Static Analysis and Optimisation of Chassis and Suspension of an All-Terrain Vehicle

Thanneru Raghu Krishna Prasad, Goutham Solasa, Nariganani SD Satyadeep, G.Suresh Babu

Abstract- The project was aimed to design the frame & suspension of the Society of Automotive Engineers (SAE) Baja car which is a single-seated all-terrain vehicle and is used for off road usage and endurance on a rough terrain. In many aspects it is similar to an All-Terrain Vehicle (ATV) except that it is much smaller in size and has safer rollover capabilities. The modeling of the frame and suspension is done by using pro-e software. This design is checked by Finite Element Analysis after estimating the load and the weight of the frame optimized.

Keywords- (SAE), (ATV)

I. INTRODUCTION

An international Mini Baja design competition is organized by the Society of Automotive Engineers (SAE) Mini Baja is an intercollegiate engineering design competition for undergraduate and graduate engineering students. The objective is for a team of students to design fabricate, and race an off-road vehicle powered by a ten horsepower Briggs and Stratton gasoline engine. The vehicle is required to have a combination frame and roll cage consisting of steel members. As weight is critical in a vehicle powered by a small engine, a balance must be found between the strength and weight of the design. This project aims to design the chassis for a mini Baja according to the SAE guidelines. Typical capabilities on basis of which these vehicles are judged are hill climbing, pulling, acceleration & maneuverability on land as well as water. This project is an attempt to design the chassis of a Mini Baja from a scratch and based on the guidelines given by SAE, certain practices by the Off-road vehicles industry and the concepts of mechanical engineering.

Chassis: A chassis consists of an internal framework that supports a man-made object. It is analogous to an animal's skeleton. An example of a chassis is the under part of a motor vehicle, consisting of the frame (on which the body is mounted) with the wheels and machinery.

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Vehicles: In the case of vehicles, the term chassis means the frame plus the "running gear" like engine, transmission, driveshaft, differential, and suspension. A body (sometimes referred to as "coachwork"), which is usually not necessary for integrity of the structure, is built on the chassis to complete the vehicle. For commercial vehicles chassis consists of an assembly of all the essential parts of a truck (without the body) to be ready for operation on the road. [1] The design of a pleasure car chassis will be different than one for commercial vehicles because of the heavier loads and constant work use. Commercial vehicle manufacturers sell "chassis only", "cowl and chassis", as well as "chassis cab" versions that can be outfitted with specialized bodies. These include motor homes, fire engines, ambulances, box trucks, etc.

In particular applications, such as school busses, government agency like National Highway Traffic Safety Administration (NHTSA) in the U.S. defines the design standards of chassis and body conversions. [3]

An armored fighting vehicles chassis comprises the bottom part of the AFV that includes the tracks, engine, driver's seat, and crew compartment. This describes the lower hull, although common usage of might include the upper hull to mean the AFV without the turret. A chassis serves as basis for platforms on tanks, armored, combat engineering vehicles etc.

Design constraints: The design of the Mini Baja frame is defined by the design safety rules set out by the SAE. The frame design discussed in this paper is compliant to the 2011 Mini Baja Rules. These rules define the frame design in two ways. First, the rules set specific requirements on the building material's material type and geometry. They also define the specific requirements of the frame geometry. The requirements were referenced when making decisions regarding the material selection, design geometry and any additional modifications to the design. A thorough review of the design and rules were made at the end of the design stage before Fabrication.

II. CHASSIS OF A MINI BAJA VEHICLE

Frame Design: To begin the initial design of the frame, there first must be set some design guidelines. These include not only design features and manufacturing methods, but also the tools to be used in the design. From that point, the areas of the design that may show weakness or high loading should be analyzed for stress concentrations should be identified for analysis.

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Design Guidelines: Before beginning the design of the frame it was important to make several global design decisions. These include such details as intended steering and suspension design and also intended fabrication methods. While these decisions are not important to the analysis of the frame, they are important to understanding the design. The rules regarding the frame geometry and driver safety must be considered as well. The design of the cars suspension will be unequal length A-arms in the front and a swing Arm in the rear. The requirements for suspension and shock mounts must be kept in mind throughout the design as well as clearance for suspension travel. As the frame and s the handlebars require the driver to have their hands farther apart than with a steering wheel it is important to consider the drivers size and arm position. This becomes a factor when verifying the driver stays within the roll envelope, or the area encased by the roll cage. This is a key factor in the rules regarding driver safety. Some decisions were made based upon past experience while others were based directly off the intended driver's biometric measurements. The intended fabrication is important due to the limitations of the abilities and skills of the build team as well as design directives. The objective is to minimize the number of welded joints on the frame in favor of bent members. Bending is less time consuming and when properly done show a much lower stress concentration. As the design progressed the manufacturability was constantly reviewed with the build team.

The design was done utilizing the Solidworks package. Solidworks was chosen over other packages because of its simple interface for creating three dimensional sketches, checking interferences, and simulating motion. The three dimensional sketching ability was extremely important, due to the number and complexity of bent members in the intended design. Solidworks interference check and motion simulation are as simple as point and click. Where many packages require the user to redefine the position, Solidworks allows the user to drag the part or assembly through its intended motion. The function also has an interference tool built in that allows the user to choose between multiple notification methods.

Initial Design: The initial design is shown in the Figure 6. Some notable features are the fact that the design consists of 4 main members: the roll hoop, the horizontal hoop, and the two perimeter hoops.

As mentioned above the design was made using the Solidworks solid modeling package. As so many factors interact in the design of the frame, the parametric properties allowed the change of a single part to automatically change the design of all parts interacting with it. In this design there are a few important loading situations that should be analyzed. These include frontal impact, side impact, rollover impact, and suspension forces

Material selection: We felt that one of the key design decisions of our frame that would greatly increase safety, reliability and performance is material selection. To ensure that we chose the optimal material, we did extensive research and compared materials in multiple categories. Our key categories for comparison were strength, weight, and cost. We shortlisted three Materials for the chassis, 1020 DOM, 4130 Chromalloy, and IS 3074 CDS4, and compared their strength, stiffness, weight and cost, as depicted in Table 1. SAE rule 31.5 states that if the standard tube size of 1"X0.12"is not used, then the material has to have equivalent bending strength of that of 1018 steel in standard tube size. Our research showed that IS 3074 CDS4 and 4130Chromoly exceeded the SAE norms. We also took into account manufacturability of the tube material. The 4130Chromoly has to be TIG welded only, which greatly increase cost and fabricating time, whereas, the rest three materials can be MIG welded also. The above data enabled us to make an accurate decision with the help of decision matrix, as shown in Table 2. The table compares weight, cost, manufacturability, and strength. Thus, IS 3074 CDS4 was selected

Parameter	IS 3074 CDS4	1018 STEEL	1020 DOM	4130 CHROMOLY
Yield Strength	430 M Pa	365 M Pa	350 M Pa	470 M Pa
Bending Stiffness	2390 Nm^2	1572.3 Nm^2	1572.3 Nm^2	1572.3 Nm^2
Bending Strength	274.95 Nm	223.96 Nm	214.76 Nm	266.92 Nm
Weight (kg/ft)	0.390 Kg	0.508 Kg	0.371 Kg	0.371 Kg
Cost/ft	121 Rs/ft	53 Rs/ft	112 Rs/ft	400 Rs/ft
REMARKS	MIG Welding, easy availability.	More weight, Base Metal.	Less Availability.	High cost, TIG Welding.

Table.1 material properties

PARAMETER	IS 3074 CDS4	1018 Steel	1020 DOM	4130 CHROMOLY
Weight	4	2	4	4
Cost	3	4	3	1
Manufacturability	4	4	4	2
Strength	4	1	3	4
Total	15	11	14	11

Table.2 material comparison matrix

III. LOADING ANALYSIS ON CHASSIS

Tube sizes: Since we didn't use the standard tube size set by SAE, we wanted to ensure that our 1.25"X0.089"tube would be satisfactory. This was done by FE Analysis in ANSYS v12 of two different pieces of tube. One tube had the standard dimensions of 1"x0.12" and the other had the 1.18"X0.079"dimensions. Here we wanted to make sure that the change in dimensions didn't drastically change the bending stress in the tube. We applied aforceof5000N to the end of each In ANSYS v12 this was done using a half model of the piece of tube and applying the proper constraints. The results were shown in fig.2, and fig.3.For side wall bracings we are using 1''×0.06''.for engine mounting we are using Anglers of higher strength and which can withstand higher vibrations .for seat mounting we are using L-Anglers

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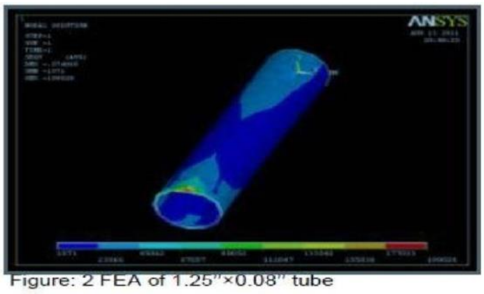


Figure: 2 FEA of 1.25"×0.08" tube

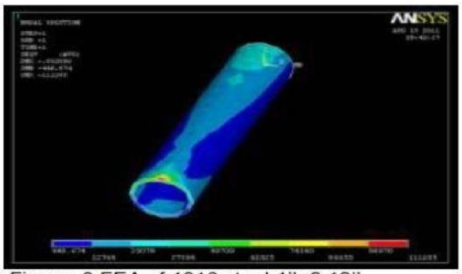


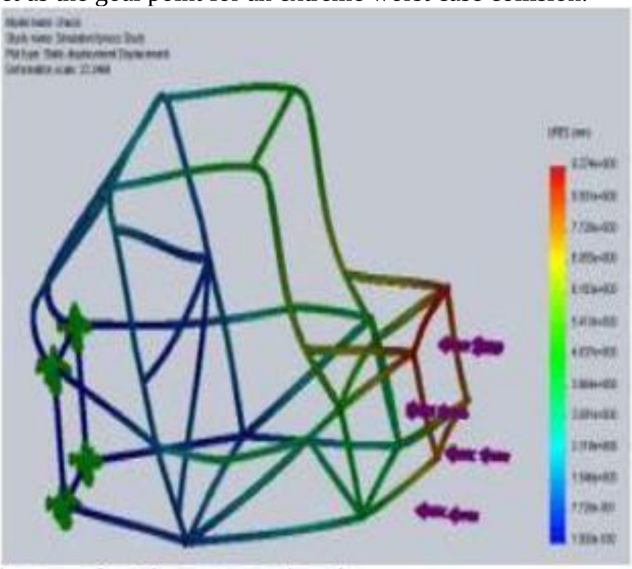
Figure: 3 FEA of 1018 steel 1"×0.12"

IV. FRAME ANALYSIS

(i) FRONT IMPACT or the static frontal impact analysis, Deceleration of 10 G's was assumed for the loading which is equivalent to a static force of 26,698 N (equivalent to 6000 lbf) load on the vehicle, assuming the weight of the vehicle is 270.16 Kg (600 lbs.).Load applied: 26698 N/m^2 on front corner

Constraints: ALL DOF's=0 on Rear corner points

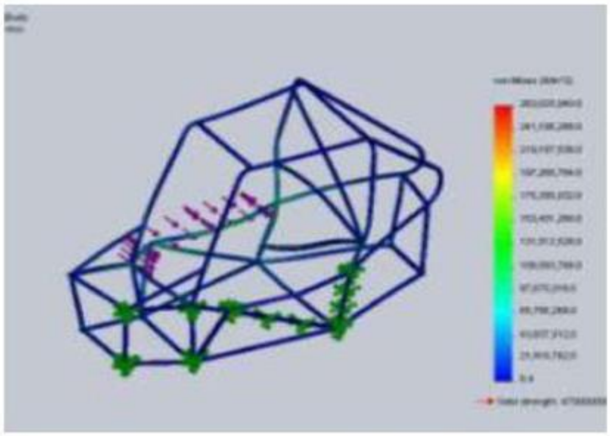
Note: Here we applied load of 10G. The research found that the human body will pass out at loads much higher than 9 times the force of gravity or 9 G's. A value of 10kG's was set as the goal point for an extreme worst case collision.



front impacts on chassis

(ii) REAR IMPACT: In this analysis a load of 5G was applied on rear corners by keeping front corners Constraint. Load applied 14000N/m^2 on rear corners

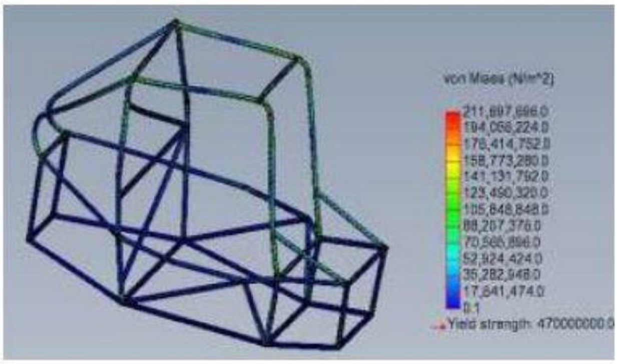
Boundary conditions: All DOF's =0 on Front corner points.



side impact on chassis

iii) SIDE IMPACT: Side impact occurs mostly when a Baja vehicle collides other side ways. In side impact a load of 5g is applied on side impact members by constraining base and opposite side. Load applied on side members 14000N/m^2

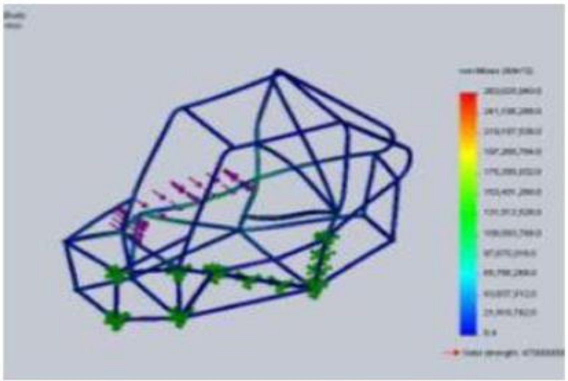
Constraints: Assuming vehicle at static Opposite side impact members ALL DOF's =0



Roll over with meshing patterns

(iv) ROLL OVER: Roll over mainly occurs at time of cornering.RHO and FBM are subjected to loads. A load of 3.5G is applieRHO and FBM junction. Loading F=7000 N is applied on top front points.

Boundary conditions: ALL DOF's =0 on all key points of bottom members



side impact on chassis

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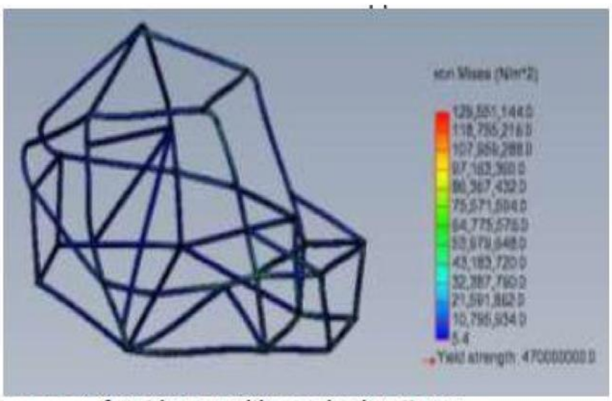
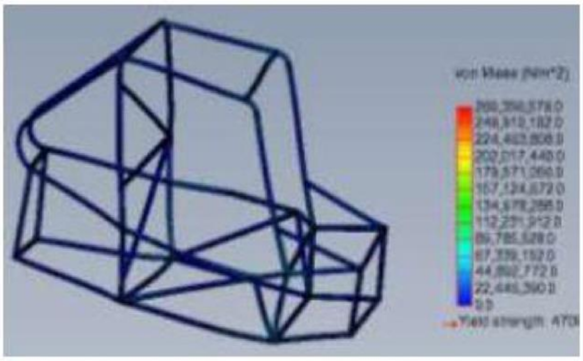
(v) FRONT BUMP: The next step in the analysis was to analyse the stresses on the shock mounts caused by a 5 g load on the shock mounts**.** The loading was applied to the 2 shock mounts in the horizontal shock hoop in the front of the vehicle. Loading f=2000N is applied on shock mounts
Constraints: All DOF's=0 at rear wheels and opposite front wheels.



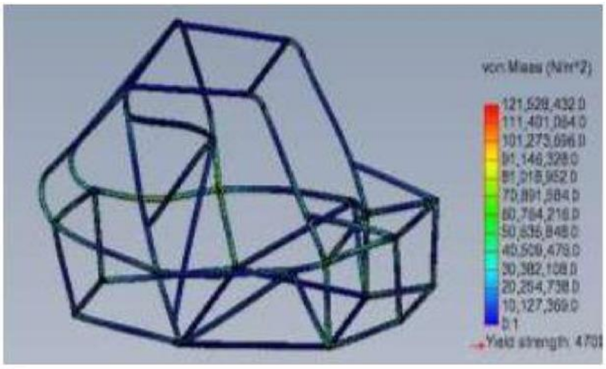
front bump with meshed patterns

(VI) REAR BUMP: The next step in analysis was to analyze the stresses on the shock mounts caused by a 5g load on rear shock mounts. The loading was applied to the 2 shock mounts in the horizontal shock hoop in the rear of the vehicle. Loading F=2500N in applied on rear shock mounts. Here for loading we consider weight of driver and vehicle.
Boundary conditions: All DOF's =0 at front wheels and rear left wheel.



Rear bump with meshed patterns

(vii) TORSION TEST: In torsion test one of the three corners are constrained and load is applied on remaining single corner. This can also be done by constraining base and applying loads in opposite directions on front and rear ends. Loading F=3500N on opposite directions on front and rear ends.
Boundary conditions ALL DOF's =0 at LFS

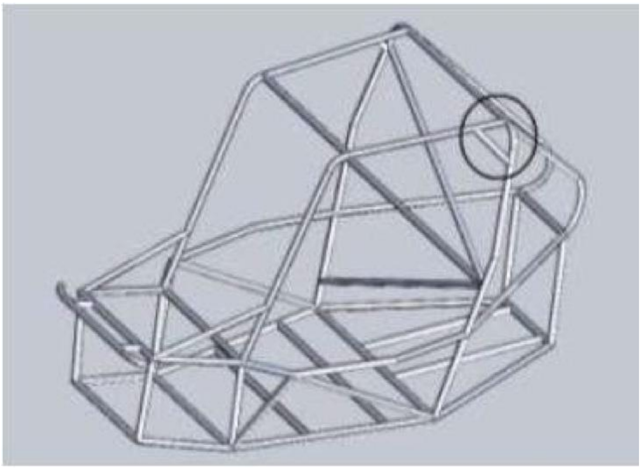


torsion test with meshed pattern

V. RES ULTS

Load Type	Load Applied	Factor of Safety	REMARKS
Front Impact	10G	2.14	Satisfied
Side Impact	5G	1.78	Need additional bracings to fire wall
Rear Impact	5G	4.5	Satisfied
Roll–over	3.5G	2.22	Satisfied
Front-Bump	3G	3.62	Satisfied
Rear-Bump	3G	2.2	Should add bracings to fire wall
Torsion	2.5G	3.86	Satisfied

From the table we came to conclusion that there should be additional bracings added to fire wall and RHO. So we have added 2 bracings.



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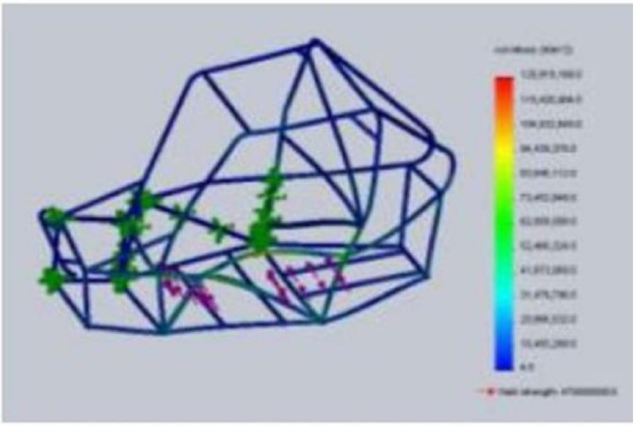
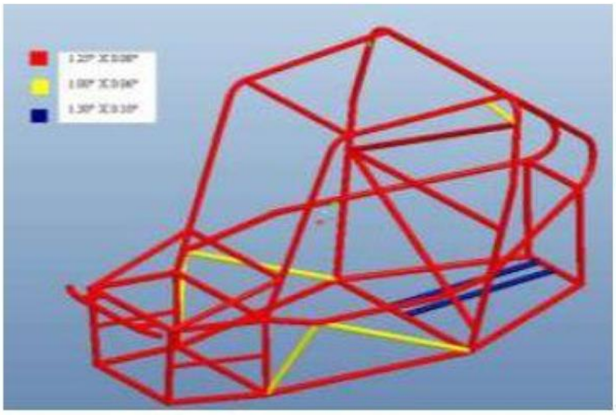
Improved chassis showing added brackets Side impact was performed again with same loads and boundary conditions on improved chassis



Optimization: chassis optimization was done based on the results and figures 13 shows the optimized chassis



Optimization of Chassis.

VI. SUSPENSION DESIGN

A-Arm Design

Introduction

The design of the arms in the wishbone suspension is to be checked for failure under the loading forces present at the wheel. For this purpose, analysis is carried out and used to obtain a minimum weight design which does not yield in the worst loading conditions as defined below. The Arm is first modeled using solidworks

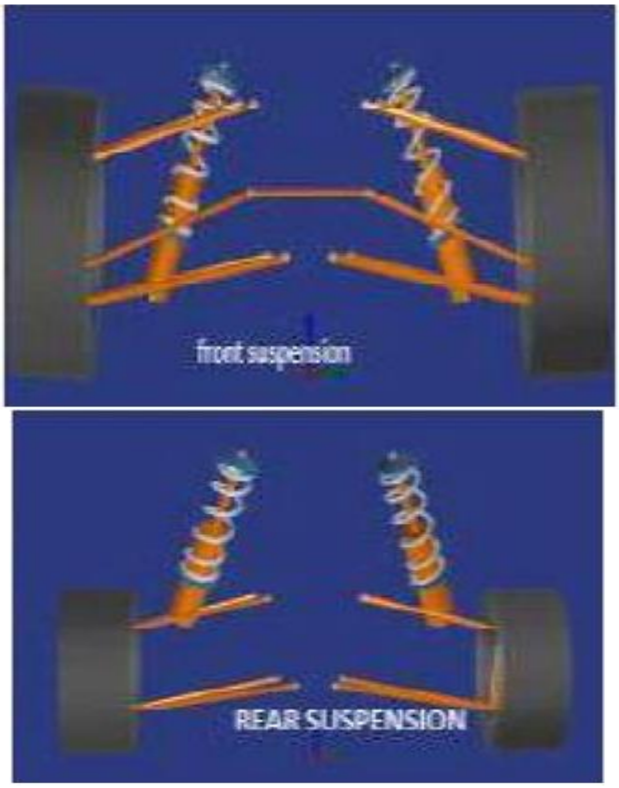
VII. DESIGN METHODOLOGY

Suspension is a compromise between conflicting requirements. The suspension imparted to the vehicle was designed to provide maximum traction during cornering, stability in straight, to minimize the shock transferred to the roll cage and to provide enough ground clearance. Double A-arm suspension of unequal length was chosen to meet the above stated requirements. This design takes up a relatively large amount of space, but provides the most optimized wheel control, limiting tire scrub which can wear out tires quickly, and providing the maximum cornering grip. The front and rear suspension were simulated in optimum k software. It also ensured the design was safe and compact.

	RATING	TRAILING ARM		DOUBLE WISHBONE		SWING ARM	
Simplicity	2	4	8	3	6	5	10
Aesthetics	1	4	4	4	4	3	3
Durability	3	4	12	4	12	4	12
Manufacturability	2	3	6	2	4	4	8
Cost	2	3	6	4	8	5	10
Weight	2	3	6	4	8	2	4
Performance	3	4	12	4	12	2	6
Safety	3	3	9	3	9	2	6
Trouble shoot	3	3	9	4	12	4	12
TOTAL RATING			72		75		71

Decision Matrix for selection of suspension

The material chosen for A-Arms is IS3074 grade CDS(cold drawn seamless) tubing. This material was chosen for its strength to weight property and to minimize the un-sprung weight. The arms at the front and rear were designed to have different roll centers at the front and the rear. This will facilitate weight transfer to the front wheels during cornering. The arm mounting points on the chassis were chosen such that the roll center remains almost constant during bump, heave and static conditions. The suspension design yielded in 305 mm of ground clearance. Figure 15, below shows the models:



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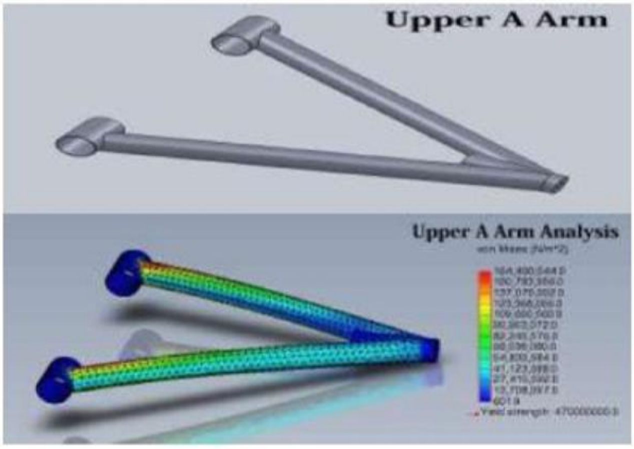
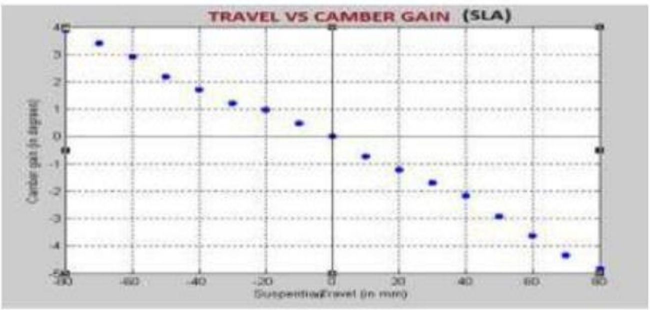
VIII. FRONT SUSPENSION

The front suspension uses unequal length double a-arms. Tires tend to produce more cornering Force at a small negative camber angle. The front arms were designed to provide a negative camber of 2 degrees to aid maneuverability. This is due to the contribution of camber thrust, an additional lateral force generated by elastic deformation as the tread rubber pulls through the tire/road interface.

The arms pick up points on the chassis were designed to limit the camber gain during wheel travel and to gain positive camber when a wheel goes over a bump. The purpose of such design is to reduce the cornering power of the front end relative to the rear during cornering over bumps (under steer). This is to ensure a safe and stable condition for the driver. Contradictory the suspension was also designed to over steer on smooth corners by employing a stiffer suspension at the rear, which will cause the rear to slide out during a turn. The lower arms were designed to house shocks at two different points which can be adjusted quite easily through which the effective stiffness of the spring c



The arms above are modeled in solid works and analysis yielded a factor of safety of 4.2 and 2.7 for lower and upper arms respectively. Graph 1:

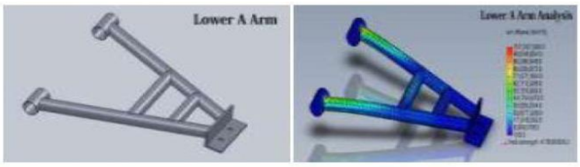


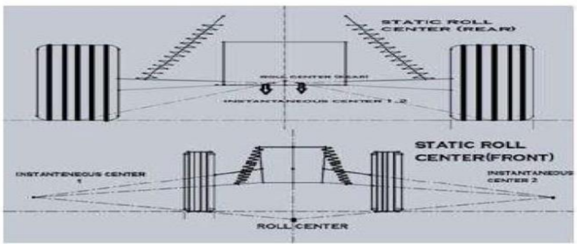
FRONT SUSPENSION SPECIFICATIONS	
SPRING RATE	1.2 kg/mm
LEVERAGE RATIO	1.75:1
WHEEL RATE	0.4 Kg/mm
NATURAL FREQUENCY	2 HZ
WHEEL FREQUENCY	120.47 CPM
EFFECTIVE SPRING RATE	0.7 Kg/mm
SHOCK MOUNTING ANGLE	48 degrees
WIRE DIAMETER	8mm
COIL DIAMETER	65mm
NUMBER OF COILS	16
LENGTH OF SPRING	265mm
SHOCK ABSORBERS	GABRIEL
TOTAL TRAVEL	153 mm

REAR SUSPENSION SPECIFICATIONS	
SPRING RATE	1.4 kg/mm
LEVERAGE RATIO	1.19:1
WHEEL RATE	0.91kg/mm
NATURAL FREQUENCY	2.33 HZ
WHEEL FREQUENCY	139.97 CPM
EFFECTIVE SPRING RATE	1.09 kg/mm
SHOCK MOUNTING ANGLE	30 degrees
WIRE DIAMETER	10mm
COIL DIAMETER	80mm
NUMBER OF COILS	14
LENGTH OF SPRING	290 mm
SHOCK ABSORBER	GABRIEL
TOTAL TRAVEL	90mm

IX. REAR SUSPENSION

The rear suspension employs unequal length A Arms. The arms were designed such that the drive train components were easily integrated and enough clearance was provided to the drive shafts. The rear track width was designed to be 372 mm. so the arms had to be relatively shorter. Anti-dive geometry was not employed to curb the additional stresses that will be induced on the arms. Gabriel shocks were used in the front and the rear along with modified compression springs. The rear suspension was designed for a maximum travel of 152 mm to ensure for the proper working of drive shafts. The pickup points on the chassis for rear arms were designed such that the static roll center was higher at the rear to aid cornering. The shocks were inclined at 25 degrees to absorb most of the transmitted shock from the tires. The thickness of the bracket is chosen as 5mm which will yield a factor of safety of 1.57.





Static Roll-Centre Diagram - Rear (top) & Front (below)

Finalizing Suspension Design

The design in developed in Section 5.3.4 was found to be satisfying all requirements and was found to be withstanding failure due to bending forces as seen from the results of finite element analysis.

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Thus this design was finalized. The engineering drawings for this design were made and are presented in Appendix D of this dissertation. Separate dimensions were used to for the front and rear arms. The Suspension and arms were along with the spring were modeled and assembled with the frame of the Mini Baja.

X. CONCLUSION

The usage of solidworks was invaluable to the design and analysis of the frame and suspension for Mini Baja Car. The analysis allowed the addition of three important and key structural components to help the vehicle with stand front and side impacts as well as the forces due to the loading of the shock mounts. While a viable solution to the stresses seen in a rollover type impact could not be found due to the set design constraints, the finite element analysis gave a very accurate prediction of where failure would occur in this situation. This prediction was validated in an actual rollover occurrence. Even though a fix was unable to be implemented in this frame design, the findings from the finite element analysis and the actual failure will allow future designers to integrate a solution to this problem into their design from the beginning.

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