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Designing of Formula Student (FSAE) Car Suspension System

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Abstract— The purpose of this manuscript/paper is not only to design and fabricate a suspension system for a formula student race car but also to provide a literature review and a full focussed study of the processing steps done to achieve at the final design. The purpose of this paper is focused on the design and analysis of the suspension system in terms of functioning, strength, weight, and innovation. Though, a specific suspension system is designed for the car itself. The paper reviews previously used designs by various FS teams and also suggests an innovative and compact design for a front suspension system for an FSAE car. The suggested suspension system is designed for both front and rear wheels, which uses a mechanical advantage providing; sleek design, and a light-weighted strong rocker arm. Further, the proposed design in this paper will include a 3D model with dimensions and also show the stress analysis and FOS (factor of safety) analysis of the rocker arms. The following simulations are done on Solidworks 2016. And the design discussed in this paper is made taking Formula Bharat 2018 rulebook guidelines into consideration. Finally, this paper will help an engineer or a team in the choosing and fabrication of a compact and precise suspension system for their formula race car.

Keywords— Formula Student, Suspension System, A-arm, Rocker Arm, Pushrod, Solidworks, Force Simulation, Stress Analysis, Factor of Safety Analysis

I. INTRODUCTION

A Suspension is the system of tyres, tyre air, springs, shock absorbers, and linkages that connects a car or a bike to its wheels and allows relative motion between them. A suspension system arrangement of a vehicle consists of the un-sprung mass which includes wheels, brakes, uprights (knuckles), and a huge part of the weight of A-arm (wishbone), dampers; and the sprung weight consisting of a full vehicle body.

The functions a suspension system serves namely are: to safeguard against the road shocks from being transmitted to the vehicle components, to comfort the occupants while road shocks are present, and to maintain the stability of the vehicle in pitching or rolling, while in motion [1].

Formula Bharat is an engineering design and fabrication competition in which Indian students present and compete with each other, by presenting a life-sized working prototype for a Formula Style Vehicle. The Formula SAE Collegiate Design Competition is regulated by firm rules and regulations to allow for fair competition and the safety of the drivers. These competitions are based on the rules and guidelines provided by the Society of Automotive Engineers (SAE). The rules shape some specific constraints in terms of the suspension and wheel assembly design and the maximum cubic capacity of the chosen engine and, it remains broad in other areas such as control mechanisms.

An FSAE competition provides an educational experience for college students. To participate in FSAE, a team works on a prototyping project from, the conceptual designing phase, up to manufacturing and fabrication. Aspects of engineering design, teamwork, project management, and finance are included as the basic standards of Formula SAE. In the event, each team is to design and manufacture a small formula racing car according to the guidelines of the contest and the racing car manufacturing standards. And the performance of the vehicle has an influential effect on the results of the contest [2].

For which, a suspension system is an important component to affect the passenger's comfort and handling stability. Hence, the research and the optimum designing of the suspension system for the FSAE car; guarantees the needed suitable performance of the vehicle.

II. RELATED WORK

Generally, it is seen that a dual wishbone (dual A-arm) is chosen as: it provides broad design independence for suspension kinematics and is seen to be the most compact enclosing for a formula student car frame chassis. Here, the suspension kinematics refers to the motion of the suspension during turns and under certain road surface geometry.

Rahul Sindhwani et al. used a pushrod suspension framework with a rocker arm (Bellcrank) arrangement in their formula student car. In their designed suspension mechanism, as the bar is pushed by the weight of the vehicle and as it moves the pressure is transferred upwards into the rocker arms which are further connected to the spring dampers; hence, balancing of the force or pressure takes place. They placed the rocker arms in between the upper and lower control arms, at the focal point. They selected Mild steel as the material for the suspension rocker arms and the A-arm pipes used are of Stainless steel (SS). The simulated factor of safety of the suspension components came out to be more than 5 under braking and turning conditions. And, it was claimed that their designed system, provided greater stability during cornering at rapid speeds, with a negative camber was developed in the front with a high tractive force on tyres and ground and furthermore increasing the contact patch of tyres [3].

M N A Zaidieet al. developed an independent-wishbone suspension system for their formula student-car. They chose the wheelbase of the car as 1525mm. They utilized CATIA and ANSYS for the preparation of a 3D model of the suspension system. Further, they simulated the suspension mechanism under 3 conditions namely braking, cornering, and bumping. The material selected for the A-arm and spring was mild steel. The residual equivalent stress developed in the full suspension assembly comprising of both A-arms, damper-spring arrangement, and uprights were about 160 MPa. Also, this stress was induced under the application of an external force of 1.6677 KN. They simultaneously compared this independent wishbone design with a previously used pushrod suspension mechanism which was actuated with the help of a rocker arm and it was observed that the overall weight of the suspension setup was reduced with a reduction in the residual stress was of about 6.2%. Finally, they concluded that an independent wishbone suspension system came out to be better than a pushrod rocker arm suspension mechanism [4].

Samant Saurabh Y et al. designed a push rod rocker arm suspension mechanism for their formula student car using Solidworks software. They developed their design by performing a kinematic and dynamic analysis along with vibration analysis. As it is previously mentioned that the minimum wheel travel should be 50mm according to the FSAE rulebook but the wheel travel for the kinematic analysis was set as 75mm i.e., 37.5mm jounce and 37.5mm rebounce. The material selected for the rocker arm was Aluminium 6061 alloy and that of the A-arm pipe was stainless steel. The spring stiffness for the suspension spring came out to be about 40 KN/m under a damping ratio of 0.7. Vibration or ride analysis of the design yielded the effect of damping ratio on comfort and wheel deflection and produced the optimum value of the coefficient of damping. Dynamic analysis of the kinematic links offered a high stiffness of the spring for a particular ground clearance under static conditions. And during vibration analysis, the damping coefficient of the wheel was neglected because it is very less when compared to the damping coefficient of the spring damper [5].

Ashish Avinash Vadhe in his paper on Design and Optimization of Formula SAE Suspension system designed a pushrod rocker arm suspension mechanism for a formula student race car using drafting and CAD model designing on Solidworks and Catia. And performed the FEA (Finite element analysis) on ANSYS software then used Lotus Shark Suspension Analysis software for dynamic analysis of the suspension. Finally, the fabrication of rocker arms was done by processes like laser-cut, grinding, welding, lathe operations, and assembly was achieved with processes like bolting and press fitting. In the calculations regarding the lengths of A-arms, the wheelbase was taken as 1600mm and the track width for front and rear wheels was taken as 1250mm and 1200mm respectively. The FOS was determined by simulation an external force of about 883 N each of the wheels as pair i.e., front wheels taken together and rear wheels taken together. The weight of the vehicle assumed for the calculations was taken to be about 230 kg with a weight distribution ratio of about 45:55. The material selected for the rocker arm and the A-arm pipe both was mild steel. Finally, a negative camber was achieved resulting in more tractive force and an increased patch of contact of the wheels during turning [6].

Khan Noor Mohammad et al. developed a double-wishbone for front wheels and an H-arm for the rear, in their All-terrain vehicle design. For the front wheels which require steering a double-wishbone framework consists of a system in which each arm controls two degrees of freedom and one tie rod controls one degree of freedom and in total the double-wishbone assembly maintains five degrees of freedom. And dual A-arm of unequal lengths were used because they result in ideal camber in the wheel travel. Here, the shorter upper arm results in a camber curve which provides maximum contact patch during wheel travel. Whereas for the rear wheels which support a high amount of vehicle weight H-arms are used, An H-arm is nothing but a linkage of shape ‘H’, having two mountings are on the vehicle chassis and two on the upright. Also, they provide zero steer condition under dynamic conditions, large space availability for damper mounting, and low unsprung weight hence being advantageous for working of the suspension. For the calculations of the lengths of wishbones, the wheelbase was taken as 1450mm and the track width for front and rear wheels was taken as 1244.6mm and 1168.4mm respectively. They used Lotus Shark Suspension Analysis software for dynamic analysis of the suspension system of the vehicle. The material selected for wishbones was AISI 4130 steel, as it has high a tensile strength bearing capacity. Further, the software simulation and analysis were done under the application of an external lateral force of about 2804N and the upward force of about 2600 N. As a result of which the maximum induced stress was about 237.04 MPa and the strain was about 0.3861mm with FOS of 2.12. Finally, the resulting ground clearance of the front and rear last member of the vehicle was 350 mm and 300 mm respectively and a minimum force of interaction with the tyre was achieved [7].

Christian Arévalo et al. studied and analysed the performance of the suspension systems, in a formula student prototype, using a push rod type mechanism comprising of a double-wishbone/double A-arm framework. They selected a wheelbase of 1600mm and a track width for front and rear wheels of 1200 mm and 1180 mm, respectively; for the calculations regarding the lengths of A-arms. And, the simulated weight of the formula student race car was taken as 345 Kg including a seated driver with a weight distribution ratio of front: rear weight of about 45:55. They selected Carbon fibre and aluminium 7075 T6 as the manufacturing material for their A-arm and pushrod design. The kinematic analysis is performed on Lotus Suspension Analysis; which is a program that allows the user to know the behaviour of the suspension by geometry establishment on the various stages in the racing track, such as bounce and rebound and roll, etc. Then a couple of maximum external tensile forces on the members of the suspension arms applied were 4313 N and 5131 N (upwards) in the front and rear respectively, and the maximum compression forces applied were 4165 N and 5119 N (downwards). Now, under the tensile loading, the maximum joint force developed was about 2.9 KN (downwards) and the maximum member force developed on the suspension arm was about 5.13 KN (upwards). And, under compressive, loading the failure forces developed in the members of the suspension arms, push-rod, and coupling arm due to buckling was about 13 KN and the FOS achieved was greater than 2. Finally, this configuration provided allows good directional control of the FS race car and an adequate negative camber gain of the wheel with the travel of the suspension or rolling of the chassis, giving a good lateral hold to the tyres along with an increased contact area [8].

Daniel Gualoto et al. designed a formula student racing suspension system by performing analysing based on the unsprung mass behaviour of the vehicle during motion and dynamic conditions. They also determined the optimal material for the manufacturing and fabrication of the suspension system components by taking into consideration the manufacturing processes costs and material costs. Here, they applied two specific combinations of materials on their suspension system which were aluminium 7075 and forged aluminium; carbon fibre and carbon fibre with AL-7075. Their calculations were done taking into account dependence of ride and roll rate, the ratio of pushrod-movement, and the subsequent spring-compression. Further, their aim was to reduce the unsprung in a Formula Student (FS) prototype. In order to obtain a better tyre response on the track, especially while taking curves as a result of the inertial forces under high speeds of the vehicle [9].

Mohd Khairul Nizam Bin Suhaimin et al. found that there is still very limited study presented or done for the determination of the kinematic and dynamic performance analysis in the types of double-wishbone suspension mechanisms which are of Short Long Arm (SLA) and Parallel Arm Suspension (PAS) style. Now, in their paper, the basis for this analysis is done by obtaining and studying the data of all the basic suspension geometry parameters such as the toe in or out geometry, camber gain, and caster gain angles, etc., further their experimental data survey and results concluded that the SLA suspension has a relatively better kinematic performance for an FSAE car usage. And, as mentioned earlier, the very main intent of a suspension system is to totally isolate the vehicle body/components (with rider) from the road bumps/ obstacles and vibrational pulses, while the transitional motion of the vehicle. Then again there are many types of suspension system mechanism for a vehicle but out of them all a double-wishbone SLA suspension is the most favourable one; in this, as the name suggests one arm of the a-arm is shorter than the other, this is due to the fact that the suspension requires an optimum geometry for its complete working. In their paper, they have used CATIA software for the preparation of the 3D model and Altair Motion View software for simulation purposes. And for the analysis purpose, they have chosen the vehicle to be 200kg (without rider) and the front wheel to wheel track length as 1200mm with a wheelbase of 1500mm. Now, as far as simulation and analysis results are concerned, they have not mentioned any material specification; the toe achieved under static conditions was about -0.1 degree and when the vertical wheel displacement of parallel suspension was set to 0mm (under dynamic conditions) the corresponding toe was 0.22 degree; during jounce condition, under the wheel 80mm upward movement, the SLA suspension gave a value of toe of about -4 degree; and as a result of these results the geometry obtained was of toe-out type. Further, the chamber gain angle came out to be negative at all the conditions (which was desirable), while the caster angle was positive in magnitude. Finally, the authors concluded that an SLA-type suspension has proved to be better than the rest after examining all the results and data [10].

Bin Zhu et al. designed and optimized an FSAE race car suspension system in their manuscript. They have here performed graphical straight line and curve analysis of a suspension system taking into consideration the various vehicle geometries like Roll centre height, Pushrod lengths, A-arm lengths, caster angle, camber angle, front toe geometry, and Kingpin inclination angle for both front and rear suspension arrangements. The simulation software used by the authors is ADAMS software. And in their research and study, they have found that the natural frequency (Hz) of the suspension system has a pivotal role of importance in the comfortable and safe riding of a vehicle. Then if the frequency is of low magnitude, the suspension is considered to be soft in nature, resulting in comfortable riding, and if it is of a high magnitude, the suspension is regarded as hard, resulting in good control of the car. For the analysis the components were assumed as rigid bodies, completely neglecting internal friction, and with considerations, such that the absorber has a linear damping characteristic. Now, for the analysis purpose they have considered the acting sprung weight as 270kg and the natural frequency ranging about 2.3 Hz for the front suspension and 2.5 Hz for rear suspension respectively. Finally, the Structural parameters of the suspension system are as follows: the roll centre height was 22mm (front) and

35mm (rear), caster angle was 1.22 degrees (front) and 0 degree (rear), kingpin angle was 1.6 degrees and 1.2-degrees, front toe angle was 2 degrees and 0.5-degree, camber angle was -2 and -1 degrees with a lower a-arm length of 340mm and 225mm, and upper a-arm length of 335mm and 220mm for front and rear respectively. Therefore, this paper also proves an independent wishbone design as the more superior one [11].

S. Chepkasov et al. studied and conceptualized the design of an FSAE race car suspension system geometry by preparation of a mathematical model of the same. Though this paper does not talk about the material selection, force analysis, and type of suspension system chosen for the FSAE race car; it does highlight and explain, the equational & mathematical model analysis approach for the same. The mathematical and equational approach adopted by the authors is quite apt and precise for the determination of the suspension system design parameters. And the examined geometries here are: A-arm angle with horizontal, angle of inclination of a-arm, camber angle, static wheel radius, and changing track lengths. Also, they found that all the before mentioned suspension geometry parameters depend upon the suspension working travel. Further, this model analysis is done by considering a 3D line CAD in a 3D line layout coordinate system. Also, they have constrained their analysis to one 1 degree of freedom (DOF). Although as mentioned above in the subheading in section 2 FSAE rules, the minimum suspension movement is meant to be 50mm here the authors have considered it to be 60mm (30 mm jounce and 30mm rebound). Then finally, they have presented the basic equations needed for suspension geometric parametric analysis and they have also concluded the advantage of negative camber geometry in the suspension system design [12].

Martin McDonald et al. examined and simulated the various external forces and internal stresses acting and induced on/ in a suspension system A-arm. They further used these simulation results in the designing of an easy and compact A-arm made of composite material. They further chose carbon-epoxy composites for the manufacturing material for the A-arms, due to their high specific stiffness, limitless formability characteristic, and strength. And in their paper, they did not perform force calculation by the previously used theoretical equational method, but they rather chose 4.5KN by physical and experimental examination of the previous year FSAE race cars as the basis force acting on the a-arm under static weight conditions. Then their manufactured a-arm was tested for failure compression load of about 18.4 KN. Further, for purpose of analysis, they chose the vehicle weight without a rider as 2200N. And the mathematical line and numerical modelling so performed was done on MATLAB software. The A-arm vertical ground clearance was taken to be 125mm. Finally, the resulting FOS after the simulation and analysis came out to be 3 and the only point of concern was the forces and stresses acting and inducing onto the fitting parts and metal washers. Also, the manufactured A-arm was laminated for the betterment of safety and strength [13].

Dennis Robertson et al. presented a review paper on the suspension system design for an FSAE race car back in the year 2009. Their review covers the following topics basic design philosophy, configuration and material selection, simulation and analysis, fabrication/ manufacturing, and implementation. According to them the very basic starting step for the suspension designing is the designing and constraining or setting of the uprights or knuckles for the vehicle followed by the A-arm design and point setting with tyre geometry selection done side by side. Then further this process is greatly affected by tyre grip (which is friction dependent), load sensitivity or weight distribution of the vehicle, slip angle of the wheel, and track and camber angle. Also, in their review, they have chosen the independent type wishbone suspension system mechanism. And, they have also mentioned the various mathematical equations corresponding or relating or making an effect on the suspension geometries, these are: teach length and vehicle weight relation, Motion ratio and wheel displacement relation, installation ratio and wheel displacement relation, frequency, and mass, or weight relation, vehicle roll rate, and frequency relation. Their paper also provides the advantages of negative camber and also proves as a reference or a source for the upright and bearing designing and selection respectively [14].

III. METHODOLOGY

The designing of the suspension system starts with the setting of the configuration, position, and geometry of the suspension system of the vehicle. Then next after the final setting, the suspension design is 3D modelled by using Computer aided designing (CAD) software like Solidworks, Catia, and Fusion 360 etc. This step is then followed by simulation and analysis of the 3D model prepared so far on software like Ansys and Solidworks etc. under which external forces are applied on specific points of the system after the selection of a suitable material. Finally, if the designed suspension system satisfies the FOS and residual stress limits then it is then fabricated and manufactured for its assembly on the vehicle for which it has been designed.

Design procedure for suspension system

1. Determination of the vehicle dimensions (track width and wheelbase).
2. Selection of tyre and rim size.
3. Selection of ground clearance.
4. Choosing the suspension parameters (jounce, rebound and spring length).
5. Selection of suspension geometry to be employed.
6. 3D Modelling of suspension mechanism.
7. Material selection.
8. Simulation and Analysis.

Proposed design for Push-Rod Rocker arm System

Push-rod suspension is an arrangement in which the suspension arm is set at an angle of about 45 degrees with respect to the chassis/frame of the car. Here, whenever the vehicle experiences jerks or vibrations its impact is transferred via the wheel assembly to the suspension knuckle and then to suspension arm, then finally to the suspension where it is absorbed and converted into heat energy.

Also, in a push-rod structure, the rocker arms are a mechanical advantage providing components that work like a seesaw and to which the other end of the push rod is connected. Generally, these are placed at the most elevated point in a vehicle so as to work effectively.

The A-arms used were of unequal lengths so as to provide optimal camber gain during wheel travel and here, the short upper A-arm helps in inducing a camber gain which further maintains maximum tyre and track contact length during wheel or vehicle motion.

Arm Designing
Now, for the start of the designing of the formula car suspension system the considered the vehicle geometries are: wheelbase is 1610 mm, the front track width is 1225 mm, rear track width is 1220 mm, total vehicle length is 2725.6mm, tyre to tyre outer width is 1410 mm, and maximum height is 1152.5 mm of main hoop, Centre of gravity height is 259.28 mm, weight distribution is 47:53. And, the suspension parameters are front and rear tyre size is 205/50-10, wheel width is 7.28 inch, suspension design travel is 30.81mm jounce and rebounce respectively.

The A-arm mounting points on the chassis frame are decided taking the wheel and tyre radius and centre into account. Further, the length of the A-arms is estimated by the use of the track widths (both front and rear), King pin inclination angle and camber angle. The proposed design of the A-arms in this paper is of unparallel and unequal length type.

So, by keeping the front track width set as 1225 mm and the upper A-arm angle of elevation as 9.4 degrees the length of the front upper A-arm is 327.3 mm and 327.2 mm respectively. While the angle between front upper A-arm pipes is 45.16 degree. And, for the front bottom A-arm the angle of elevation is 0 degrees i.e., it is parallel with the horizontal and the length of front bottom A-arm is 432.07 mm and 432 mm respectively. While the angle between front bottom A-arm pipes is 50 degrees. For the rear of the vehicle the track length as specified before is 1220 mm so the angle of elevation for upper rear A-arm is the length of its members was 4.8 degrees and the length of the rear upper A-arm is 304.5 mm and 304.5 mm respectively. While the angle between rear upper A-arm pipes is 50 degrees. And, for the rear bottom A-arm the angle of elevation is 1.9 degrees and the length of rear bottom A-arm is 414.4 mm and 414.4 mm respectively. While the angle between rear bottom A-arm pipes is 50 degrees.

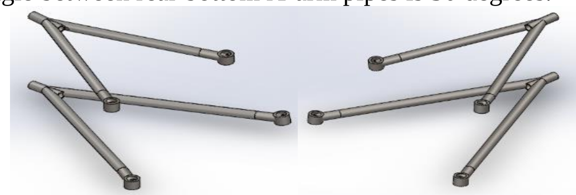


Figure 1. .Rear and Front A-arms

Pushrod and Suspension Mountings and Lengths
Here, the push rod is connected between the bottom A-arm and the lower end of the rocker arm i.e., one end of the push rod is screwed to the bottom A-arm and the other end is screwed to one of the 3 holes on the rocker arm pair (assembly of two rocker arms separated by a bushing in between). First, the mounting location of the suspension dampers and spring assembly is decided on the chassis frame (ahead of the main role hoop) i.e., a pipe member on the chassis is chosen for mounting of the suspension dampers and spring assembly onto which a mount with 2 holes on it is welded. Then, the angle of the suspension assembly is decided taking into consideration the best angle at which the damper travel is maximum and the oil spillage or leakage from the compression chamber of the damper is minimum. Also, here a gas nitrogen damper can be used so as to remove the condition of oil spillage. Further, both the suspensions are screwed to the rocker and are hence hanging in air hinged from one side only till now. Then after this the length of the pushrod is determined as the distance between the lower hole on rocker and the mounting point on the lower A-arm is measured. The pushrod is screwed to hole number 3 in the following figure.

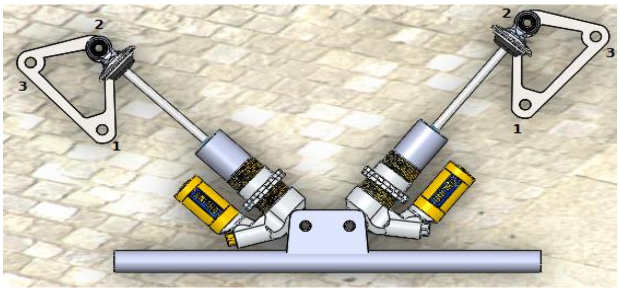


Figure 2. Pushrod Length determination

Force Application and Simulation & Analysis
In order to find the total working performance and potency of the suspension system each of its parts is modelled on a 3D modelling software here, on Solidworks and then the analysis on the full suspension system is done. The Force study of the 3D design is done taking the effect of maximum turning and braking forces anticipated during the motion of the vehicle. Now, for the simulation and analysis the material selected for the A-arms is AISI 1020 Steel. And Mild steel is selected as the base material for the rocker arms force and stress analysis.

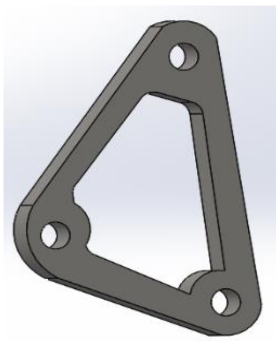


Figure 3. Proposed Rocker Design

Force Determination for FOS and Stress Analysis
For the purpose of calculations, the overall weight of the vehicle is taken as 317 kg (this accounts for vehicle weight including member weight and welding weight plus driver weight of about 75 kg). Further, the force analysis (study) is carried out under 2 iterations or conditions first when the driver is seated and second under the presence of a bump on the race track which results in extra compression in the suspension assembly.

Calculations
Assumptions: g (acceleration due to gravity) = 9.81m/sec^2, weight distribution is 47:53 i.e., Front weight: Rear weight.
1. Longitudinal Forces during Braking on the A-arms: Due to the inertial effect of the rear weight onto the front weight or section.
Now,
Force at the front section = inertia force coming from the rear section i.e., mass at the rear side of the vehicle x acceleration ($F = ma$)
Here, the mass of total vehicle (m):

(Equation. 1) $m = 317kg$

(Equation. 2) $F = 317 * 9.81(N)$

(Equation. 3) $F = 3109.77\ N$

Which gives the force on each wheel =>

$$3109.77 / 2 = 1554.885\ N$$

=> **Longitudinal Force = 1554.885 N**

2. Lateral Forces due to centrifugal effect during vehicle turning:
Let the vehicle turn at a 5m turning radius and at a speed of $35kmph = 9.73\ m/s$
We know,

(Equation. 4) $Centrifugal\ Force\ (C.F) = \frac{mv^2}{r}$

For the front wheel load:

(Equation. 5) $C.F = front\ weight\ ratio * \frac{mv^2}{r}$

Taking $front\ weight\ ratio = 0.47$,
We get,

(Equation. 6) $C.F = 0.47 * 317 * \frac{9.73^2}{5}\ (N)$

$$=> C.F = 2821.06\ N$$

=>Centrifugal Force = 2821.06 N

IV. Results and Discussion

The Simulation parameters considered for the CAE analysis of the proposed Rocker Arm Design are as follows:

1) Base Material for analysis - Cast Alloy Steel
2) Elastic Modulus = 27557170.16 psi
3) Poisson's Ratio = 0.26
4) Tensile Strength = 64988.87 psi
5) Yield Strength = 34994 psi
6) Static Loading Condition with seated driver of 75 kg

FOS (Factor of Safety) Analysis
FOS is the fractional ratio of Yield Strength and Working Stress for a material or piece.
Mathematically,

(Equation. 7) $FOS = \frac{Yield\ Strength}{Working\ Stress}$

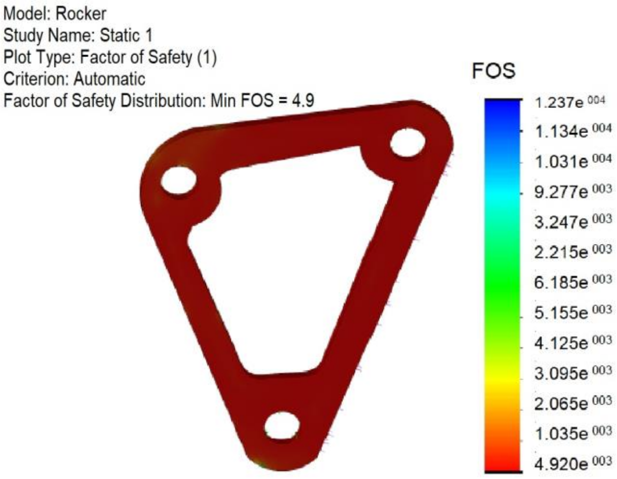
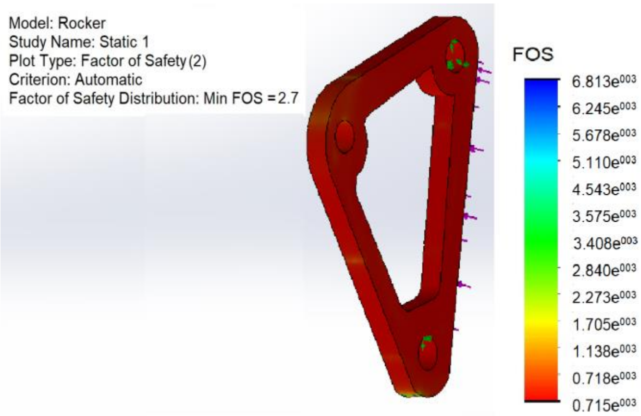


Figure 4. FOS Simulation for Designed Rocker (When Longitudinal forces are in action on it)

Corresponding to the above result image, we find that, the FOS for the rocker under static loading of longitudinal forces, comes out to be "**4.9**".



FOS Simulation for Designed Rocker (When Centrifugal/ Turning forces are in action on it)

Corresponding to the above result image, we find that, the FOS for the rocker under static loading of Centrifugal/ Turning forces, comes out to be "**2.7**".

Stress Analysis

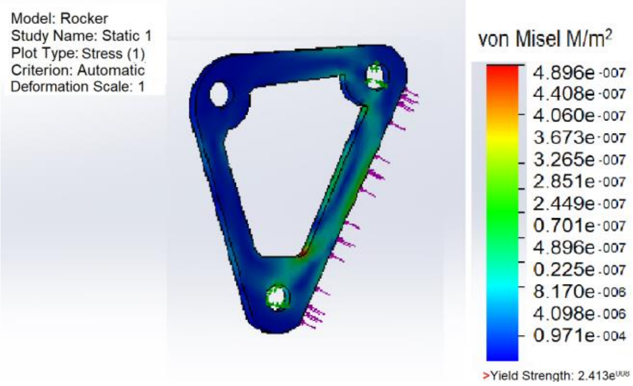


Figure 5. Stress Analysis for Designed Rocker (When Longitudinal forces are in action on it)

Corresponding to the above result image, we can see that the stress localizations/ zones, for the rocker under static loading of longitudinal forces, can be seen to be blue in color. Which implies that the proposed design is overly protected for its majority areas/ portions; against the static loads during longitudinal forces.

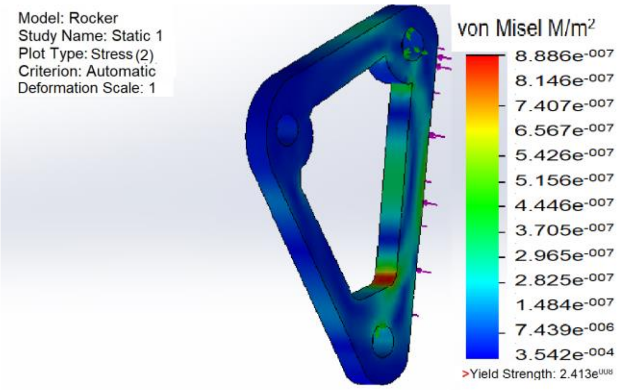


Figure 6. Stress Analysis for Designed Rocker (When Centrifugal/ Turning forces are in action on it)

Corresponding to the above result image, we can see that the stress localizations/ zones, for the rocker under static loading of Centrifugal/ Turning forces, can also be seen to be blue in color. Which implies that the proposed design is overly protected for its majority areas/ portions; against the static loads during centrifugal/ turning forces.

Hence, from the FOS results and the stress concentration results under both types of design consideration loads: the longitudinal loads and the centrifugal loads; are good from a designing perspective, so, the proposed and simulated rocker is perfectly fit for actual manufacturing.

Discussion

After going through the various researches and findings it can be said that in order to achieve best results (high effectiveness), a suspension must incorporate an optimum kinematic design in order to make the tyre as perpendicular as possible with respect to the road track, for maintaining fine cushioning and enough elasticity rates to keep the tyre grounded always. The components of external forces, both horizontal and vertical must be resistant so that they do not lead to failure of the mechanism under the application of static and dynamic loadings. Also, it is quite evident that the length of upper control arms determines the curvature of the camber curve. But, if upper and lower arms were of the same length, the resulting camber curvature would be in a straight line and if the upper arm is shorter than the lower one, the net resulting curvature would be in a concave negative geometry which is generally preferred while turning and cornering.

The previously reviewed researches and designs of the suspension systems, presented in the previous sections of this paper are tabulated/ and briefed in the following table.

Table.1. Various Reviewed Suspension Designs

Type of Mech.	**Material of Components**	**Factor of Safety (FOS)**	**Major Findings**
Push Rod Rocker arm	Rocker Arm-Mild Steel A-arm pipe-Stainless steel	Greater than 5	High stability during cornering. High tractive force on tyres. Negative front camber. High tyre-road contact [3].
Wishbone type	A-arm and spring- Mild Steel	Not Specified	Overall weight reduction of system. Residual-stress reduction of about 6.2% when compared to push rod type arrangement [4].
Push Rod Rocker arm	Rocker Arm-Al 6061 A-arm pipe-Stainless steel	2.4	Good stiffness of suspension spring for a particular ground clearance. High Robustness and sustainability of the system. Optimum value of Coef. of damping [5].
Push Rod Rocker arm	Rocker Arm-Mild Steel A-arm pipe-Mild Steel	2	Negative camber developed on tyres. High tractive force. Increased patch of contact of the wheels during turning [6].
Front A-arm And Rear H-arm type	A-arms-AISI 4130 H-arms-AISI 4130	2.12	High ground clearance ranging from 300-350 mm. Minimum force of interaction of tyre and racing track [7].
Wishbone type	A-arms-Carbon fibre Push rod-Al 7075 T6	Greater than 2	Allows a good directional control of the vehicle. Adequate negative chamber gain. High lateral hold to the tyres. Increased tyre-road contact area [8].

Additional Information

Some teams and engineers also give a 4th hole in the rocker sometimes, this is done in order to give a connection link between both the suspension assemblies for front and rear arrangements respectively. Here, a rod (member) is connected or screwed to the rocker pairs which in term connects and transfers the movement of any of the one suspension to the other. And this significantly important member is known as an anti-roll bar. Therefore, as its name suggests it reduces or acts as a prevention under the roll over or rolling condition of a vehicle under high-speed turning or cornering about the instantaneous centre "I".

The wheel base and the track width for both front and rear of the vehicle wheel pairs is determined taking into consideration the formula student guidelines and the optimum Ackerman wheel turning radius about the instantaneous centre.

V. Conclusion and Future Scope

Now, after knowing the function, working and need of a suspension system; And going through the various reviews of the different designs of FSAE suspension systems designed by various authors it is quite evident that a double-wishbone/double A-arm mechanism suspension system is relatively simple in its design, easy to modify, failure stress resistant, highly adaptable and also light in weight if made by using composite materials are most widely used by various FS steams across the globe.

However, the push rod rocker suspension mechanism is the most preferred one amongst all the available options as it has some advantages over conventional mechanisms. These advantages include the provision of more stability of the vehicle as a result of negative camber leading to a higher traction, Over-steer configuration of vehicle leading to reduced steering effort and better handling, A lower COG of the vehicle, less rolling possibility, etc.

Also, the FOS and stress analysis of the push rod rocker suspension system came out to be better than the ones discussed and reviewed in the above table.

So, after being more complex and time consuming in design and calculations it is preferred by formula student teams as it has a sleek, compact and innovative look.

And, in terms of space consumption of its components in the vehicle rear and front this design proved to be better; and on the top of it all the assembly and disassembly of this type of system is better.

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References

[1] Dr. K. Singh, "Automobile Engineering," *Standard Publishers Distributors*, **India**, pp.170-209, 2007.

[2] Wirawan, J. W., Ubaidillah, Aditra, R., Alnursyah, R., Rahman, R. A., &Cahyono, S. I., "Design analysis of formula student race car suspension system", *AIP Conference Proceedings (AIP Publishing LLC)*, Vol. **1931**, Issue. **1**, pp. **03-51**, **2018**.

[3] Sindhwani, R., Bhatnagar, A., Soni, A., Sisodia, A., Singh, P. L.,Kaushik V., Sharma S., Phanden RK., "Design and optimization of suspension for formula Society of Automotive Engineers (FSAE) vehicle", *Materials Today: Proceedings*, **2020**.

[4] Zaidie, M. N. A., Hashim, M. S. M., Tasyrif, M., Basha, M. H., Ibrahim, I., Kamaruddin, N. S., &Shahriman, A. B., "Analysis of a front suspension system for UniART FSAE car using FEA", *Journal of Physics: Conference Series*, Vol. **908**, Issue. **1**, pp. **120-129**, **2017**.

[5] Saurabh, Y. S., Kumar, S., Jain, K. K., Behera, S. K., Gandhi, D., Raghavendra, S., & Kalita, K., "Design of suspension system for formula student race car", *Procedia Engineering*, Vol. **144**, pp.**1138-1149**, **2016**.

[6] Vadhe, A. A., "Design and optimization of formula sae suspension system", *International Journal of Current Engineering and Technology*, Vol. **8**, Issue. **3** pp. **609-635**, **2018**.

[7] Mohammad, K. N., Singh, V., Das, N. R., Nayak, P., & Patil, B. R., "Dynamic Analysis of the Front and Rear Suspension System of an All-Terrain Vehicle", pp. **3216-3224**, **2018**.

[8] Arevalo, C., Medina, A., & Valladolid, J., "kinematic and dynamic study of the suspension system of an electric single seater competition formula student", *Ingenius-revista De Ciencia Y Tecnologia*, Vol. **20**, pp. **96-107**, **2018**.

[9] Fajardo-Pruna, Marcelo & Pillajo, Giovanny & Gualoto-Cóndor, Daniel., "Dynamic and kinematic analysis of a racing-suspension in a Formula-Student", *International Conference on Engineering, Management and Automotive Technology*, **2018**.

[10] Suhaimin, M. K. N. B., Ebrahim, Z. B., Muhammad, M. R. B., & Manaf, M. Z. B., "A. kinematic analysis performance between short long arm and parallel suspension for racing car", *The Turkish Online Journal of Design, Art and Communication - TOJDAC* , pp. **2697-2709**, **2018**.

[11] Zhu, B., & Sun, N., "Design and Optimization of FSAE Race Car suspension system", *In 3rd International Conference on Mechanical Engineering and Intelligent Systems (Atlantis Press)*, pp. **1019-1022**, **2015**.

[12] Chepkasov, S., Markin, G., & Akulova, A., "Suspension kinematics study of the" Formula SAE" sports car", *International Conference on Industrial Engineering (Procedia Engineering)*, Vol. **150**, pp. **1280-1286 2016**.

[13] McDonald, M., Joyce, P., & Hamilton, L., "Designing Composite Suspension Arms for a Formula SAE Vehicle", *SAE Technical Paper*, Vol. **12.** Issue. **62**, **2011**

[14] Robertson, D., & Delagrammatikas, G. J., "The suspension system of the 2009 cooper union fsae vehicle: A comprehensive design review", *SAE International Journal of Passenger Cars-Mechanical Systems*, Vol. **03** Issue. **11**, pp. **366-380**, **2010**.

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