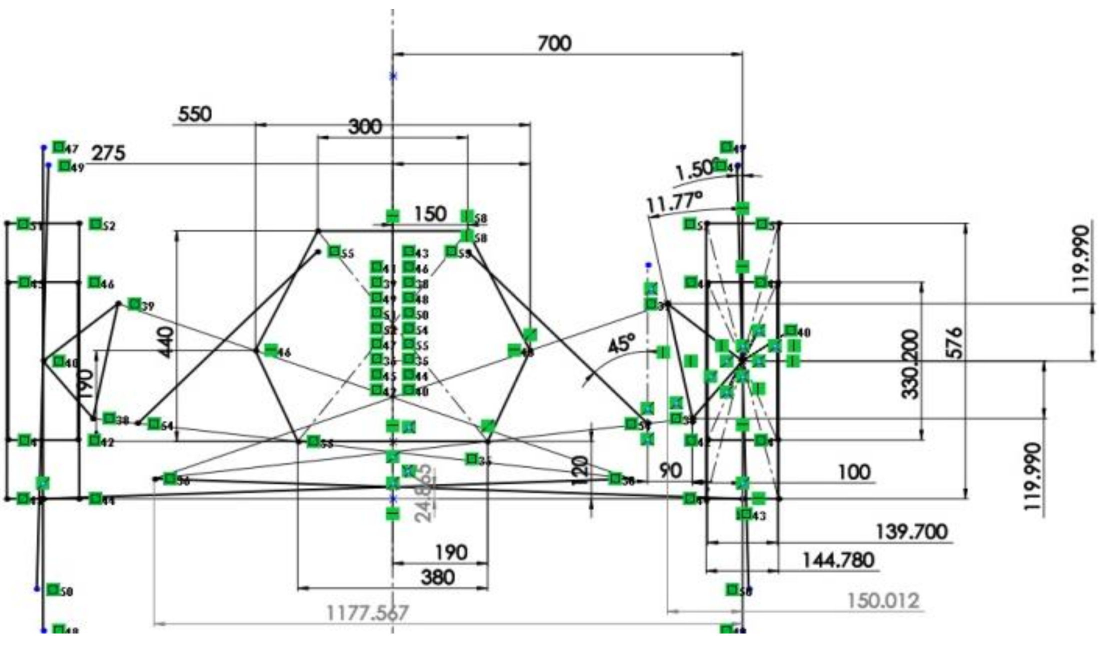

Fig. 1 Front Suspension Geometry

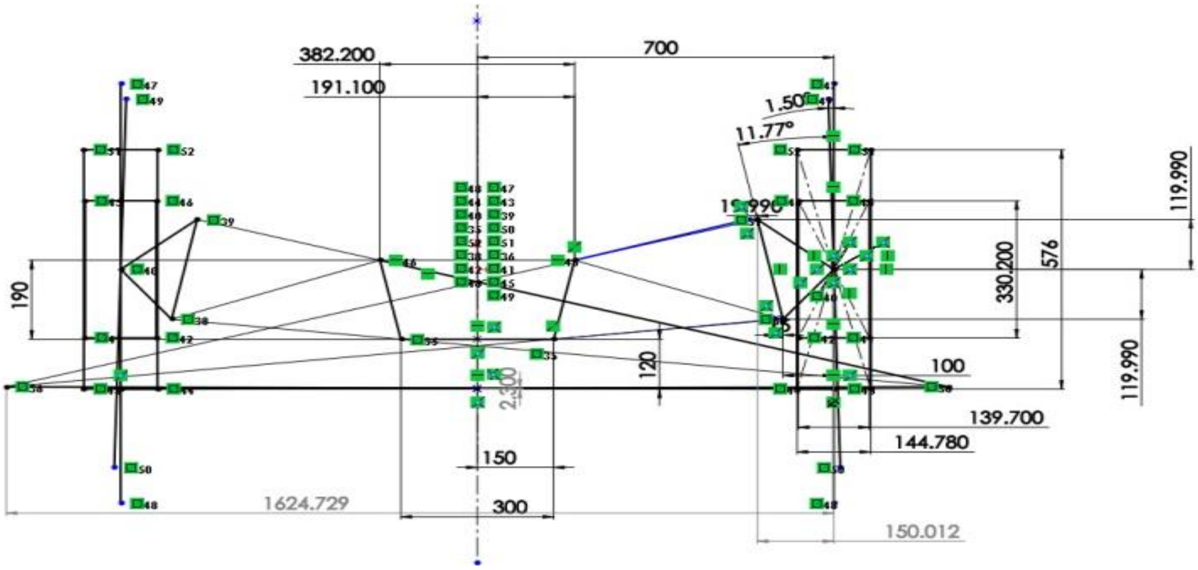

Fig. 2 Rear Suspension Geometry

In the above suspension geometry the camber angle at front suspension is taken as -1º and for rear it is -1º. The King pin Inclination (KPI) angle is taken as 8º and caster angle for front is +3º. One thing one has to keep in mind that while designing the suspension geometry every design decision is a compromise based on several other factors.

Over the past 30 years, most of the factors relating to independent suspension design have been thoroughly tested and developed. The science has been researched and the results are pretty much agreed upon. Radical departures from proven practices will probably result in an ill-handling car. The value present here in the following design exercise are the ones that have been proven to work correctly. Be advised you can use other values on your car, but you should understand how these variations can affect your car's handling.

D. Detailed design and analysis of upright:

With the suspension geometries fixed the focus shifts to the mechanical layout and design of the upright assemblies. The goals are being able to package the necessary components at their correct location and orientation within the confine of the wheel. At the same time, the types of construction, material, sizing of bearing and pivots, as well as adjustment method will have to be decided. While designing it is necessary to achieve the design goals set earlier, otherwise the desired performance will not be achieved. Design of upright is needed to be less complex and as lighter as possible. To maximize the strength and minimize the deflection of the uprights, many design iterations consisting of various shapes were performed.

Following are the CAD model of the final front and rear upright designs:

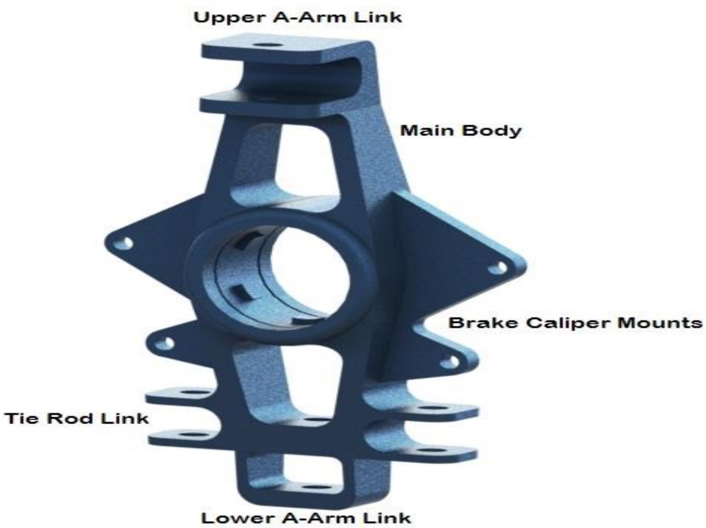

Fig. 3 Front Upright

Fig. 4 Rear Upright

The above images are of the front and rear upright which have been designed according to the goals set earlier. Both the front and rear uprights can be used in either left side or in the right side. The design is simpler and also lighter in weight which reduces the overall cost of machining. The uprights have a bore in the center meant which contains Oil seal, Circlip, Spacer and Bearing. A groove has been made of dimension according to the standard Circlip used. The designation of the bearing used is 6007. Gap is made in the spacer at regular interval between the bearings, which helps to push the bearing out in case of bearing change. Oil seals on both sides have been added which prevents the lubrication from leakage.

Finite Element Analysis was executed on each iteration in cornering, braking, and a combination of cornering and braking situations as a worst case scenario. These situations are seen while performing typical maneuvers on a Formula SAE course. To simulate a cornering force of 1.3 g, the spindle hole was rigidly constrained while a load of 895.0 N was applied to the upper ball joint and a load of 2304.7 N was applied to the lower ball joint in the opposite direction. Braking was simulated in Finite Element Analysis by rigidly constraining the spindle hole and applying a force of 1121.1 N at each of the brake caliper mounting locations. Following are the findings and results:

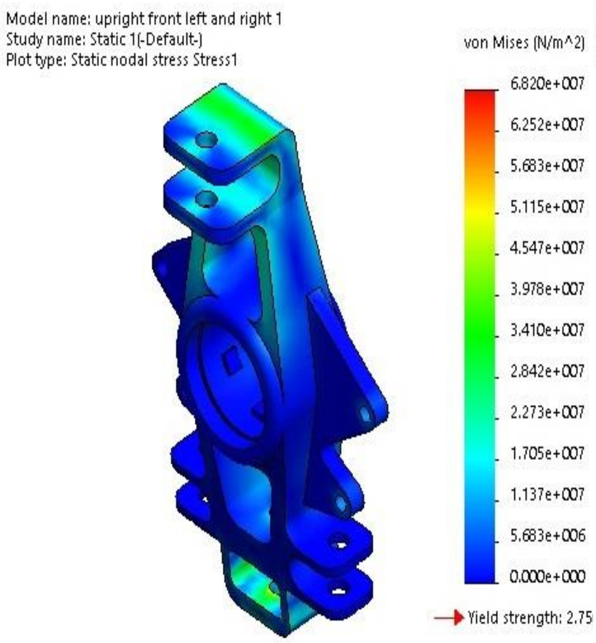

Fig. 5 Front Upright Stress Plot

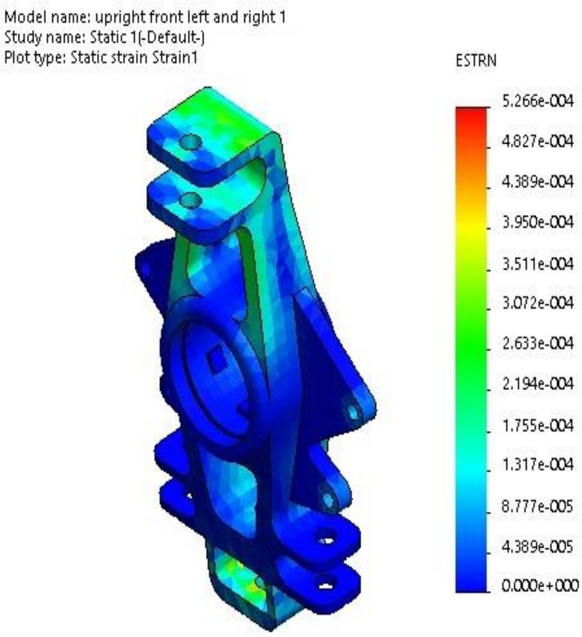

Fig. 6 Front Upright Strain Plot

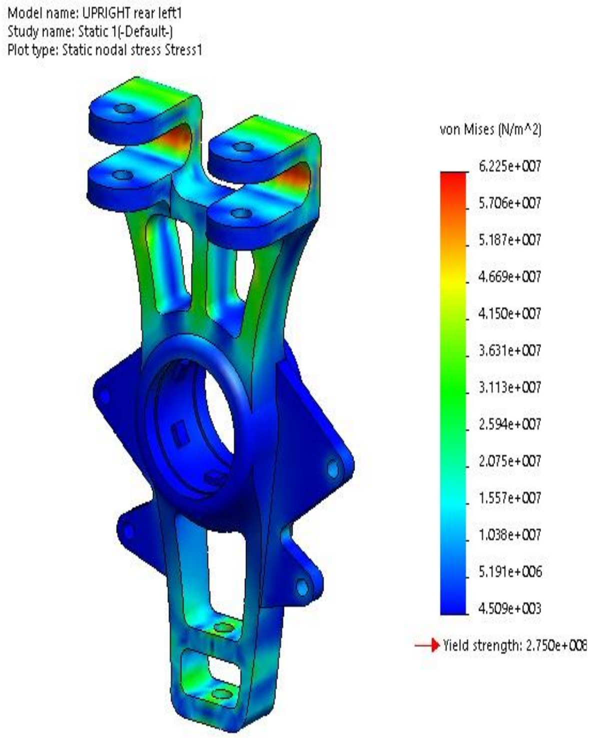

Fig. 7 Rear Upright Stress Plot

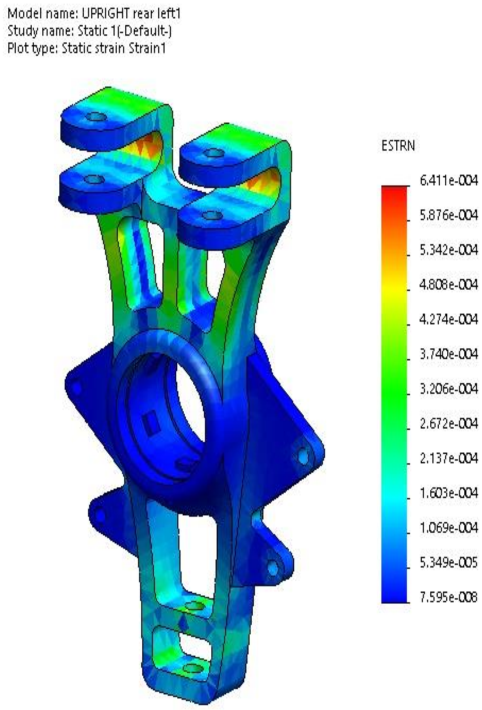

Fig. 8 Rear Upright Strain Plot

E. Components in Upright Assembly:

After a series of design practices, the final model of front and rear upright is ready. To make the uprights functional a list of components associated with its working is required. Some of the components are chosen by following the universal standards. The components are as follows:

- **Hub:** The front hubs are manufactured from 6061 T6 aluminum due to its superior strength to weight ratio. Also, in order to minimize weight without compromising strength, the front hub utilizes a four-leaf clover pattern to hold the lugs and the disc rotor fasteners. The OD of hub shaft is equal to the ID of bearing. The main function of the hub is to hold the rotate the wheel freely. Another key function of the hub is to allow the disk rotors to rotate freely.

Fig. 9 Hub

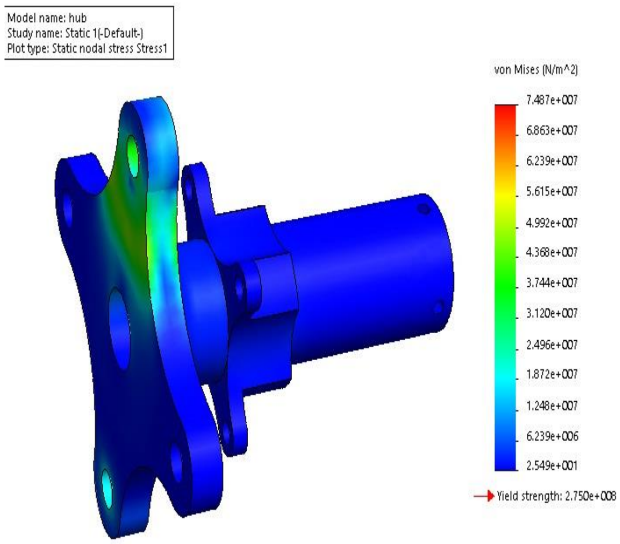

Fig. 10 Hub Stress Analysis

Finite Element Analysis was performed on the front hubs to validate their design. A braking force of 1.4g applied to the brake rotor fastener holes. Also, a cornering force of 1.3 g was simulated by applying a force of 4469.9 N on the bottom lug hole and 3024.2 N on the top lug hole in opposite directions while constraining the brake rotor fingers from translating. This loading resulted in a safety factor of 3.7.

- **Disk Rotor Flange:** After the hub is designed, disk rotor is needed to mount on it. We chose OEM 200mm disk rotors as it can freely rotate inside the space provided and are easily available. As the disk has three mountings, a flange was designed to hold the disk rotor which can be then mounted on hub.

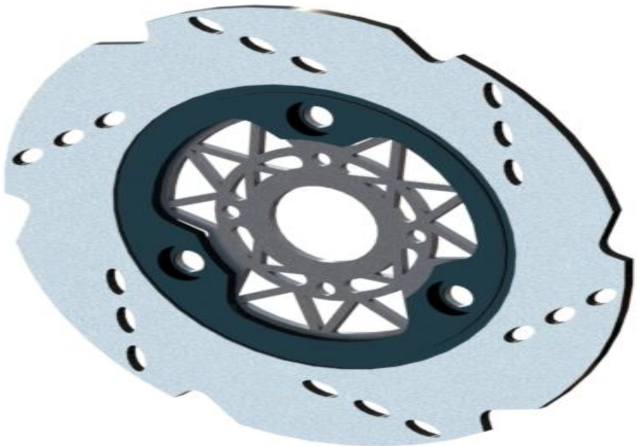

Fig. 11 Disk Rotor Flange

- **Final Upright Assembly:** After designing all the components by achieving all the goals that were set earlier, all the components are needed to be assembled to achieve their proper function. In the assembly two circlips of size 62 mm were used. For that two grooves were made inside the bearing bore at a distance of 4.5mm from the outer surface of the upright. Two bearings of designation 6007 are used and the spacer in between them is machined along with the upright. To prevent the leakage of lubrication an oil seal is used. The size of oil seal used is 35 x 62 x 10. Two piston caliper of 35mm diameter is mounted on uprights. The brake mountings are needed to be designed with precision such that the disk rotor doesn't get to much attached with the brake pads. To design the brake mounting it is better to draw outline of brake rotor, caliper and the upright and locate the mounting points. By updating this in actual CAD model we can get the actual brake mountings. Although certain fixtures are required to make to get the exact location.

Fig. 12 Final Upright Assembly

IV. CONCLUSION

The purpose of this thesis project is not only to design and manufacture the upright assemblies for the 2015 SUPRA SAEINDA car, but also to provide an in depth study in the process taken to arrive at the final design. With the overall design being carefully considered beforehand, the manufacturing process being controlled closely, and that many design features have been proven effective within the performance requirement of the vehicle. The FEA result indicates that the upright assembly is able to perform safely in real track condition as per performance requirement.

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