MODELING AND ANALYSIS OF UPRIGHT FOR FORMULA STUDENT VEHICLE

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***Abstract*:** The upright knuckle attaches the wheel, brake rotor, hub, brake caliper, 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.

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. Different materials and production process are considered and compared for fabrication of upright like CNC, Aluminum casting, 3D printing. And we decided to go with 3D printing considering the point that it offers production with different materials and this method is capable of production of complex shapes which are unattainable by conventional manufacturing process. Different materials are considered for 3d printing of upright but AlSi10Mg offers better properties and the powder is relatively cheap and easily available.

KEYWORDS: Upright, Lotus shark, Solid Works, ANSYS, Casting, CNC, 3D printing, AlSi10Mg.

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 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.

Fig.1.1. suspension syatem

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.

Fig.1 2.Leaf spring **Fig.1 3.**Coil spring

1.1.2 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.

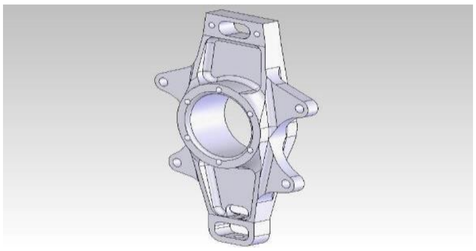


Fig.1 4. Upright of formula student vehicle

1.2 TYPES OF SUSPENSION

Automobile suspension is classified of two types i.e., Dependent suspension and Independent suspension.

1.2.1. DEPENDENT SUSPENSION

In Dependent Suspension there is a rigid linkage between the two wheels of the same axle. Force acting on one wheel will affect the opposite wheel. For each motion of the wheel caused by road irregularities affect the coupled wheel as well. It is mostly employed in heavy vehicles. It can bear shocks with a great capacity than independent suspension.

Solid axle suspension is most widely used dependent type of suspension system. It is mostly used in rear wheels in which the rear axle is supported and located by two leaf springs. The vertical movement of one wheel influences the other. They are simple and economical to manufacture. They are so rigid that there is no change in track width, toe-in, and camber on a full bump which helps in the low wearing of tires. The main disadvantage is that the mass of the beam is included in the un-sprung weight of the vehicle which results in low ride quality. The cornering ability is also poor due to zero camber angle.

1.2.2. INDEPENDENT SUSPENSION SYSTEM

Independent suspension is any automobile suspension system that allows each wheel on the same axle to move vertically (i.e., reacting to a bump on the road) independently of the others. This is contrasted with dependent system in which the wheels are linked– Movement on one side does not affect the wheel on the other side. Independent Implies to the motion or path of movement of the wheels or suspension. It is common for the left and right sides of the suspension to be connected with anti-roll bars or other

Such mechanisms. The anti-roll bar ties the left and right suspension spring rates together but does not tie their motion together. Independent suspension typically offers better ride quality and handling characteristics, due to lower un-sprung weight and the ability of each wheel to address the road undisturbed by activities of the other wheel on the vehicle.

There are no of types of Independent suspension system but MacPherson strut, double–Wishbone suspension, Trailing arm is most widely used Independent type suspension system.

1.2.3 DOUBLE-WISHBONE SUSPENSION

In automobiles, a double wishbone suspension is an independent suspension design using two (occasionally parallel) wishbone-shaped arms to locate the wheel. Each wishbone or arm has two mounting points to the chassis and one joint at the knuckle. The shock absorber and coil spring mount to the wishbones to control vertical movement. Double wishbone designs allow the engineer to carefully control the motion of the wheel throughout suspension travel, controlling such parameters as camber angle, caster angle, toe pattern, roll centre height, scrub radius etc.

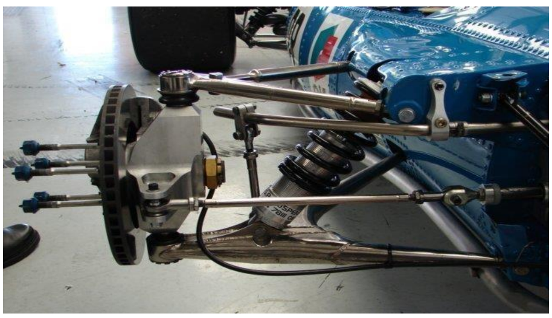


Fig.1.5. Double-wishbone suspension

1.2.4 MAC PHERSON STRUT

This is the most common, widely used front suspension system in cars today. It is a very simple and effective design that uses a strut-type spring and shock absorber that work as a team that will pivot on a single ball joint.

One problem with this system is that once the spring or the top plate becomes worn, the driver of a car with this system may hear a loud noise at full lock (i.e. steering wheel turned to the extreme left or extreme right positions), as the struts spring jumps back into place. This noise is often confused with CV-joint knock.

Fig.1.6. Mac person strut

1.3 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.

1.3.1. 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 center 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.

Fig 1.7. Double-wishbone pushrod suspension

1.3.4Double-wishbones pull rod suspension

For pull-rod suspension systems, the only difference is the orientation of the rocker arms. In a push-rod system, the rocker arms are placed at the highest point in the assembly. As such, the rod is under pressure as it transfers compression forces upwards into the rocker arms. In a pull-rod system however, the rocker arms are located between the upper and lower control arms, at the centre of the assembly. As such, the rod is under tension as it pulls against the rocker arms.

Fig.1. 8. Double-wishbone pull rod suspension

For our purpose pushrod suspension is employed at front and rear because of ease ofAdjustability and easy mounting rocker to the frame and push rod to the upright

1.4. SOFT WARES

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.

1.4.1. 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.

1.4.2 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.

1.4.3 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.

1.4.4. 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.

4. Scope of the Project

Every product in this world is made with some creative designs. So, without design no product can exist in the world. We have designed this product for the student formula competition in which we had participated and learnt about quitea few things which will be established in this project.

2. Literature Review

Tune To Win by Carroll Smith, 1978. 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 books covers the concepts like lateral load transfer and longitudinal load transfer that helps in determining the track 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.[1]

Race Car Vehicle Dynamics by Douglas L. Milliken. To find the load transfer and breaking calculations in dynamic conditions this book contain experimental results and the book goes into 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 tyre under different conditions like roll, maximum cornering etc. that help in selecting the tyre to initiate the suspension design. [2]

Fundamentals of Vehicle Dynamics by Thomas D. Gillespie. This book provides a foundation of engineering principles and analytical methods to explain the performance of an automotive vehicle, with chapters focussing 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 are among 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. [3]

Anshul dhakar and rishav ranjan, Forces are generated at the tire contact patch during various manoeuvres 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.[4]

Badih A. Jawad and Jason Baumann, 2002. 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 mainly focus on the types of suspension geometries suitable for Formula student vehicles, thus helps in choosing the vehicle suspension system.[5]

Detailed design report of design of Upright and hubs, by zubair, karthik, 2016. This research points 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 also concentrates 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. [6]

Design and optimization of Formula SAE suspension system, by Ashish Avinash Vadhe, 2018. 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. [7]

Design of Suspension system for a Formula Student race car, Y. Sumanth saurabh, Santosh Kumar, 2016. 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 suspension system are made using Solid works.

The Finite element analysis of the components is done using ANSYS Workbench. Both kinematic and dynamic analysis of the designed suspension system is performed. The results of 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. [8]

Car Suspension design. 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. [9]

Suspension secrets. The calculations for this project is referred from the former site and the site also focus on the dynamics of the vehicle and gives brief over view every vehicle dynamics concept. The load transfer calculations like lateral load transfer; longitudinal load transfer and diagonal load transfer are explained in great detail. [10]

Mat web. This cite gives every property of the materials used for the Upright so the optimum material can be chosen by comparing the properties like strength, Strength to weight ratio, Density etc. [11]

Design and 3D printing of steering wheel of a formula student vehicle, this paper concentrate on the design and 3d printing of the steering wheel and also compares different 3d printing processes like SLA, FDM etc. and that comparison gives insights about which process to be selected for a particular component and feasibility of printing and estimation of cost of production process and time complexity of the process.

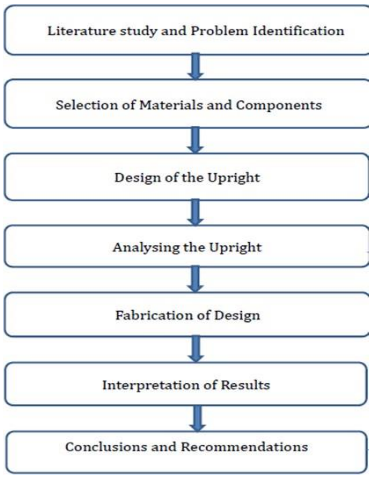
This paper also gives idea about the material selection as it compares and contrast PLA, Acrynotrile Butadiene Styrene (ABS), Polyethylene Terephthalate Glycol (PETG), polycarbonate (PC). the materials were compared in the terms of the materials were compared on the parameters that were important to our usage which are Fatigue Resistance, Printability, Weight, Durability, Stiffness and Ultimate Strength. [12]

Comprehensive View on Racing Car Upright Design and Manufacturing, this research paper discuss about the design and 3d printing process of a formula student upright along with topology optimization. This paper helps us in selecting the material and production process for 3d printing of the FSAE upright, the paper compares different materials like AlSi10Mg, Ti6Al4V ELI, and Mar aging steel M300. The materials were compared based on density, yield strength, modulus of elasticity and powder size.

This paper also concentrates on the topological optimization of the upright and explains the process of topological optimization and compares different 3d printing process like SLA, FDM, LOM, SLS etc. [13]

Rapid prototyping techniques and classification and comparision, Dharipalli Hyndhavi, S.Bhanu Murthy: This paper presents an overview of rapid prototyping technology, its importance, classification and comparison of properties of products obtained by adopting some of the rapid prototyping techniques namely, Fused Deposition Modeling (FDM), Stereo Lithography Apparatus (SLA), Selective Laser Sintering (SLS) and other methods and the applications of rapid prototyping in various disciplines. [14]

2. Methodology



3.1. Design Calculation

A. Force calculation

For the calculation of loads and load paths in wheel assembly, we need to take parameters from the geometry of thecar, the track and the procured components such as Tire-data. The following data have been obtained from standard FSAE race car:
The acceleration during various actions of the car (i.e. braking, cornering and throttling) are calculated using three equations of motion, considering acceleration as constant throughout the particular event. Data from Suspension Geometry.

$$v = u + at$$
$$s = ut + \frac{1}{2}at^2$$
$$v^2 = u^2 + 2as$$

The braking acceleration is calculated when the car de-accelerates from a speed of 60kmph to 0kmph in a braking distance of half the skid-pad circumference. Similarly, lateral acceleration is calculated assuming the maximum cornering speed as 40kmph and a lateral acceleration of around 1.4g has been obtained. The various speeds assumed are from standard FSAE race cars participating in the event. The coefficient of friction has been obtained from tire data which varies accordingto the normal load on the tire (FZ).

B. **Calculation of the forces during various maneuvers**

of The upright takes longitudinal force during braking and acceleration, and lateral forces during cornering. Hence, extreme forces are considered for a situation, when the car brakes during cornering. The total amount of traction is considered constant. The Circle of Traction shows the total amount of traction distributed between lateral forces and longitudinal forces.

1) **longitudinal force calculation**

The longitudinal forces are developed by an upright during acceleration and deceleration. It is evident that a driver experience more g's of force during deceleration (braking). The mass transfer during braking has been calculated using the following equation: (Mass Transfer) * 'g' * Wheel Base = (Mass of the Car) * Braking g's * 'g' * Centre of Gravity (Z). The coefficient of friction is a variable obtained from the tire data which depends on the net normal force, FZ after mass transfer. The system is considered as a beam with Frictional Force and the reaction forces on upright.

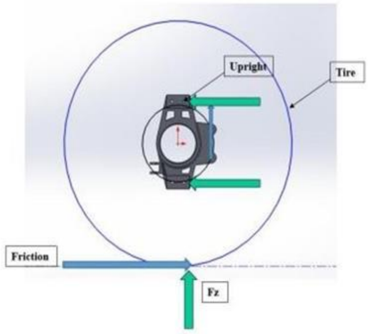


Fig. 4. FBD during Braking (Side View)

The distances between the reaction forces and frictional forceare obtained from the Suspension Geometry and Tire Specifications (such as Tire Diameter, Aspect Ratio, etc.) The equations were put in MS Excel and the longitudinal forces during braking were obtained.

2) **Lateral force calculation**

The lateral forces are developed by an upright during cornering or while steering. The mass transfer during cornering has been calculated using the following equation:
(Mass Transfer) * 'g' * Track Width = (Mass of the Car) * Cornering g's * 'g' * Centre of Gravity (Z). Since the track- width front and rear are different the load transfer is differentin both cases. The reaction forces here as well are calculated considering beam structure. And the distances were again takenfrom the data extracted (Tire Data, Suspension Geometry, etc.).

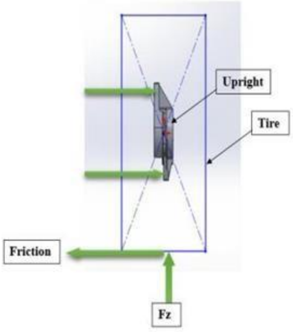


Fig. 5. FBD during cornering (Front view)

3) Linkages force

The linkages in a corner of a FSAE race car consist of two wish-bones having four links, a tie/toe rod and a push/pull rod. The tire forces are transferred to the links through upright. Sincethere are no bending forces, axial forces are developed in all linkages.

Fig. 6. Linkages in corner of car

A model has been generated which can be used for any suspension geometry just by changing the coordinates of the suspension point and other vehicle parameters such as mass ofthe car, center of gravity distance, weight bias etc. Manual calculations have been developed to calculate the forces on all the links. Factor of safety for each link has been calculated by using the forces obtained by FEA Analysis. These forces are essential to design the upright and other suspension componentssuch as upright clamps, bell cranks, hubs for any car using double wishbone suspension

3.1.1. Fabrication of Upright

A. Fabrication process

The Upright is made of MS 1018 by the following operations

- Facing
- Turning
- Boring
- Drilling
- Cutting
- Welding

The Fabrication process starts with the facing of the MS plateof thickness 6mm respectively. 1mm is removed by facing. A hole is made at the center of diameter 40 mm for the seating of the bearing. The holes are drilled as described in the design.

Then according to the resulted castor angle of 5 degree and camber angle of 6 degree a hole of 4mm has been drilled on topof the plate

Each pieces of the upright have been fabricated using the Laser cutting process with the CAD drawings.

B. Assembling process

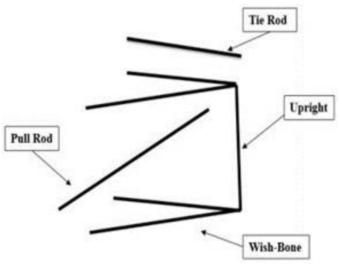
The Upright and the sub assembly parts are assembled together. The sub assembled parts are 2 X SKF ball bearings, Wheel hub. These are assembled together.

C. Advantages

1. Feasible to use (easily remove and fix the wheel).
2. Economically low cost for production.
3. Strength to withstand high torque is increased.
4. Easily weldability.

D. Applications

1. Upright is used between the tire (wheel hub) and chassis of the Formula student car to hold the wheel and to connect the wheel to the transmission shaft.
2. Upright is also used to mount the A arms to the chassis.
3. It controls the suspension geometry of the vehicle.



5. Future Scope

Upright is now fabricated by the material of MS 1018 but inthe future the material can be changed as ANSI 7075-T6 whichis of increased strength and the design can also be optimized by removing the unwanted material after changing the material. Ifthe material used (ANSI 7075-T6) according to the cost requirements the upright will be developed which will have lessweight without sacrificing the strength.

Also, design change can be made in which material reductionand structural change can be driven to get the optimized component.

6.Rusult and Discussions

- The model is developed in solid works using the points extracted in lotus shark
- The chosen material (ALSI10MG) is relatively less dense than the materials that are used in manufacturing by CNC or other process.
- 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 analyzed 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.

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