Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 3, March, 2021: 3140-3149

Design, Develop, and Manufacture a Vehicle within the specifications of the SAE Baja

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Abstract

The purpose of the Society of Automotive Engineers (SAE) Baja was to design, develop, and manufacture a vehicle within the specifications of the SAE Baja The team used stress analysis to ensure that all designed components could withstand the rigors of an SAE Baja competition without component failure. Physical analysis was conducted to find the appropriate gear reduction required to meet our design specifications for top speed and maximum torque. The team worked diligently with manufacturers to ensure that the components could be manufactured and used the WPI SAE chapter to ensure that the car was completed in a timely fashion. Engineering analysis as well as diligent communication with all stakeholders allowed the MQP to create a fully operational and competitive vehicle that meets the Mini Baja SAE competition specifications

I. Introduction :

Roll cage is the skeleton of an ATV. The roll cage not only forms the structural base but also 3D surrounding the occupant which protect the occupant in case of impact and roll over of vehicle. The roll cage also adds the aesthetics of the vehicle. Roll-Cage is a frame of pipes providing a rigid structure and robust design to the vehicle. They can be used either as the onlyframe (like in ATVs) or as the inner supporting structure in the conventional vehicles to provide strength against impacts. Here at the institute we designed and manufactured our roll cage and impact analysis is done using ANSYS.

The design process of this single-person vehicle is iterative and based on several engineering and reverse engineering processes. Following are the major points which were considered for designing the off road vehicle: 1. *Endurance*

2. *Safety and Ergonomics*

3. *Market availability*

4. *Cost of the components*

5. *Standardization and Serviceability*

6. *Manoeuvrability*

7. *Safe engineering practices*

II. DESIGN METHODOLOGY

Modelling of roll-cage is done with consideration of safety and aesthetics. All specification mentioned in SAE rulebook is taken into consideration. Designing of roll cage is done with ergonomic and safety conditions as specified in SAE rule book.

III.COMPONENTS OF ROLL CAGE

Roll cage consists of primary and secondary members Primary Members

- Rear roll hoop member
- Rear hoop overhead members
- Front bracing member
- Lateral cross member
- Front lateral cross member

Secondary Members

- Lateral diagonal bracing
- Lower frame side
- Side impact member
- Fore/ aft bracing
- Under seat member
- All other required cross members
- Tube to mount safety seat belts

IV.DESIGNING PROCESS

- Designing reference model
- Doing modification in reference model
- Changing the model according to suspension and steering mechanism
- Changing design clearance after prototype
- Analyzing the finalized design
- Comparing the difference between former and later design
- Finding solution in reducing fault in designing process.

V Material Selection

Material selection for BAJA SAE vehicle is one of the key design decisions that has great influence on the safety, reliability, and performance of the vehicle. It also decides the weight of the vehicle, fabrication processes and cost. The qualities that were given due importance are yield strength, the strength to weight ratio and good weldability property. As per the guidelines of the SAE BAJA rule book the minimum carbon content should be 0.18%. The materials selected for the study include AISI 1018, AISI 1020 and AISI 4130. Table 1&2 give the details of the chemical composition and Mechanical Properties of the materials.

Table 1: Chemical composition of AISI 1018, AISI 1020 & AISI 4130 steel

Element (%)	**AISI 1018**	**AISI 1020**	**AISI 4130**
Carbon, C	0.15 – 0.20	0.17 – 0.230	0.28 – 0.33
Iron, Fe	98.81 – 99.26	99.08 – 99.53	97.03 – 98.22
Manganese, Mn	0.60 – 0.90	0.30 – 0.60	0.40 – 0.60
Phosphorous, P	≤ 0.04	≤ 0.04	0.035
Sulfur, S	≤ 0.05	≤ 0.05	0.04
Chromium, Cr	–	–	0.80 – 1.10
Molybdenum, Mo	–	–	0.15 – 0.25

Table 2: Mechanical Properties of AISI 1018, AISI 1020 & AISI 4130 steel

Parameter	**AISI 1018**	**AISI 1020**	**AISI 4130**
Tensile Strength (MPa)	440	395	560
Yield Strength (MPa)	370	295	460

Poisson Ratio	0.290	0.290	0.295
% Elongation	15	36.50	21.50
Strength to Weight Ratio	55-70	65-85	90-120
Modulus of Elasticity (GPa)	205	200	210

The above mentioned materials have low carbon content, hence can be welded easily. **However, AISI 4130 alloy steel is selected as it has high yield strength and strength to weight ratio than other materials**. The AISI 4130 alloy steel also has very high tensile strength and corrosion resistance as it contains chromium and molybdenum as strengthening agents.

Static analysis

In static analysis ATV is considered in static state and maximum possible force is applied to roll cage with suitable constraints as per different conditions. Static analysis is done in ANSYS Static Structural. As per earlier studies impact time of roll cage in case of impact with rigid body (wall, floor etc.) is taken as 0.13 sec, while that in case of impact with a deformable object (another ATV), impact time is taken as 0.30 sec

VI Design of A Chassis

The preliminary design of a chassis is made using Solidworks 3D modelling software. A custom template of circular cross section for the roll cage member was created as per the design and it was applied to members and chassis structure was made using weldments.

The Rear Roll Hoop (RRH) defines the back side of the roll cage, it is a vertical member connected to rear Lateral Cross (LC) members on the top and bottom The RRH is a continuous tube and Lateral Diagonal Bracing (LDB) members are used for providing more support. Two Side Impact Members (SIM) define a horizontal mid-plane within the roll cage. These members are joined to the RRH and extend generally forward

Two Lower Frame Side (LFS) members define the lower right and left edges of the roll cage. These members are joined to the bottom of the RRH and are extended forward. The forward ends of the LFS members are joined by the Front LC member. The LFS members are joined by the Under Seat Members (USM) that pass directly below the driver and is positioned in such a way to prevent the driver from passing through the plane of the LFS in the event of seat failure.

The Roll Hoop Overhead (RHO) members form the top plane of the roll cage provides safety to the driver in case of roll over. The RHO are made up of two continuous members running from the intersection of front LC till the top of RRH. The lower right and left edges of the roll cage are defined by two Lower Frame Side (LFS) members. These members are joined to the bottom of the RRH and extend generally forward. Front Bracing Members (FBM) are used to join the RHO, the SIM and the LFS.

VII Analysis Of The Chassis

The BAJA SAE vehicle chassis is analysed using Ansys workbench for determining strength enough to sustain any impact and protect the driver and other vehicle components. In the analysis of frame, a quantity named G-Force is used to obtain the stress and deformation information in various impact scenarios . G-force is a measure of acceleration, when multiplied with the mass gives the magnitude of the dynamic force. The dynamic forces thus obtained are applied to the chassis to get stress and displacement values. The different tests performed are Front Impact, Rear Impact and Side Impact.

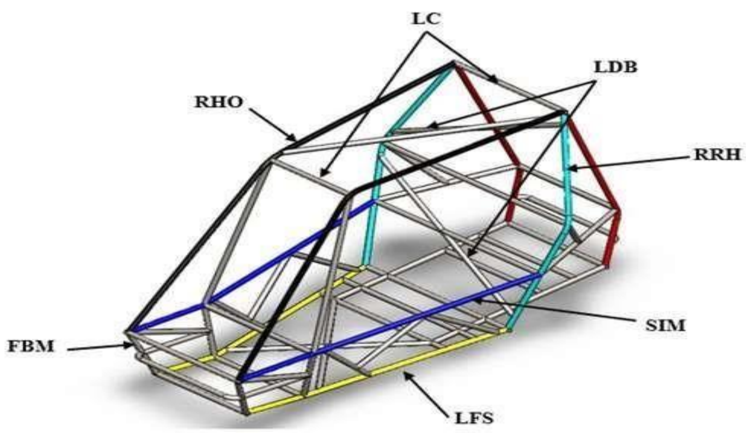

Fig 2: Chassis Design

Meshing

Element size: 20 mm

Element Type: Beam

Solver Type: Direct Sparse Solver

Number of Elements: 4562

Analysis Type: Static

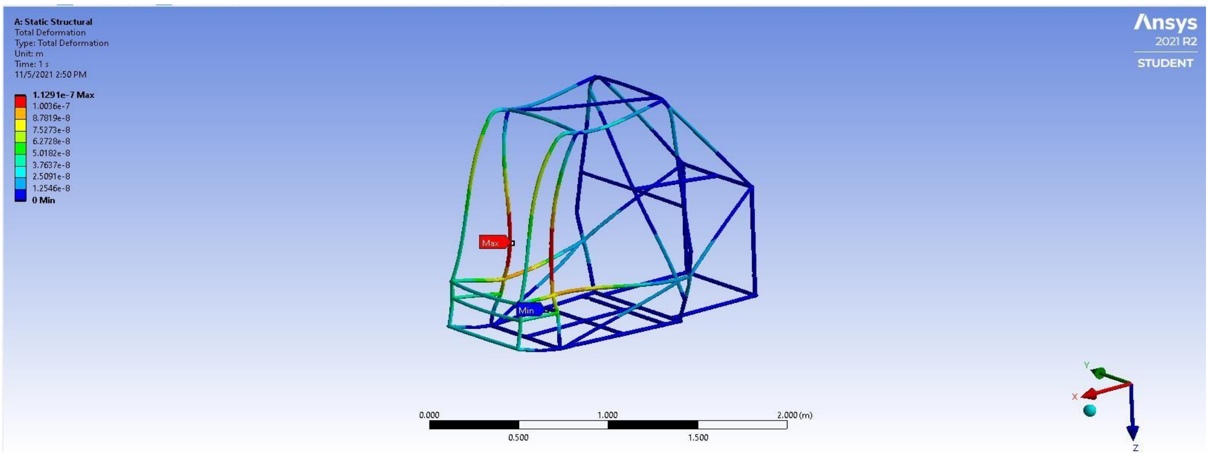

Fig 3: Von Mises Stress Pattern for Front Impact

Front Impact Test

For Front impact test a G-Force of 10G is considered. Assuming mass of the vehicle (m) including the driver as 350 Kg the Front impact load (F1) is calculated

$F1 = \text{m} \times \text{a}$ $F1 = 350 \times 10 \times 9.81 = 34335\ N$

The rear section of the chassis is fixed and the impact load (F1) is applied on front junctions where FBM, SIM and LFS members join.

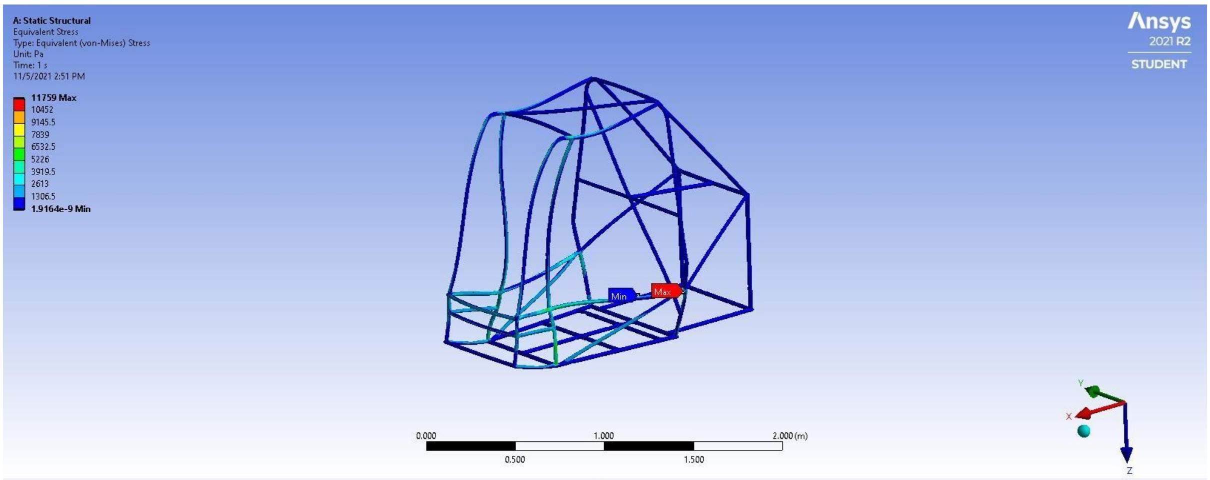

Fig 4: Displacement Pattern for Front Impact

Maximum Von Mises stress for Front Impact = **221.35 N/mm^2**

Factor of Safety, FOS = 460/221.35 = **2.07**

Rear and Side Impact Test:

For Rear and Side impact test, the G-Force of 4G is considered. Similar to Front impact test, the Rear and Side impact tests required sections were fixed and load was applied to obtain stress and displacement values.

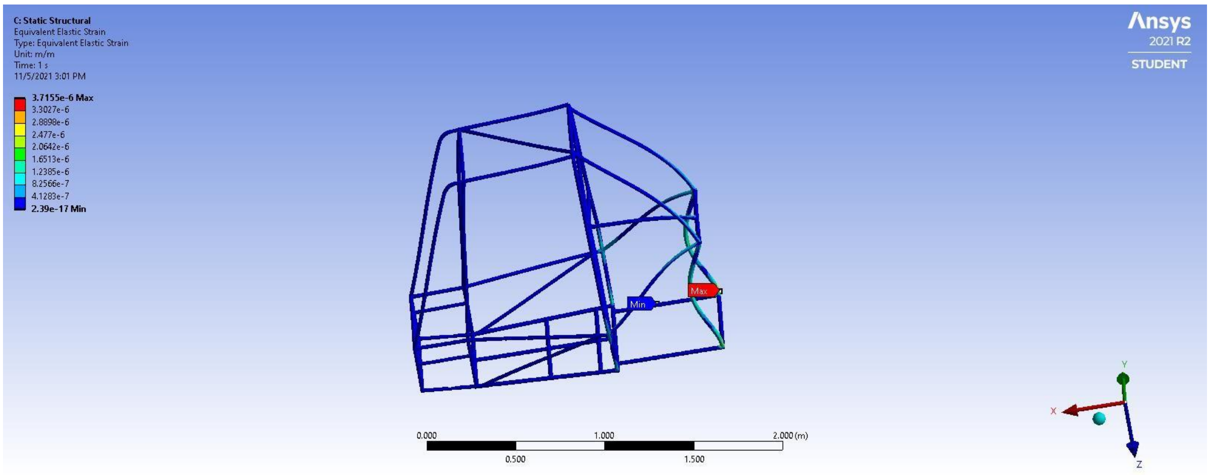

Fig 5: Von Mises Stress Pattern for Side Impact

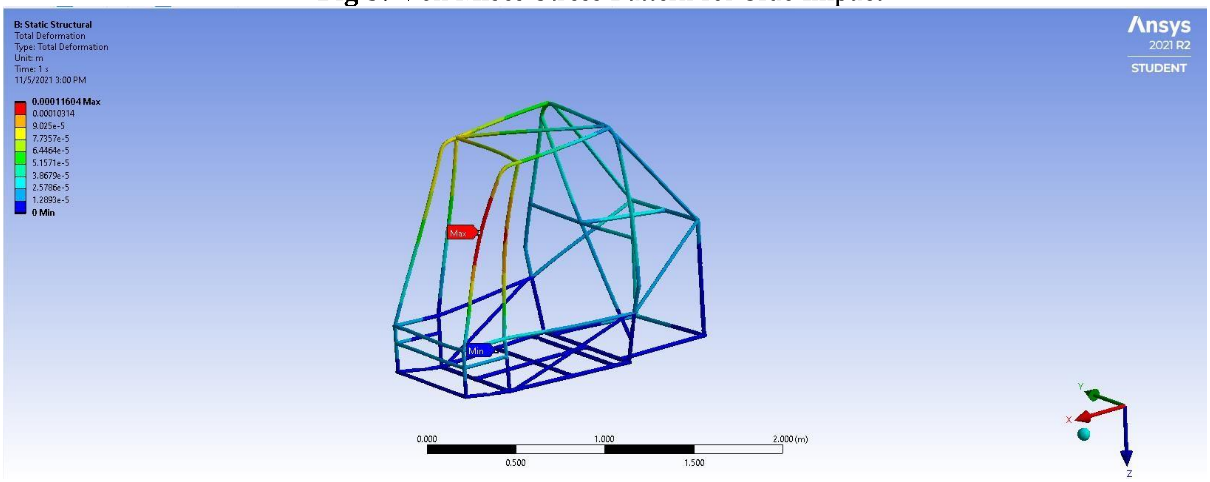

Fig 6 : Displacement Pattern for Side Impact

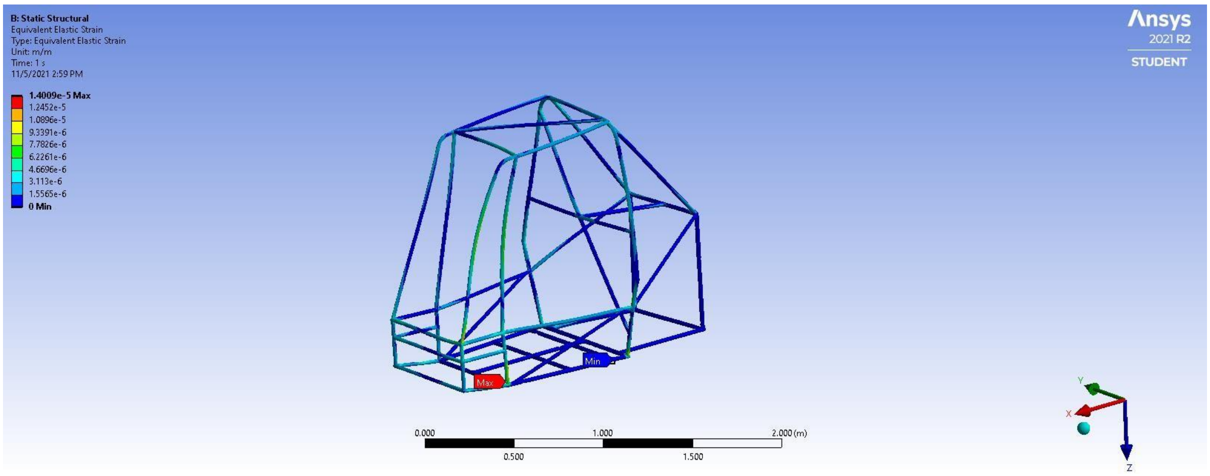

Fig 7: Von Mises Stress Pattern for Rear Impact

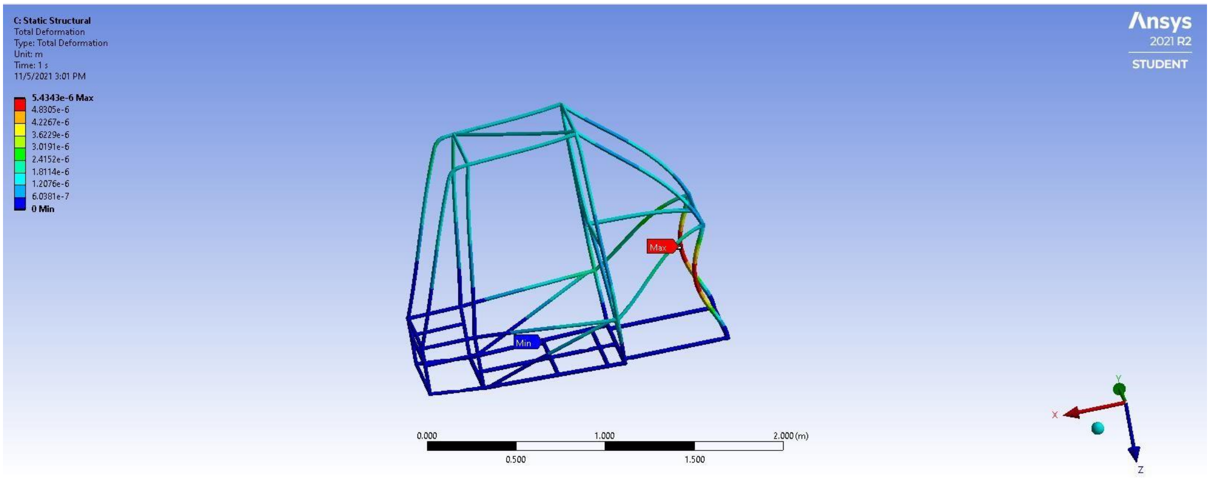

Fig 8 : Displacement Pattern for Rear Impact

Table 3: Stress and displacement analysis of chassis

Test	**G- Force**	**Load Applied (N)**	**Maximum Von Mises Stress (N/mm2)**	**Maximum Displacement (mm)**	**FOS**
Front	10G	34335	221.35	1.78	2.07
Rear	4G	13734	188.07	2.28	2.45
Side	4G	13734	185.72	0.303	2.48

SUSPENSION

OBJECTIVE

The suspension is responsible for dissipating the energy obtained from the impacts absorbed by the shocks. These impacts are caused by the uneven terrain. It is also responsible for maintaining the vehicles stability and ride height when managing obstacles. Another point is to reduce vibration for the vehicles durability and drivers comfort.

DESIGN

The rear suspension was a major improvement in design over the previous car. A three link suspension was opted in order to work in conjunction with the new drive train, as shown in Figure 5.

This configuration gives us better bump absorption due to its long trailing arm, 63.5cm (25in). Both, front and rear, arms are made out of 2.54cm (1in) OD tube 4130 Chromalloy steel. Front arms have a wall thickness of 1.651mm (0.065in) and rear trailing arms have a thickness of 2.108mm (0.083in)

The front suspension works with a double A-arm system. Both upper and lower arms have identical length so the wheels vertical plane is maintained at all times during shock travel. Front suspension is equipped with two FOX 2.0 Air shocks® with 11.43cm (4.5in) of travel. This setup gives us 26.67cm (10.5in) of total wheel travel, giving the car great ability to manage rocks, bumps and other obstacles while maintaining good traction.

ANALYSIS

The vehicles weight distribution is 33% in the front and 66% in the rear; therefore the rear shocks must be stronger than the front shocks. The use of the FOX 2.0 Air shocks ® allow the team to easily

adjust the spring rate of the shocks at any time by adding or extracting nitrogen. The spring rate of the shocks is equivalent to 19.733kg/m (1.105 lb/in) per 6.895kPa (1psi) of nitrogen. The working pressures of the shocks in normal condition are 1.296MPa (188psi) in each shock in the front and 1.551Mpa (225psi) in each shock in the rear. Figure 6 shows the analysis made with Solidworks® Simulation to prove the resistance the A-arms considering a 4.448kN (1000 lbf). Figure 6. Front suspension analysis in Solidworks®Simulation.

STEERING

OBJETIVE

The steering subsystem is responsible for the control of the vehicle. In the design process of this process of this subsystem the goal is to achieve a small turning radius and steering stability. The speed of response and the driver´s input are also prime factors for the design of the steering system.

DESIGN

The steering system works with a VW® off-road rack and pinion. The rack travels one and a half turns from lock to lock which allows good control of the vehicle and good responding speed. The rack is connected to 2 tie rods working in front of the shocks for reduced weight. The rack travels 8.89cm (3.5in) from lock to look to make the wheel turn. The front wheels configuration has a 3.5° camber angle and an 11.5° caster angle. The caster tends to drive the wheels forward, which makes it easier to maintain the car in a straight direction, also the inclination of the knuckle helps to reduce the turning radius to 198.12cm (78in), as shown in Figure 7.

DRIVETRAIN

OBJECTIVE

The objective of the drivetrain is providing to the driver more than the enough torque to the wheels from the engine to the wheels. The calculations were made in order to select the proper

components that satisfy a top speed of 13.411m/s (30mph) to 15.646m/s. (35mph) and to provide the car the enough strength to climb a 60° incline.

DESIGN

The main component of the drivetrain is the Briggs & Stratton engine which gives 19.66Nm (14.5 lb-ft) of torque at 3800 rpm and 10 hp at 3800 rpm, The system is composed by a CV-Tech® CVT Pulley System with a PWB50 drive pulley and a TAS-99 driven pulley, which gives us a ratio of 0.65:1 at the hi ratio position and 3.6:1 at the low ratio position.

After the driven pulley we use an H-12 FNR Independent Suspension Transaxle from DANA®. This component includes the transmission, which allows the vehicle to reverse. This component also includes the differential, with a total reduction of 11.47:1.

The use of the transaxle gives to the system a lot of reliability, strength and a high factor of safety.

ANALYSIS

For the evaluation of the torque required to obtain the enough strength to climb the 60° incline we made a simple study case, Also we evaluate the Gravity Center of the car, as shown in Figure 10, in order to reach the closes value to 60° between the GC of the car and the rear axle to obtain stability.

VI. Conclusion

The chassis of BAJA vehicle is designed as per the specifications of BAJA SAE India 2021 rulebook. AISI 4130 material was selected for the chassis as it has high yield strength and strength to weight ratio as compared to others. Circular cross section was selected as it has very high torsional rigidity and uniform distribution of forces which results in improving strength of the chassis. A preliminary design of the chassis is made using SOLIDWORKS software. The stress analysis results and displacement pattern from ANSYS workbench indicate that the chassis is indeed safe enough to sustain the impact and protect the driver and other components.

References

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Specification of Team Asura Baja Vehicle

Model	Briggs & Stratton OHV Intek
Displacement	305 cc
Compression Ratio	8:01
Power	10HP
Torque	19.66Nm (14.5 ft-lbs)
DANA Transaxle	11.47:1 Ratio
CV Tech Pulleys	3.6:1 to 0.65:1 Ratio
Total reduction	41.3:1 to 7.5:1
Overall Length	254cm (100in)

Wheel Base	176.53cm (69.5in)
Overall Width	161.29cm (63.5in)
Ground Clearance	35.56cm (14in)
Weight	215.456kg (475 lb)
Front Suspension	Double A-arm, 26.67cm (10.5in) travel
Rear Suspension	Three link, 17.78cm (7in) travel
Front Shocks	FOX 2.0 Air Shocks, 11.43cm (4.5in) travel
Rear Shocks	FOX 2.0 Air Shocks,11.43cm (4.5in) travel
VW off-road Rack & Pinion	Rack 8.89cm (3.5in) travel
Camber Angle	3.5°
Caster Angle	11.5°
Front Wheels	10 x 5 Douglas 0.190 Aluminum Wheels
Rear Wheels	12 x 8 Douglas 0.190 Aluminum Wheels
Front Tires	23 x 8 R10 ITP HOLESHOT XCT AT Tires
Rear Tires	25 x 10 R12 ITP HOLESHOT ATR AT Tires
Master Cylinder	VW® 19mm
Calipers	Honda 2009 TRX450R w/rotors
Kill Switches	Ski Doo kill switches
Lights	Breaking and reverse
Reverse Alarm	Back up alarm 97db
Max speed	15.646m/s (35 mph) @ 3800 rpm
Turning radius	198.12cm (78in)

Desired values from CAE Analysis

Tensile strength, ultimate	560 MPa	81200 psi
Tensile strength, yield	460 MPa	66700 psi
Modulus of elasticity	190-210 GPa	27557-30458 ksi
Bulk modulus (Typical for steel)	140 GPa	20300 ksi
Shear modulus (Typical for steel)	80 GPa	11600 ksi
Poisson ratio	0.27-0.30	0.27-0.30
Elongation at break (in 50 mm)	21.50%	21.50%

Reduction of area	59.6	59.60%
Hardness, Brinell	217	217
Hardness, Knoop (Converted from Brinell hardness)	240	240
Hardness, Rockwell B (Converted from Brinell hardness)	95	95
Hardness, Rockwell C (Converted from Brinell hardness, value below normal HRC range, for comparison purposes only.)	17	17
Hardness, Vickers (Converted from Brinell hardness)	228	228
Machinability (Annealed and cold drawn. Based on 100% machinability for AISI 1212 steel.) Tensile strength, ultimate	70	70