Design of Roll-Cage of an All-Terrain Vehicle

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Abstract: This thesis deals with the design and analysis of anAll-Terrain Vehicle. The goal of this thesis is to develop an appropriate All-Terrain Vehicle and analyse it for many areas of design and safety. The design should be able to withstand a weight of 300 kgs while also providing comfort in a variety of driving circumstances. Many processes are done to get the desired design of this All-Terrain Vehicle. The first step is to do literature research of existing All-Terrain Vehicle and their designs. Following that, the designing thoughts were used to create designs and sketches. SolidWorks and Ansys software were used to create the structural three-dimensional solid modelling of the All-Terrain Vehicle's Roll cage. After the design and sketch are completed, they are analysed for a variety of characteristics utilising analytic tools. Based on the analysis results, changes are made to the design, and the final design that passes all analytical tests is finalised. Thus, by completing this project, the project's goal is met. Finally, the project's conclusion and recommendations for the future plan have been appended to this thesis.

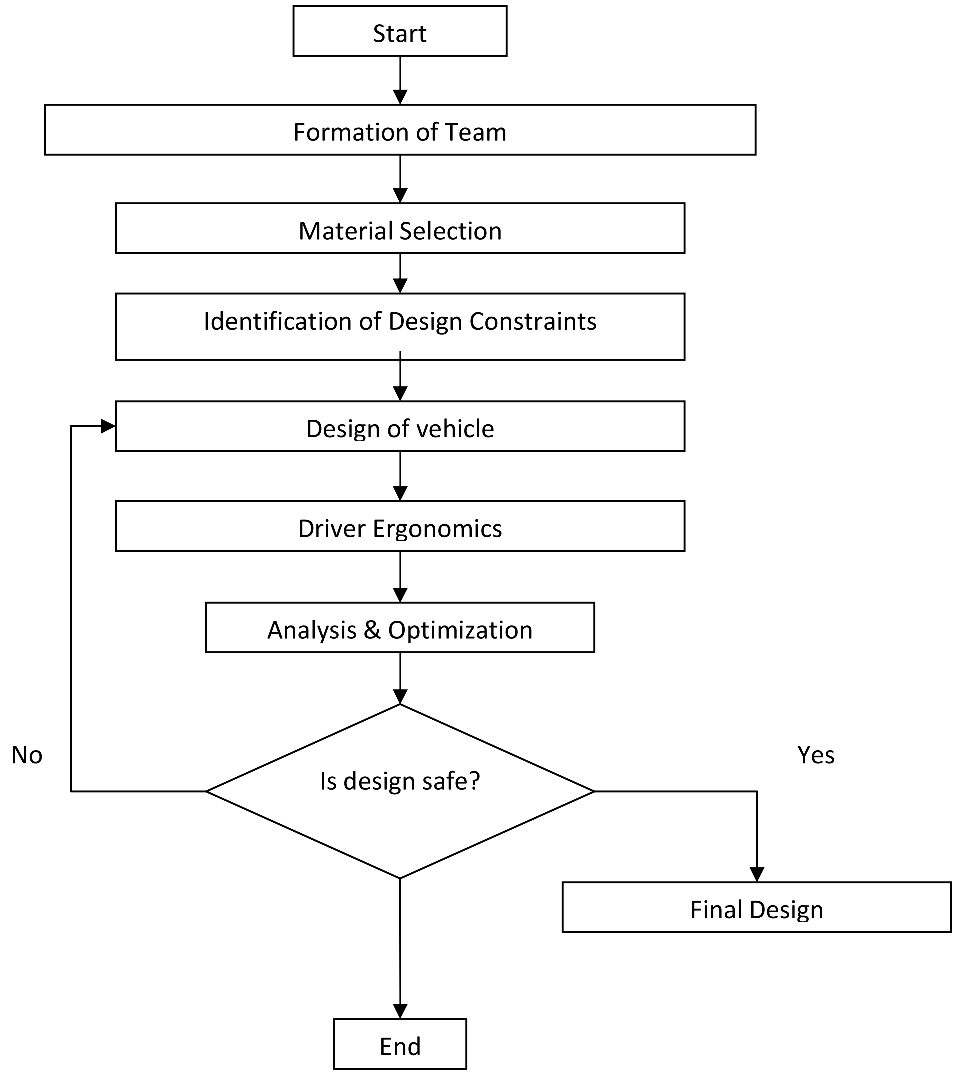
Keyword: All-Terrain Vehicle, Chassis/frame design, FEA

Introduction

The Society of Automotive Engineers (SAE) runs design contests to immerse students in the fundamentals of mobility engineering. SAE conducts a BAJA event every year. The goal of the student team is to create a dynamically balanced vehicle that can traverse all types of terrain. The SAE BAJA vehicle development document imposes limitations on vehicle weight, form and size, and measurements. The goal of the SAE BAJA competition is to emulate real-world engineering design projects and the problems that come with them. Furthermore, it creates the best-performing vehicle with a durable and cost-effective vehicle structure that meets all SAE BAJA design standards. An all-terrain vehicle's structural foundation is the roll cage. The chassis frame houses the vehicle's components such as the power source, transmission system, axles, wheels and tyres, suspension system, controlling systems such as braking, steering, and so on, as well as electrical system parts. Extensive research was carried out in order to design each of the vehicle's major components. It is believed that each component is important, hence the vehicle was developed as a whole, attempting to optimise each component while continually contemplating how other components will be affected. In order to create a successful design, this encouraged us to think outside the box, do more comprehensive research, and rework components along the route. Using SOLIDWORKS 2020, a preliminary design of the Roll Cage structure was created in a 3D environment while keeping the practical objectives and SAE Baja standards in mind. Because weight is crucial in a vehicle driven by a tiny engine, a balance must be struck between the design's strength and weight. In addition to conventional analysis, the use of solid modelling and finite element analysis (FEA) tools is highly effective in optimising this equilibrium. Later, the design is evaluated against all modes of failure using ANSYS 2020 Software to do different simulations and stress analyses. In ANSYS, Finite Element Analysis (FEA) is performed on a 3D model of a roll cage in scenarios of front impact, rear impact, side impact, Roll-over, Torsional Rigidity, and Modal analysis. The design is adjusted in accordance with the results of the testing. The study shows the distribution of stresses and deformation of the frame members when subjected to the imposed loads. If the stress created in the chassis members was discovered to be more than the material's yield limit, the current frame was adjusted for a safe design. The revised design was submitted to the same analysis, and iterations proceeded until the stress and deformation were within the intended limits. After successfully designing the roll cage, it is ready for fabrication.

Proposed Methodology

In this section, we propose the design methodology of All -Terrain Vehicle. The design process consists of six steps:



1. **Formation of team** - In the initial stage of the methodology, a team of design engineers is to be formed. The team members should have adequate knowledge and working experience in the CAD and CAE software and should also have market knowledge. The primary responsibility of the team is to design the frame and other working components of the vehicle.

2. **Selection of material** -Material selection is one of the critical design considerations that considerably improves the safety, dependability, and performance of any automotive design. Our first step was to perform a market study to determine the material's availability. Based on market research, we have AISI 1018and AISI 4130 steel for frame material. Following are the specification of the material:

Properties	**AISI 1018**	**AISI 4130**
Density	7.87 g/cm^3	7.85 g/cm^3
Yield Strength	417 MPa	638 MPa

Tensile Strength	440 MPa	560 MPa
Ultimate Strength	473 MPa	810 MPa
Bending Strength	402.9 MPa	415 MPa
Preferred Welding Type	MIG	TIG
Availability	Easily Available	Not easily available
Cost	Cheap	Expensive

According to the data shown above, AISI 4130 has a substantially higher strength-to-weight ratio. In addition, by adopting AISI 4130, we may achieve a straight weight reduction of 17% per tube length without sacrificing strength.Following table shows the chemical composition of AISI 4130:

Element	**Content (%)**
Iron, Fe	97.03-98.22
Chromium, Cr	0.80-1.10
Manganese, Mn	0.40-0.60
Carbon, C	0.280-0.330
Silicon, Si	0.15-0.30
Molybdenum, Mo	0.15-0.25
Sulphur, S	0.040
Phosphorus, P	0.035

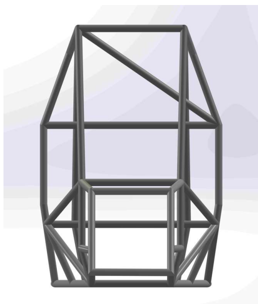
For our design we have selected rod of exterior diameter of 25.4 mm (1 inch) and a wall thickness of 3 mm (0.120 in).

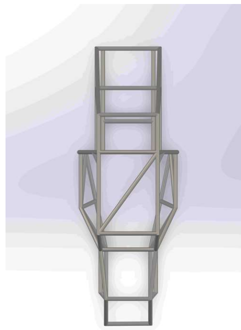
3. **Identification of Design Constraints**–In this section we identify the design constraints to design a safe and comfortable vehicle for driver.

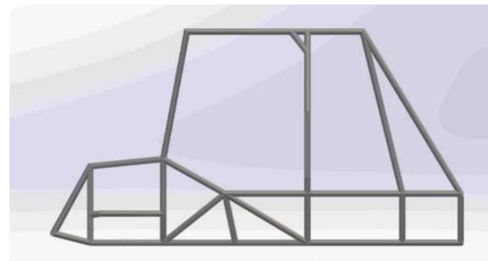
4. **Design of Chassis -** This section covers the chassis' design features. The chassis is responsible for linking the powertrain, control, and suspension systems, among other things. Driver ergonomics and safety take priority since the driver must be comfortable in order to operate the automobile effectively. Mounting points and overall frame geometry are essential design considerations that impact desirable characteristics like as weight distribution and suspension performance. The chassis must also be strong enough to handle all loads while being lightweight.For many of the design aspects, the team used the previously developed chassis and research as a knowledge foundation and baseline. This was required due to the iterative design approach, which is utilised to make the design process more efficient. As a result of this, the crew implemented several changes, boosting the overall vehicle quality.

5. **Driver Ergonomics -**Ergonomics is the study of how-to layout and design the driving controls and safety features of a vehicle based on the demands of the driver in order to improve human welfare and overall system performance in a particular environment. For the application of Baja, it was vital to design a driver envelope that would not only accommodate the intended drivers, but would also provide comfort, safety, and stability to the driver for an extended period of time. The foot box was intended to be as tiny as possible while yet leaving the driver enough space to operate the controls securely, allowing adequate mobility of the driver's feet to manipulate the gas and stop pedals.The size and form of the foot box also allowed for optimal placement of the brake pedal and assembly low and between the lower frame components, resulting in a low centre of gravity. This was accomplished by the use of a plate that incorporated the brake pedal, master cylinders, and gas pedal. Because the brake and gas pedals are integrated and correctly spaced, the driver of the automobile can use the pedals with one or both feet, depending on the driver's desire. The brake pedal and assembly were also meticulously developed to optimise driving efficiency in both regular and emergency braking scenarios.The position of the steering wheel within the cockpit was the second region of the driver envelope that was explored. To avoid driver interference or overextension of the arms, the steering wheel should be placed at a comfortable distance of the driver's chest.The position and inclination of the driver's seat were the final ergonomic parameters examined. The seat is critical in providing enough support to the driver's back to allow him to remain upright with a good vision of the track ahead, to apply

the necessary forces to the gas and brake pedals, and to support the driver's weight shift while turning or landing from a jump. To accurately calculate the inclination of the seat, extensive research was conducted both online and through trial-and-error with many members of the team being tested.







6. **Analysis and Optimization–**The analysis consists of following steps:

a. **Meshing constraints and calculations**–As this roll cage was created by tracing key points, lines, and splines, each member of the roll cage is thought to be suitably restricted at every joint. The roll cage is to be fastened from the back side for the boundary conditions for the frontal impact test, and the front member will come across the applied force. Similarly, during the side impact test, one side of the roll cage parts is fixed while the other side is loaded. The lowest portions of the roll cage are fastened during the rollover impact test. The roll cage must be attached from the rear side torsional impact tests.The load will be distributed among the number of joints framed by front members in the direction opposite to the frame, i.e., in the X axis.

b. **Analytical calculation for determining impact on roll cage** -To effectively calculate the impact force, we must first determine the vehicle's deceleration after contact. Momentum formulae were utilised to estimate the vehicle's deceleration in order to approximate the worst-case situation. The vehicle was assumed to have a top speed of 50 km/hr and a total weight of 300 kg, and the circumstances of head on hits, oblique collisions, and inelastic or partly elastic crashes were used with a crash pulse consideration of 0.1s.The forces which were impacted on the roll cage were decelerations up to 6g and it is calculated as follows: -

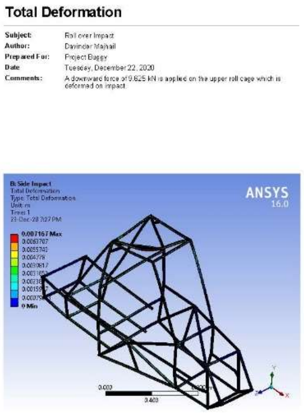
Assume gravitational force = $9.8\ m/s^2 \approx 10\ m/s^2$
F = mass of the vehicle × gravitational force acting on the vehicle = $300 \times 10 = 3000$ N
Max force applied = 6g = 18000 N

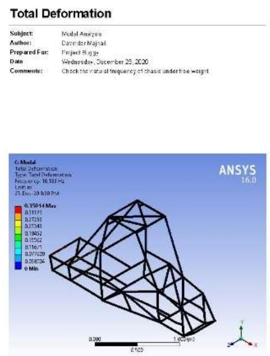
Following test are done in roll cage –

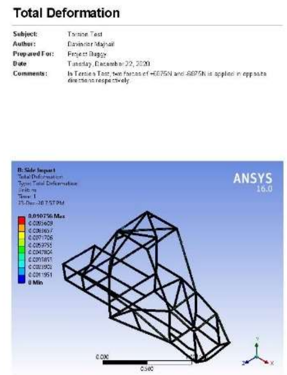
1. Rear Impact analysis
2. Frontal Bump Analysis
3. Roll Over Impact
4. Torsional Test
5. Modal Analysis

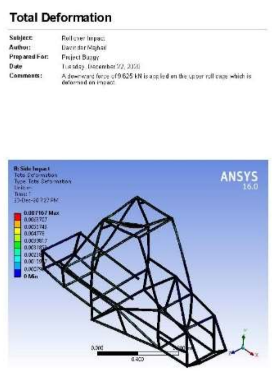
Results from these tests are shown in the table:

Type of impacts	Loading Force (N)	Maximum Deformation (mm)
Rear	18000	6.232
Front	18000	0.83
Roll over	15000	7.452
Torsion	15000	8.322









Result and Conclusion

The following design was completed after completing the front impact, side impact, roll over, and torsion assessments and making the appropriate changes and based on our calculation the design is safe.

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