# SAE Baja Chassis Team

# Initial Design Report

**Ryan Carley: Subteam Lead & Front End Specialist**

**Wyatt Walker: CAD Manager & Cockpit Specialist**

**Charles Anderson: Web Design, Manufacturing, & Rear End Specialist**

**Fall 2024-Spring 2025**

**Project Sponsors:** Gore, H&S Field Services, Poba Medical, Harsh Co, Anonymous Donor

**Faculty Advisor:** David Willy

**Instructor:** David Willy

# DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

# EXECUTIVE SUMMARY

This report documents work done by the NAU Baja Chassis team from August 26th- October 18th, 2024. The goal of this project is to design and build an off-road vehicle using fundamental engineering principles taught in the Northern Arizona Mechanical Engineering program as well as engineering principles practiced by SAE. May 1st-5th the team plans to compete amongst other schools, from across the nation and internationally, in the SAE Baja event located in Marana, Arizona. The car will compete in several events such as Hill Climb, Endurance, Acceleration, Suspension, Dynamic, and overall scoring.

The entire NAU Baja Team is composed of 15 team members split among subteams. This subteam, the chassis team, is responsible for the safety of the driver and ensuring that the frame is compliant with the rules and regulations set forth by the rulebook provided by SAE. This document will cover basic background information about the project and event, as well as design requirements set by SAE and the team's own personal requirements based on goals established by the team. This document will also cover research completed by the team that will be implemented into the design of the chassis. This will include mathematical calculations and benchmarking criteria. The decision-making process will also be documented, through the concept generation and selection criteria. This report marks the quarterway mark in the semester with plenty more to do in upcoming months.

# TABLE OF CONTENTS

## Contents

# 1 BACKGROUND

This chapter of the report will cover the research and decision-making process of the project. It will go over the project requirements from both the customer and engineering standpoints. Both of these criteria will be organized in a QFD diagram that shows the relationship and importance to one another. The document will also cover different types of benchmarking components and determine why some designs were successful while others were not. Sources and information that will be used in the project, will also be discussed as well as their relevance and importance. These sources will influence the team's calculations, which will also be discussed in this report. Lastly, this report will cover design topics and iterations, as well as the different criteria that alter the designs.

## *1.1 Project Description*

For the SAE Baja 2025 NAU capstone project the objective is to design, fabricate, and perform in the competition that will be held in Arizona in 2025. As a capstone project, the team was tasked with reaching out to sponsors and managing the funds raised. The design constraints have been defined in the SAE Baja rulebook for the 2025 competition. The team has to pass a technical inspection to make sure that the vehicle is safe and meets guidelines. The project is important for the team as mechanical engineering seniors to be able to design an automobile with design constraints and goals to achieve.

## *1.2 Deliverables*

The main deliverable for the team is to provide a well-built chassis that is guaranteed to pass SAE technical inspection prior to competition. This inspection ensures that the chassis was designed to adhere to the rule book. If the chassis does not pass technical inspection, the entire team will not be able to compete in the events. Another deliverable to be considered is driver safety. The chassis needs to be designed in such a way that it ensures that the driver will be unharmed in a variety of situations and collisions.

## *1.3 Success Metrics*

The team has defined that the overall success of the project is dependent on how well the car performs in competition. Not only is one of the goals to pass technical inspection, but the team would like to place high in all the events in comparison to the other teams at the competition. Since the frame is vital to other subteams in terms of drivetrain, suspension, and steering, their ability to perform well is dependent on the overall chassis design. So therefore the entire team's success is considered to be the metric for success for the chassis.

# 2 Requirements

In this chapter of the report, the customer and engineering requirements are discussed as well as the QFD that was generated by the team. The more general requirements are from the customer requirements and the more specific requirements are defined by the SAE rulebook and used for the engineering requirements.

## *2.1 Customer Requirements (CRs)*

The customer requirements for the chassis team are to prioritize safety, durability, performance, and passing the technical requirements. These are basic requirements that the team has set to make sure that the frame is the best that it can be. The team has also set other requirements for affordability, comfort for the driver, aesthetics, balanced weight, and ease of fabrication. These requirements are more secondary than the previous ones listed and allow for more creative design and flexibility with other subteams.

## *2.2 Engineering Requirements (ERs)*

The frame team is primarily in charge of passing tech inspection and making sure that the frame meets the design constraints defined by SAE. The engineering requirements will alter the overall design of the frame and will help to prioritize the main goal for the team to pass the technical inspection. These engineering requirements are from the rule book provided by SAE and are shown in Table 1 in Appendix A.

## *2.3 House of Quality (HoQ)*

Figures 1 and 2 are the QFD that the team generated based on the requirements from the rulebook and some of the requirements that the team wanted to accomplish. The customer requirements prioritize the safety, performance, and durability of the frame. Most of the engineering requirements have to do with the clearances that are required and the length of certain members that the rulebook specifies. As the team prioritizes these requirements the goals to pass technical inspection and perform well in the competition will be accomplishable.

| Frame QFD | |
|---|---|
| Team Members | |
| Ryan Carley | |
| Charles Anderson | |
| Wyatt Walker | |

| Baja 25' Frame | |
|---|---|
| Date: 9/9/24 | |

| Relationship | | Legend | |
|---|---|---|---|
| Strong | 9 | A | NAU 2024 #44 |
| Moderate | 3 | B | Cornell 2024 #73 |
| Weak | 1 | C | ETS 2024 #27 |

Technical Requirements

| Customer Weights | Customer Requirments | Increase Strength | Light Weight | Low Cost | Driver Egress | B.3.2.17 Roll Cage Spec sheet filled out | B.3.2.16 Primary members steel OD, ID requirements | B.3.2.16 Alternate Material requirements | B.3.2.3 Secondary members OD, ID requirements | B.3.2.15 Welding samples requirements | B.3.2.1 Straight (40in) and bent members (33in unsupported, <30deg length |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Performance | 9 | 9 | -3 | 9 | | 9 | 3 | 9 | | |
| 3 | Safety | 9 | -3 | -3 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 5 | Durability | 9 | -3 | -1 | 1 | | 9 | 9 | 9 | 9 | 9 |
| 4 | Affordable | -3 | 3 | 9 | 1 | | 9 | 9 | 9 | | 3 |
| 8 | Comfort | 1 | 1 | -3 | 9 | | | | | | |
| 7 | Ease of Fabrication | -3 | 3 | -1 | -3 | | 3 | 3 | 3 | 9 | 3 |
| 9 | Aesthetics | 1 | 1 | -3 | -1 | | | | | 3 | 3 |
| 1 | Pass Techs | 9 | -1 | -1 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 6 | Balanced Weight | -3 | -1 | -3 | 1 | | 3 | 3 | 3 | | 3 |
| Technical Requirement Units | | psi | lbs | $ | Seconds | N/A | Inches | N/A | Inches | N/A | Inches |
| Technical Requirement Targets | | | 100 | 2500 | 5 | | 1,0.065,0.11 | | 1,0.035 | | 40,33 |

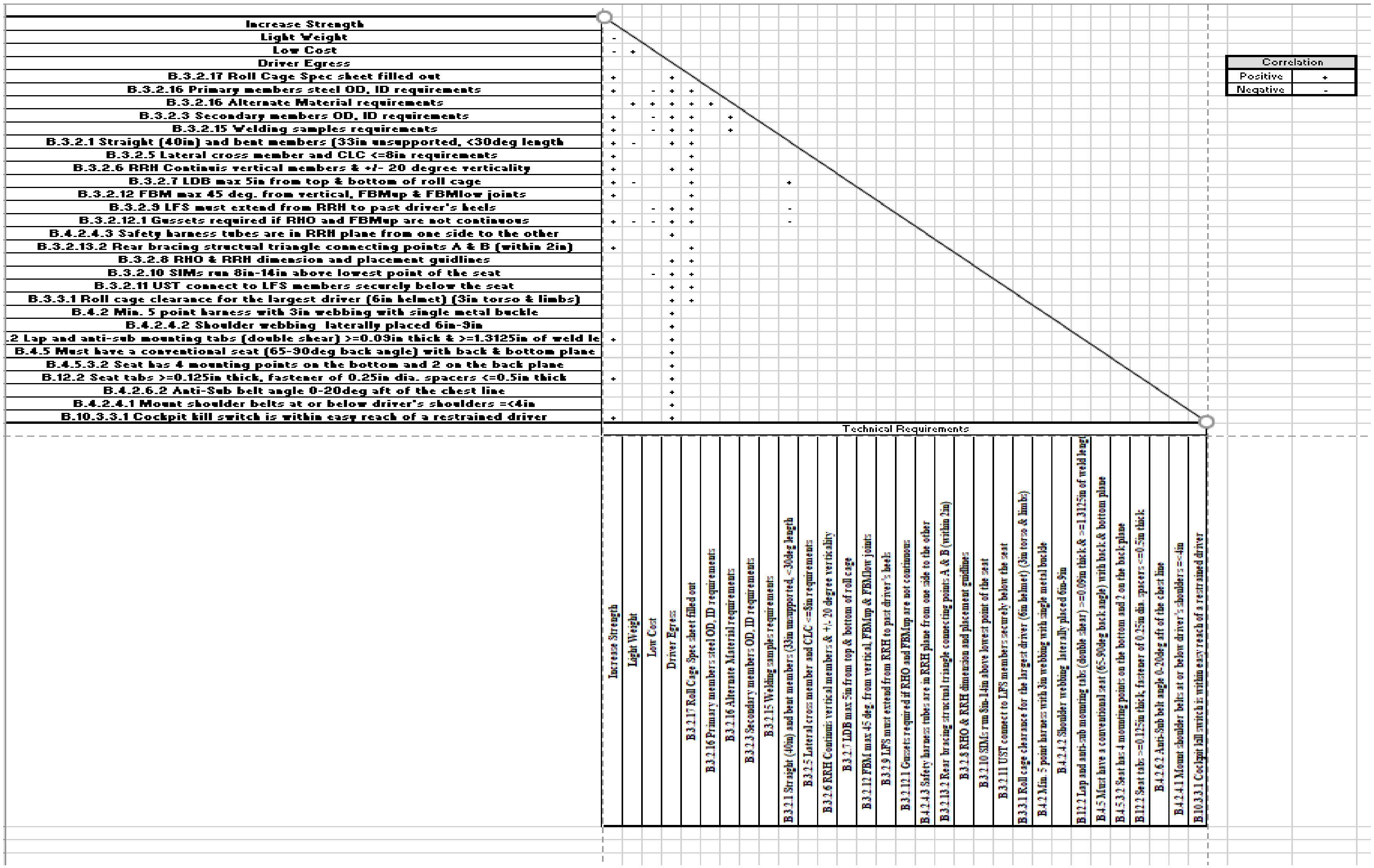
| Customer Weights | Customer Requirments | B.3.2.5 Lateral cross member and CLC <=8in requirements | B.3.2.6 RRH Continuis vertical members & +/- 20 degree verticality | B.3.2.7 LDB max 5in from top & bottom of roll cage | B.3.2.12 FBM max 45 deg. from vertical, FBMup & FBMlow joints | B.3.2.9 LFS must extend from RRH to past driver's heels | B.3.2.12.1 Gussets required if RHO and FBMup are not continuous | B.4.2.4.3 Safety harness tubes are in RRH plane from one side to the other | B.3.2.13.2 Rear bracing structural triangle connecting points A & B (within 2in) | B.3.2.8 RHO & RRH dimension and placement guidlines | B.3.2.10 SIMs run 8in-14in above lowest point of the seat |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Performance | | | 1 | 3 | 3 | 9 | | 3 | 1 | 1 |
| 3 | Safety | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 5 | Durability | 9 | 3 | 9 | 9 | 9 | 9 | 3 | 3 | 9 | 9 |
| 4 | Affordable | | 1 | 3 | 1 | 3 | 1 | 1 | 1 | 3 | 1 |
| 8 | Comfort | | 9 | | | 3 | | 9 | | 9 | 9 |
| 7 | Ease of Fabrication | 3 | 3 | 3 | 3 | 3 | -3 | -1 | -3 | -3 | 1 |
| 9 | Aesthetics | 3 | 9 | 3 | 9 | 3 | 9 | | 3 | 9 | 9 |
| 1 | Pass Techs | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 6 | Balanced Weight | 3 | 3 | | 3 | 1 | 1 | | 9 | 3 | 1 |
| Technical Requirement Units | | Inches | N/A | Inches | N/A | N/A | N/A | N/A | N/A | N/A | Inches |
| Technical Requirement Targets | | 8 | | 5 | | | | | | | 8,14 |

| Customer Weights | Customer Requirments | B.3.2.11 UST connect to LFS members securely below the seat | B.3.3.1 Roll cage clearance for the largest driver (6in helmet) (3in torso & limbs) | B.4.2 Min. 5 point harness with 3in webbing with single metal buckle | B.4.2.4.2 Shoulder webbing laterally placed 6in-9in | B.12.2 Lap and anti-sub mounting tabs (double shear) >=0.09in thick & >=1.3125in of weld leng | B.4.5 Must have a conventional seat (65-90deg back angle) with back & bottom plane | B.4.5.3.2 Seat has 4 mounting points on the bottom and 2 on the back plane | B.12.2 Seat tabs >=0.125in thick, fastener of 0.25in dia. spacers <=0.5in thick | B.4.2.6.2 Anti-Sub belt angle 0-20deg aft of the chest line | B.4.2.4.1 Mount shoulder belts at or below driver's shoulders =<4in | B.10.3.3.1 Cockpit kill switch is within easy reach of a restrained driver |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Performance | 1 | | 1 | | | | | | | | 3 |
| 3 | Safety | 9 | 9 | 9 | 9 | 9 | 3 | 3 | 9 | 9 | 9 | 9 |
| 5 | Durability | 3 | | | | 3 | 1 | 1 | 3 | | | |
| 4 | Affordable | 1 | | 1 | | 1 | 3 | 3 | 1 | 1 | | |
| 8 | Comfort | 9 | 9 | 9 | 9 | | 9 | | 1 | 9 | 9 | |
| 7 | Ease of Fabrication | -3 | -3 | 1 | 1 | -1 | -3 | -3 | -3 | | -3 | -1 |
| 9 | Aesthetics | | 9 | 3 | | | 3 | | | | 1 | |
| 1 | Pass Techs | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| 6 | Balanced Weight | 3 | 3 | | | | | | | | | |
| Technical Requirement Units | | N/A | Inches | Inches | Inches | Inches | N/A | N/A | Inches | N/A | Inches | N/A |
| Technical Requirement Targets | | | 6,3 | 3 | 6,9 | 0.09,1.3125 | | | 0.125,0.25,0. | | 4 | |

Customer Opinion Survey

| Customer Weights | Customer Requirments | 1 Poor | 2 OK | 3 Acceptable | 4 Good | 5 Excellent |
|---|---|---|---|---|---|---|
| 2 | Performance | | A | | C | B |
| 3 | Safety | | | | | ABC |
| 5 | Durability | | | A | | BC |
| 4 | Affordable | C | B | A | | |
| 8 | Comfort | A | | | B | C |
| 7 | Ease of Fabrication | | AC | B | | |
| 9 | Aesthetics | | | A | B | C |
| 1 | Pass Techs | | | | A | BC |
| 6 | Balanced Weight | | | A | B | C |

**Figure(1): QFD**

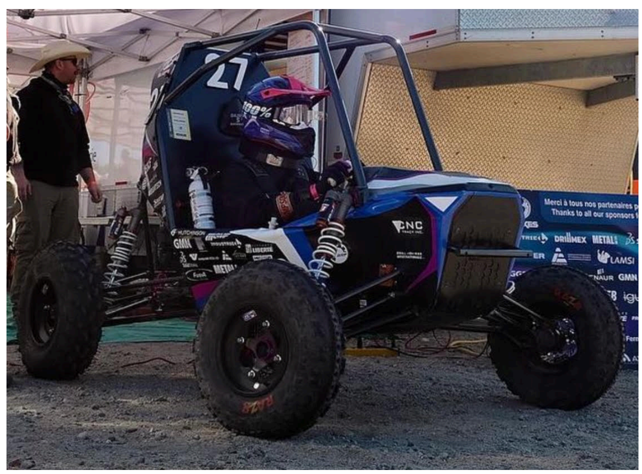



**Figure(2): Top of The QFD**

# 3 Research Within Your Design Space

## *3.1 Benchmarking*

For the benchmarking research, the team took a look at some previous designs from different schools and compared them to find their strengths and weaknesses. The three different designs that were taken into consideration were NAU #44 from 2023-2024. ETS #27 from 2023-2024, and Cornell #73 from 2023-2024. Both ETS and Cornell mounted their front shocks to the front bracing members, while NAU mounted their shocks lower on the frame. This Style of mounting for ETS and Cornell gives the suspension more vertical travel. NAU's front end also is far more cramped and is lower in the car compared to both ETS and Cornell. Based on the images as well, the main cockpit seems to be wider on both ETS and Cornell, compared to NAU. This gives the driver more room for maneuverability and is more comfortable with extra room.  NAU also has a higher seating position compared to ETS and Cornell and this creates a higher center of gravity for the NAU car. These benchmarking selections are valid because of how each of these vehicles performed in the 2023-2024 competition. Cornell placed 1st overall and ETS placed 2nd overall, while NAU placed 33rd. Taking this into consideration, the chassis team would like to incorporate these elements in the design, to help improve the overall performance of the design.





**Figures(3-5): NAU #44, ETS#27, & Cornell #73**

## *3.2 Literature Review*

### 3.2.1 Charles:

- The Procedure Handbook of Arc Welding [1]

  Chapter 2 Designing for Arc Welding: This chapter discusses some characteristics that should be considered when designing a structural system that requires welding. It discusses key topics of being able to satisfy stiffness and strength requirements if a torque will be applied, as well as being able to locate when and where failure will most likely occur. This chapter also covers information such as material selection and choosing common metals compared to specialized materials. This chapter emphasizes room for improvement and how to make designs better and easier through manufacturing processes such as bending, notching, and coping. All of these factors will be taken into consideration for the design and will make the manufacturing process easier.

- Material Science and Engineering [2]

  Chapter 11 Applications and Processing of Metal Alloys: This chapter talks about the benefits of using different alloyed metals for different applications. For the chassis, the team plans to use medium carbon steel in 4130 Chromoly tubing. According to Table 11.2a [] in the textbook, the tubing has a composition range of 0.8-1.10% Chromium and 0.15-0.25% Molybdenum. The textbook also mentions the advantages and disadvantages of using medium-carbon steel over low-carbon steel. Mild steel has higher strength and toughness, but is also less ductile and in most cases requires heat treatment. Since the team wanted a more rigid frame, this information from the textbook influenced the decision to go with a mild steel like 4130 Chromolly.

- Effect of Preheating Temperatures On Impact Properties [3]

  This paper discusses the differences of preheating 4130 Chromolly tubing at different temperatures, before welding, to increase the maximum amount of impact energy that the material can handle. In this paper, the authors found that 250 degrees Celsius was optimal for increasing the impact energy. At that temperature, the 100mm X 75mm X 15mm test sample could absorb 50 J. This is more energy compared to 200 degrees Celsius and 150 degrees Celsius. This paper showed ways that the team could improve the material properties of the 4130 by just preheating the metal before welding the members.

- SAE Baja Final Proposal Report [4]
  This report is from the NAU SAE Baja Team of 2021, which placed top 5 overall. This document is a summary of their entire process, giving the team some insight into different methods and ideas. This report shows some FEA calculations for the frame, which in turn will give some metrics to aim for. This document also shows how other parts will mate up in the frame. This document is a good reference and a great example of how to execute this project successfully.

- Stress analysis of a roll cage[5]
  This YouTube video goes over the basics of applying and simulating stress calculations upon impact on a roll cage. Given that the geometry of the roll cage in the video is not the same as the roll cage being designed, the team will have to use these fundamentals from the video and apply them to the design, while coming up with new and other ways of simulating these impacts.

- Designing a Roll Cage in Solidworks [6]

  This YouTube video is a great instructional tool that teaches how to build a roll cage from scratch using SolidWorks. The video teaches the importance of using different reference planes for different geometries. The video also touches a little bit on how to use the weldment feature on SolidWorks. This video was a huge help in figuring out how to make the CAD drawing for the chassis, as not a single team member had any prior experience in doing so.

- ASTM- AISI 4130 Steel [7]

  This standard by the American Society of Testing and Materials specifies the material properties of 4130. This standard gives a material characteristic such as density, yield strength, modulus of elasticity, Poisson's ratio, etc. This is a great resource for the team to figure out material properties for calculations.

### 3.2.2 Wyatt:

- Shigley’s Mechanical Engineering Design [8]
  - Chapter 2 section 2-1 Material Strength and Stiffness

  This resource was useful for choosing an alternative material for the frame over the defined 1018 steel that is given in the textbook. The team found it necessary to look at other materials that can be lighter and more available on the market. An equivalency calculation was done to prove that the alternate material was viable with our rules.

- Machinery’s Handbook [9]
    - Bending Sheet Metal pg.1346-1353

  This section of the Machinery’s Handbook shows some factors that can be useful when the team is bending and coping with the frame. It shows useful calculations that can be used by the team to save materials and help avoid mistakes.

- Design and Optimization of Mini Baja Chassis [10]

  This source is an article that goes over an FEA of a Baja chassis and shows the results of impacts that were in a few different locations. This could be useful for the team to get an idea of what can be acceptable for displacement and stress outcomes of an FEA.

- Design, analysis, and optimization of all-terrain vehicle chassis ensuring structural rigidity (6 Finite Element Analysis) [11]

  This article shows FEAs on a Baja chassis and shows where the fixed points are and explains its thought process through the simulations. The FEAs were done with ANSYS and went through a front impact, side impact, and rear impact. These examples can prove useful when the team does an FEA on our frame design.

- Plastic Deformation Analysis in Tube Bending [12]

  This source goes through some calculations of bending tubes and can help the team when it comes to bending the tubing so that material isn’t wasted and fabrication is more efficient and organized with plenty of resources.

- 2024 Baja SAE Roll Cage Doc. Package. Pg. 8 [13]

  This is a document provided by SAE for the Baja competition and has the equivalency calculations in it. They are required documents for the competition if an alternative material is used which for our case will be important. The calculations for the material of the tubing were figured out prior to the team buying the tubing.

- Techniques to improve weld penetration in TIG welding [14]

  This source is a guide for what to look for when doing TIG welding. This includes what are the best practices and what to look for in a good weld. This will be useful for the team since there is a welder in the team that will help with fabrication as well as the other members of the team being aware of what constitutes a good weld.

### 3.2.3 Ryan:

- Engineering Analysis with ANSYS Software (Ch.3) [15]

  This chapter highlights two-dimensional & three-dimensional stress analysis using ANSYS. While the ANSYS simulations used in the book are outdated, the hand calculations will still prove to be valuable for first-iteration calculations of stress concentrations.

- The Automotive Chassis (Second Edition) (Ch. 6) [16]

  Chapter six in this book provides a step-by-step process for finding the center of mass of a frame. The center of mass is vital to the frame's success because the frame needs to be as balanced as possible to assist with steering. Additionally, by finding the center of mass it will make calculating braking and acceleration capacity and the climbing ability much more accurate.

- ASTM A500/A500M-23 [17]

  This standard explains the ASTM standard for inspecting and welding steel tubing. Further, it explains that the tubing must go through a flattening test, flaring test, and wedge crush test before being available for purchase.

- Analysis of Roll Cage and Various Design Parameters of an All-Terrain Vehicle (Baja) [18]

  This paper outlines the chemical composition of 4130 Chromoly steel and why it is the best option for the Baja frame tubing. Additionally, it highlights equations for solving the forces that the car would need to withstand to be used in FEA simulations.

- Design, analysis, and optimization of all-terrain vehicle chassis ensuring structural rigidity (5. Calculations) [19]

  This paper shows detailed instructions for calculating the forces that will be used in simulations to find stress concentrations and displacement. It also shows how to effectively summarize the results of the simulations in an organized manner.

- Static and Modal Analysis of All Terrain Vehicle Roll-Cage [20]

  This paper is used to demonstrate how to calculate very specific impacts. For example, bump impacts and torsional impacts are both necessary to ensure the safety of the driver but are very complicated to derive. This source lays out each variable and how to accurately simulate each scenario.

- Introduction to Simulations (FEA) [21]

  This source is a YouTube video that goes through the basics of performing an FEA using SolidWorks Simulation. The creator of this video, Aryan Fallahi, gives a step-by-step explanation of the interface and how to accurately set up and run a simulation.

- Bentley Garner Shares Tips for Successfully Welding Chromoly Tube [22]

  In this YouTube video Bentley Garner, an experienced welder, shows how to properly clean and prep Chromoltubesbe for welding. This video will prove valuable once the frame is ready to be welded. Additionally, he explains what type of welding wire is needed to get good penetration on the welds.

## *3.3 Mathematical Modeling*

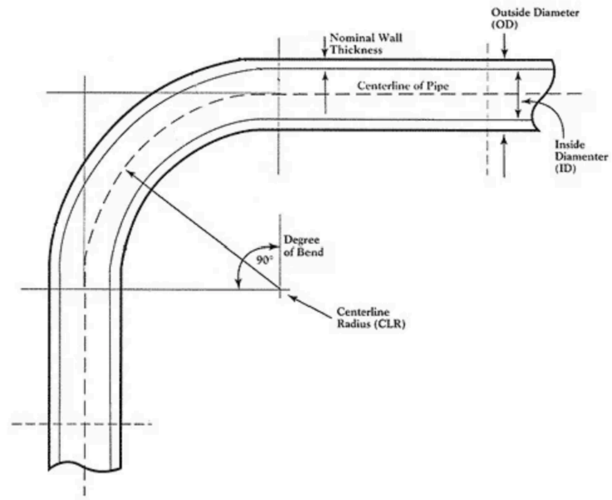
**3.3.1 Charles:**

This first Mathematical modeling will be used to calculate the full amount of length of the f tube needed for members with bends in them. The real roll hoop, the member directly positioned behind the driver separating the engine and the cockpit, is required to be made from one continuous tube. The chassis team has designed it in a way where there are 4 bends, two of different angles. In order to figure out the total length of the f tube needed to make that entire member, the team needed to calculate the arc length of each of these bends. In order to do so, the team used the following equations:

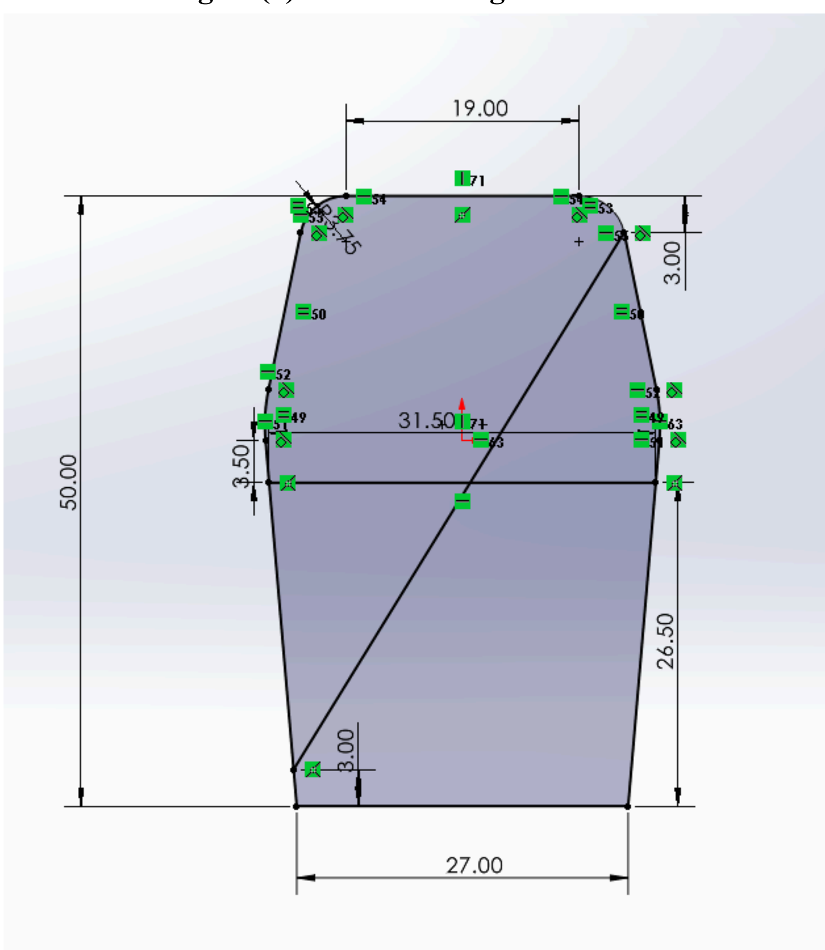
$$rad = \theta \cdot \frac{\pi}{180} \qquad L = rad \cdot \ clr$$

Converting degrees to radians Length= radians * centerline radius

Figure 6 helps visualize the calculations.




**Figure(6): Tube Bending Illustration**




**Figure(7): Rear Roll Hoop**

The first bend is 16.02 degrees, convert this to radians

$$16.02 \ * \ \Pi/180 \ = \ 0.28\, radians$$

Then multiply by the C.L.R.

$$0.28 \ * \ 14.7 \ = 4.12 ”$$

Therefore the total length needed for that bend is 4.12 inches. We need to repeat that calculation but using a 78.46-degree bend and a CLR of 3.75 to get a total length of 5.14 inches. To figure out how much tubing we need to complete this entire member we add the length of straight and bent members together like so and divide by 12 to convert to feet.

$$(2 * 5.14 \ + \ 2 * 4.12 \ + \ 2 * 30 \ + \ 2 * 13.17 \ + \ 19)/12 = \ 10.32\, ft$$

As simple of a calculation as this is, it determined the purchasing process for materials, requiring the team to purchase tubing in 12 ft quantities to ensure that there was enough material to successfully bend the RRH member.

**3.3.2 Wyatt:**

The mathematical modeling shown in Figure 8 was for the equivalency calculations that are required by SAE for teams using different materials than what is given in the rulebook. The rulebook states that the frame must be made of steel of 0.18% carbon content with an outside diameter of 1 inch and a wall thickness of 0.118 inches. The wall thickness of the tubing can be as low as 0.063 inches as long as the bending stiffness and bending strength are equivalent to or higher than the 1018 steel with the 0.118-inch wall thickness. The team wanted to use 4130 chromoly steel for its weldability, availability on the market, and lower wall thickness so that the frame is lightweight. The calculations prove that the 4130 chromoly will serve as a stronger and lighter option than the 1018 steel with a stronger bending stiffness and strength.

**1018 Steel**

OD = 25mm = 0.984in
Wall Thickness = 3mm = 0.118in
ID = 19mm = 0.748in
E = 205 GPa = 29733200 psi (Modulus of Elasticity for all steels)
Sy = 365 MPa = 52939.6 psi
C = OD/2 = 12.5mm = 0.492in (Distance to neutral axis)

Bending Stiffness (Kbreq)

I = Second moment of area for the structural cross section
I = pi/64*(OD^4-ID^4)
I = pi/64*(0.984^4-0.748^4)
I = 0.0308in^4

Kbreq = E*I
Kbreq = 29733200psi * 0.0308in^4
Kbreq = 915,782.56 lbf*in^2

Bending Strength (Sbreq)

Sbreq = (Sy*I)/C
Sbreq = (52939.6 psi*0.0308in^4)/0.492in
Sbreq = 3,314.11 lbf*in

**4130 Chromoly Steel**

OD = 1.25in
Wall Thickness = 0.065in
ID = 1.12in
E = 205 GPa = 29733200 psi (Modulus of Elasticity for all steels)
Sy = 63100 psi [2]
C = OD/2 = 0.625in (Distance to neutral axis)

Bending Stiffness (Kbreq)

I = Second moment of area for the structural cross section
I = pi/64*(OD^4-ID^4)
I = pi/64*(1.25^4-1.12^4)
I = 0.0426in^4

Kbreq = E*I
Kbreq = 29733200psi * 0.0426in^4
Kbreq = 1,266,634.32 lbf*in^2

Bending Strength (Sbreq)

Sbreq = (Sy*I)/C
Sbreq = (63100 psi*0.0426in^4)/0.625in
Sbreq = 4,300.9 lbf*in

**Figure(8): Tubing Equivalency Calculations**

### 3.3 .3 Ryan:

## Estimated Weight of the Frame:

$$Weight = Density \times Volume \qquad V_{tube} = V_{outer} - V_{inner}$$

### Primary Members:

$$OD = 1.25\ in$$

$$Wall\ Thickness = .065in$$

$$Density = .284\ \frac{lbs}{in^3}$$

$$Lenght \approx 49ft$$

$$\left(\pi \times \left(\frac{1.25in}{2}\right)^2 \times (49ft \times 12in)\right) - (\pi \times (.56in)^2 \times (49ft \times 12in)) = 143.28\ in^3$$

$$143.28\ in^3 \times .284\frac{lbs}{in^3} = 40.73\ lbs$$

### Secondary Members:

$$OD = 1\ in$$

$$Wall\ Thickness = .035in$$

$$Density = .284\ \frac{lbs}{in^3}$$

$$Lenght \approx 36ft$$

$$\left(\pi \times \left(\frac{1in}{2}\right)^2 \times (36ft \times 12in)\right) - (\pi \times (.465in)^2 \times (36ft \times 12in)) = 43.53\ in^3$$

$$43.53\ in^3 \times .284\frac{lbs}{in^3} = 12.35\ lbs$$

$$Total\ Weight \approx 54\ lbs$$

*Not including weight of welds*

**Figure (9): Weight of Frame**

This mathematical model shown in Figure 9 calculates the frame's weight. The frame needs to be as light as possible without compromising the integrity of the design. The calculations above are overestimated because the numbers are rounded up. However, the total estimated weight is still acceptable. The intention of keeping the frame as lightweight as possible is because the other sub-components of the car will increase the weight of the car significantly. The lighter the car is when it comes to competition the faster it will be overall. It is important to acknowledge that this estimated weight does not account for the weight of the welds.

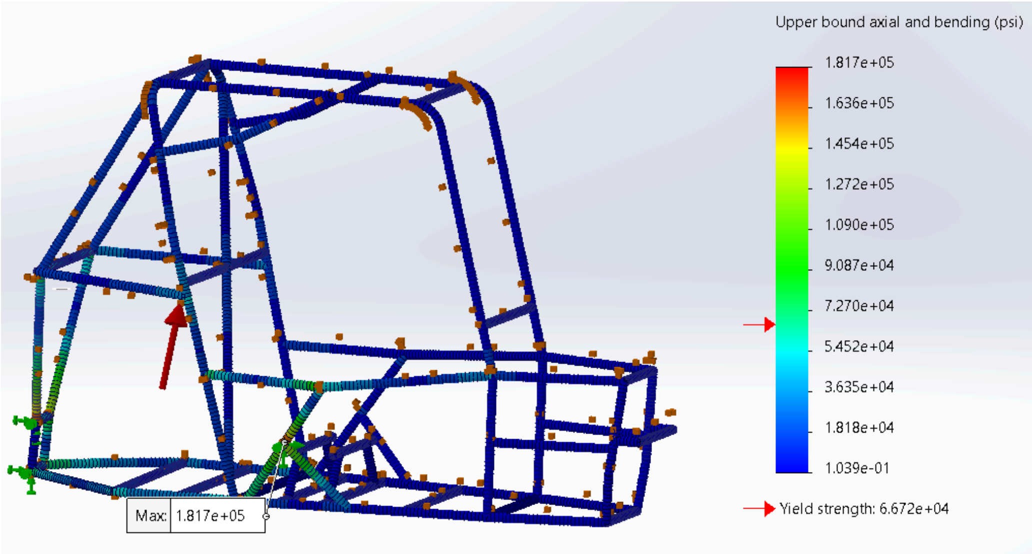



**Figure (10): FEA of Stress Analysis, Jumping the Car and Falling 10 ft Then Landing on One Rear Wheel**

The max stress for this simulation shown in Figure 10 occurs where the trailing arm is mounted to the side impact member supports. The max stress at that point is 1.817x10^5 psi. Considering the yield strength of 4130 Chromoly Steel is 6.672x10^4 psi this scenario would permanently deform this member and possibly break the member. With this knowledge, we will refine the design of these support members to withstand the forces that the frame would see for this specific scenario.

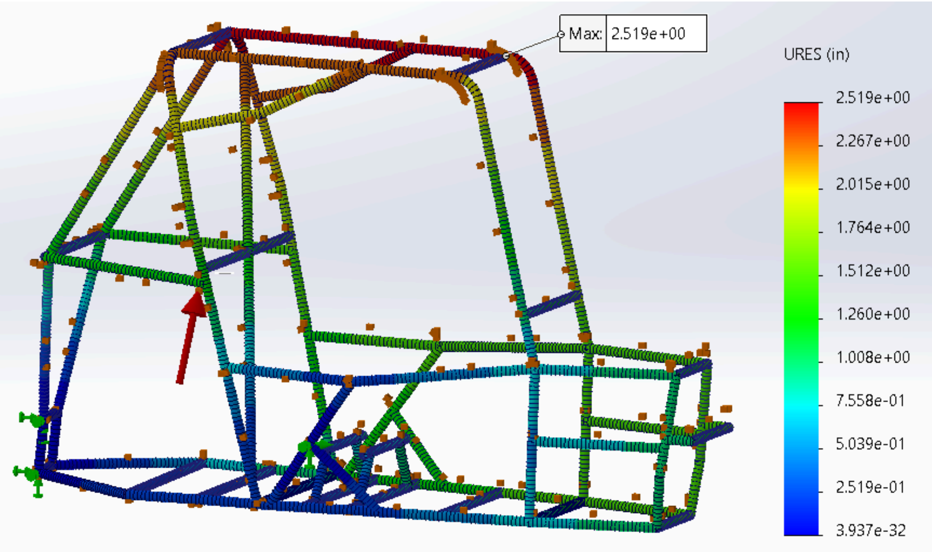



**Figure (11): FEA of Displacement Analysis, Jumping the Car and Falling 10 ft then Landing on One Rear Wheel**

The max displacement of the frame for this scenario shown in Figure 11 is 2.5 inches on the front bracing member. This displacement is extremely high. This displacement value will go down considerably once exact suspension mounting points are defined, the suspension mounts used in the simulation are estimated to be within four inches of the final locations. However, it is very crucial to know where the weakest parts of the car will be. In this case, it is the bend on the front bracing member. The gussets on the front bracing member are also not in their final position, with the information from this simulation the exact locations of the gussets can be finalized.

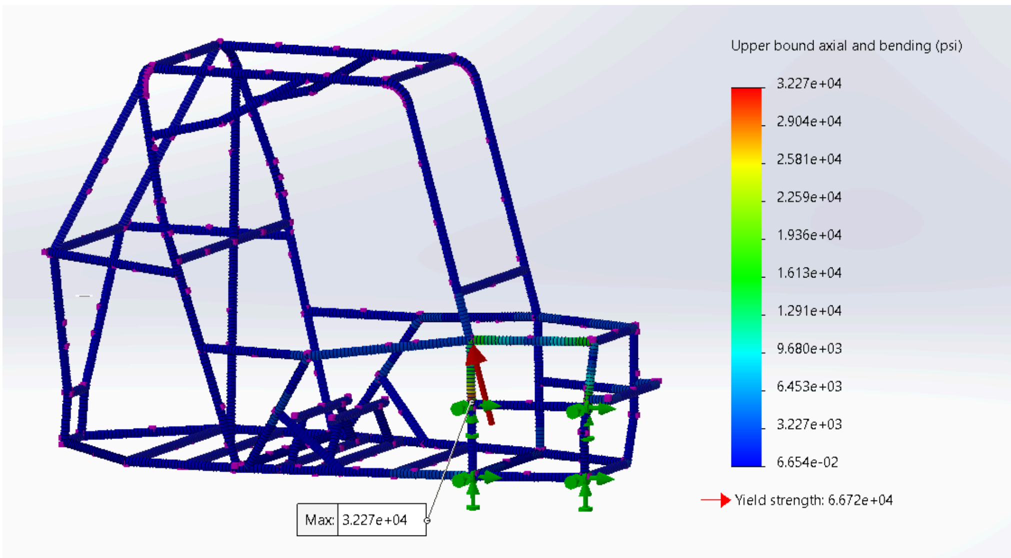



**Figure (12): FEA of Stress Analysis, Jumping the Car and Falling 10 ft then Landing on One Front Wheel**

Similar to the previous scenario except the whole car landed on one front wheel after falling from a 10 ft drop. The stress analysis from Figure 12 shows a very high concentration of stress where the upper control arms would be mounted. The max stress at that point is 3.227x10^4 psi which is less than the yield strength but it is too close to be comfortable with the supports in the front. It is important to acknowledge that the point force applied to the front bracing member is not exactly how the shock will be forced into the frame but the position in the simulation is within four inches of the final location of the shock mount.

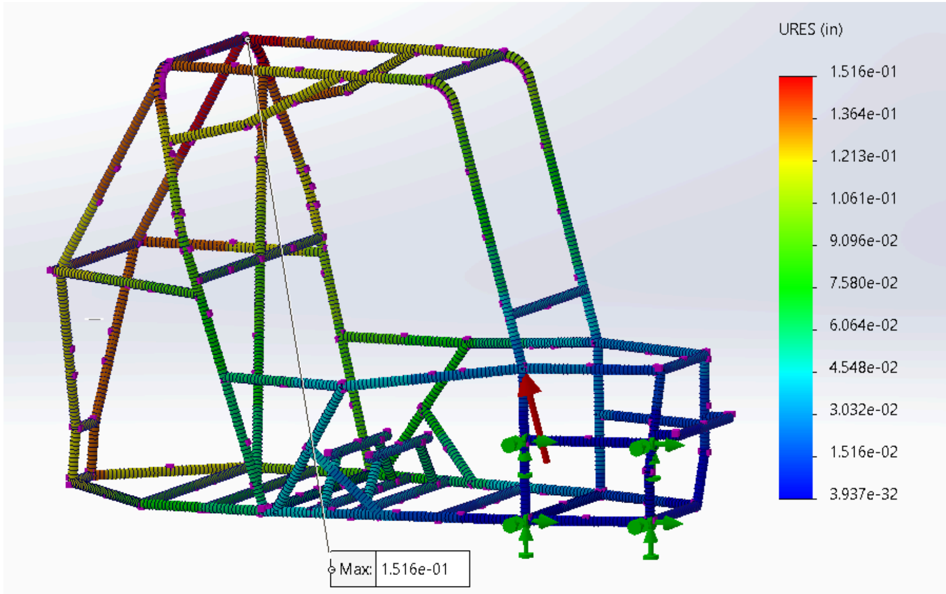



**Figure (13): FEA of Displacement Analysis, Jumping the Car and Falling 10 ft then Landing on One Font Wheel**

The simulation in Figure 13 highlights the max displacement location of the frame if the car were to fall 10 ft and land on the right front wheel. The design of the frame was able to dissipate the force, redirecting it toward the rear of the car. The max displacement is .152 inches this is an acceptable displacement given the magnitude of the force is 2000 lbf.

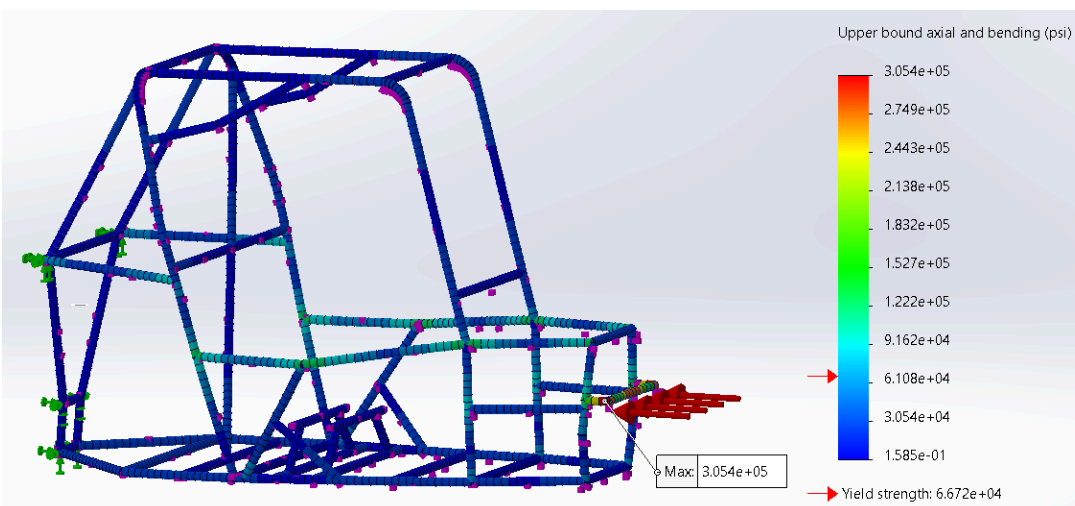



**Figure (14): FEA of Stress Analysis: Hitting a Wall Going 25 mph**

Figure 14 is a stress analysis simulation representing the car traveling at 25 mph and hitting a barrier or another stationary obstacle. The max stress is on the tow bar with a value of 3.05x10^5 psi however, the stress quickly dissipates through the front end of the frame. While the towbar would break the structural rigidity of the front of the frame would remain the same.

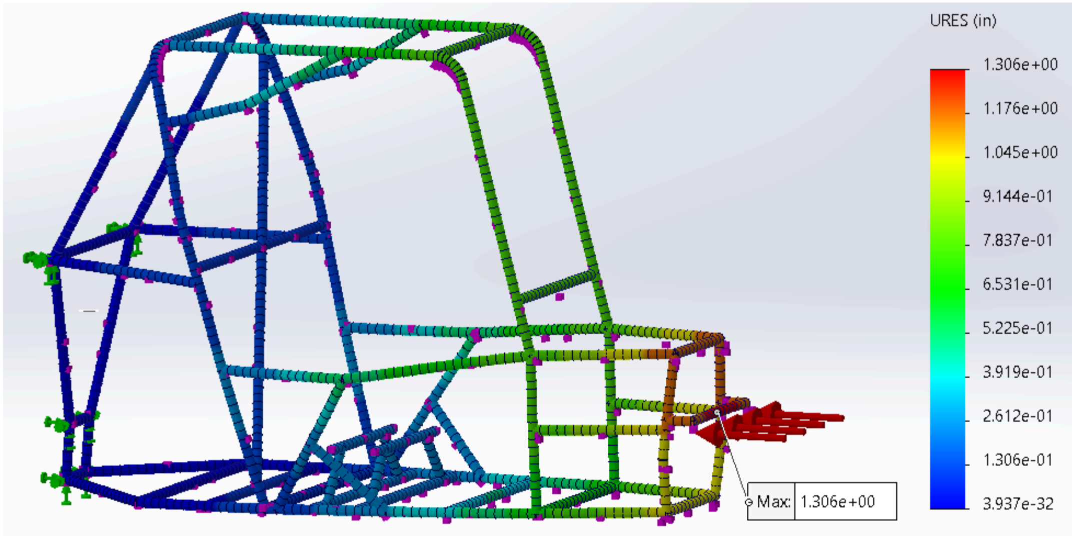



**Figure (15): FEA of Displacement Analysis: Hitting a Wall Going 25 mph**

Figure 15 shows the deformation of the previous simulation, the results are similar to the results in Figure 14. The towbar absorbs the most force which causes the max deformation to be on the towbar which is 1.306 inches.

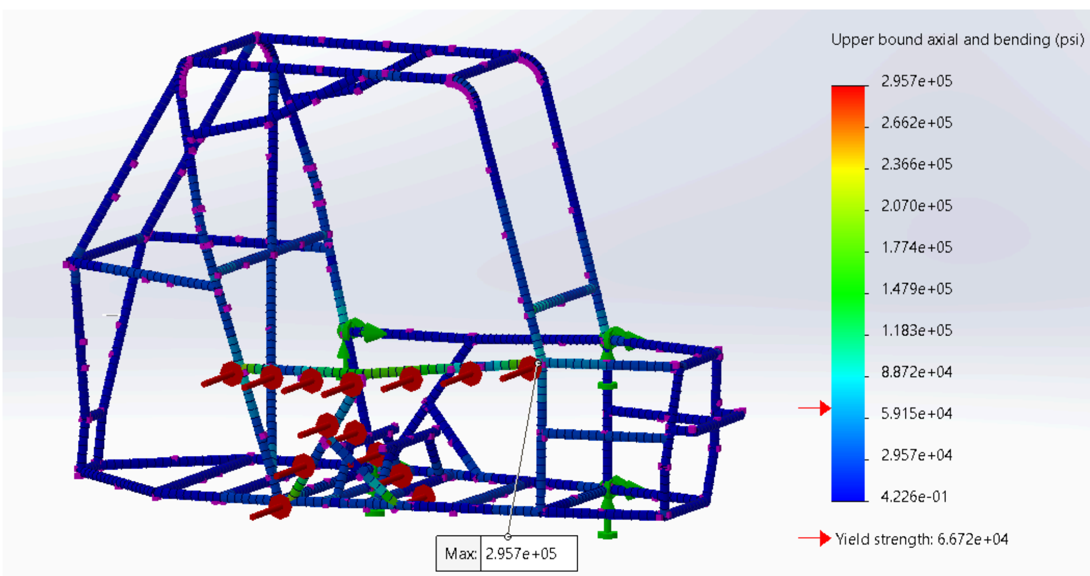



**Figure (16): FEA of Stress Analysis: Car Getting T-Boned by Another Driver going 25 mph**

The final simulation on the frame for this report is a scenario where the car gets T-Boned by another competitor moving 25 mph. While this scenario is unlikely the frame needs to be designed for worst-case scenarios and successfully protect the driver. The max stress of this scenario occurs where the Side Impact Member (SIMmeetset the Front Bracing Member (FBM) with a value of 2.957x10^5. This joint would break however, the strength of the welder does not account for this simulation.

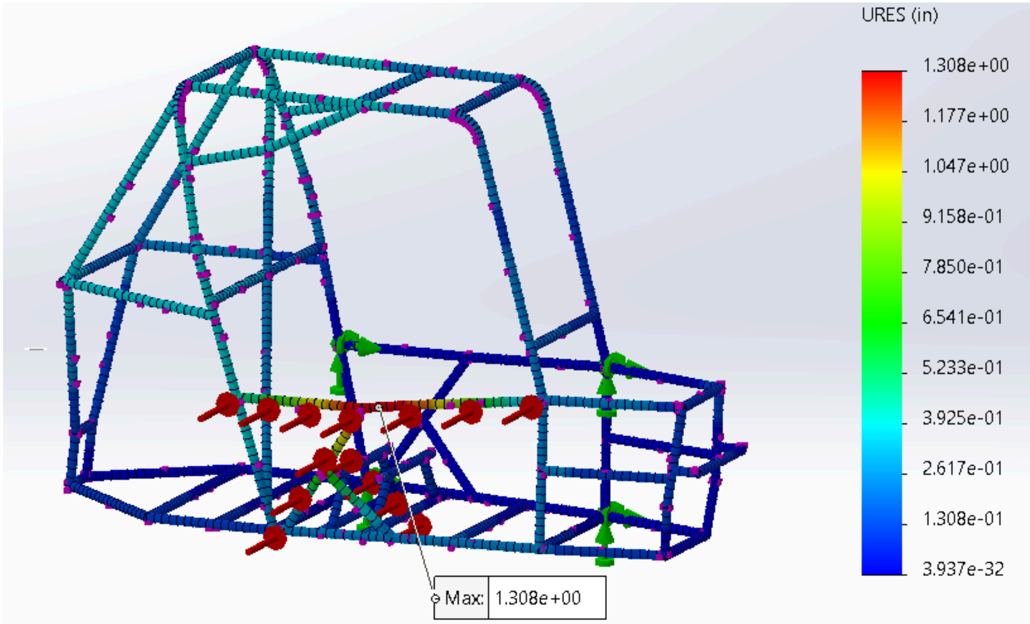



**Figure (17): FEA of Displacement Analysis: Car Getting T-Boned by Another Driver going 25 mph**

In the same scenario as the previous the max displacement occurs on the SIM at 1.308 inches. This deformation would not affect the driver however, the car would more than likely need to be taken out of the competition.

# 4 Design Concepts

## *4.1 Functional Decomposition*

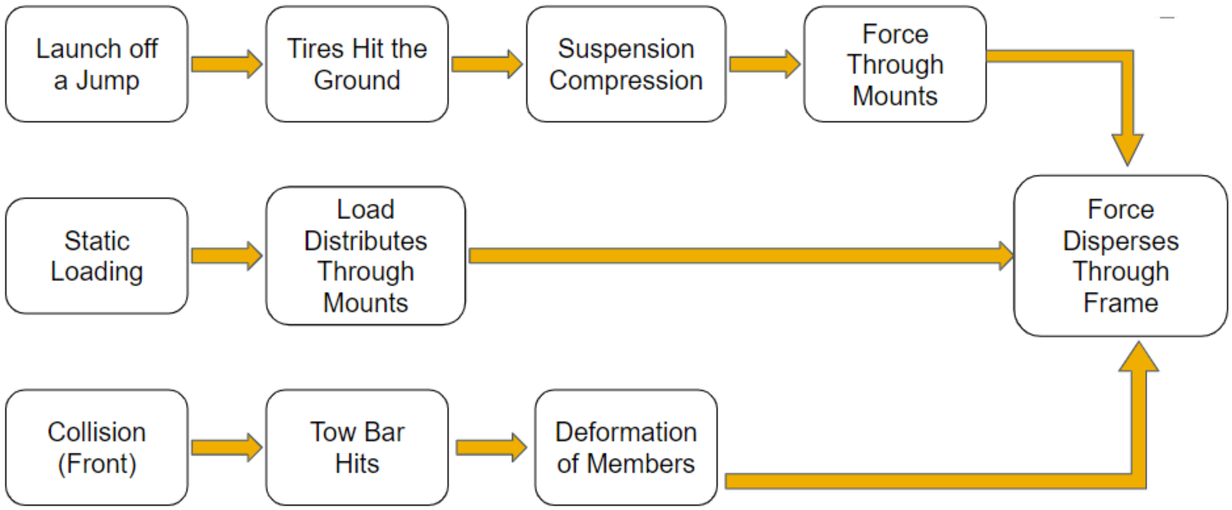



**Figure (18): Functional Model**

Figure 18 shows a functional model of how the frame should react to the three given scenarios on the left side. Essentially, the main objective of the frame is to effectively disperse loads throughout various members to minimize stress concentrations on any given member. For example, the first scenario is the car launching a jump, the tires would then hit the ground, the suspension would become fully compressed and the forces would be translated through the suspension mounts and into the different members of the frame.

## *4.2 Concept Generation*

For the concept generation, the team took a direct compare and contrast approach, looking at two different designs and ideas and listing the advantages and disadvantages of each. One of the first design iterations the team looked at was a front-braced roll cage vs a rear-braced roll cage.

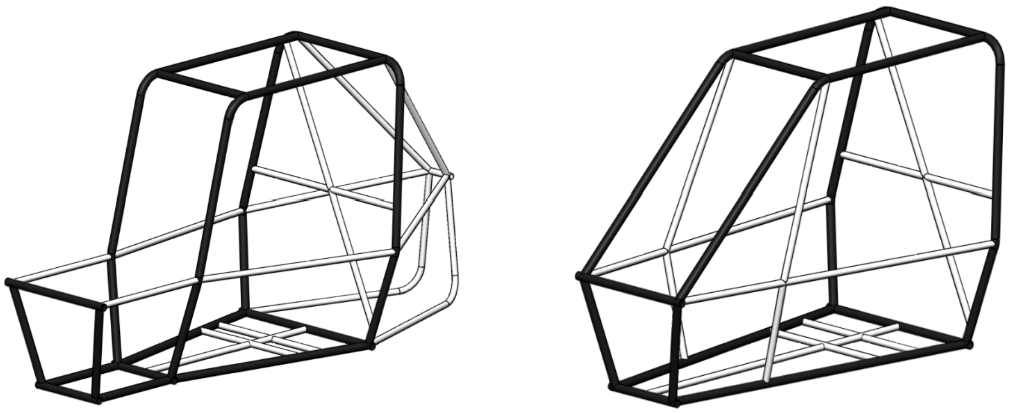


**Figure (19): Rear Braced frame (left) Front Braced Frame (right)**

The rear braced frame provides a lighter weight frame and creates a more open cockpit by having the engine at the rear. With the front braced frame, the engine is usually mounted in the front end of the car, this gives the car a better weight distribution from front to rear however, these frames are a little bit heavier and more cramped in the front.

For the second concept generation, the chassis team also compared the pros and cons of in-board vs out-board brakes for front brakes.


**Figure (20): In-board Brakes**

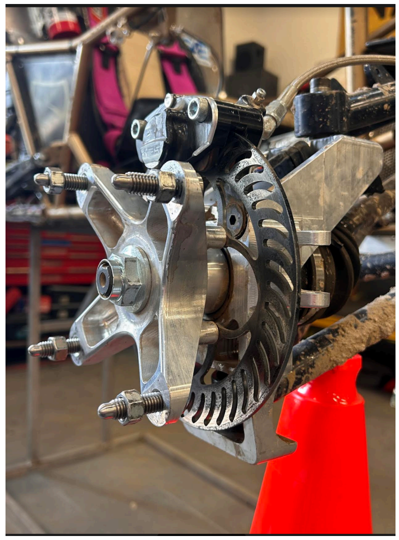


**Figure (21): Out-Board Brakes**

Another concept the frame team needed to decide on was whether or not the pedals should be floor-mounted or hanging pedals. Both options will affect the frame and the ergonomics of the driver.

**Figure (22): Floor Mounted Pedals**

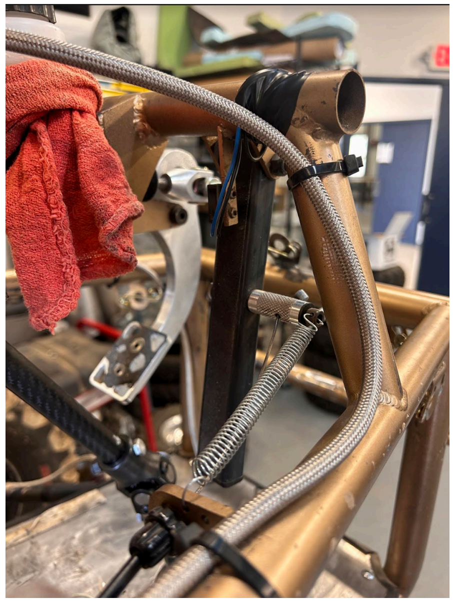


**Figure (23): Hanging Pedals**

The final concept the frame team decided on is the shape of the Side Impact Members (SIM). The two options were having the SIM bend more inward versus angling them outward.

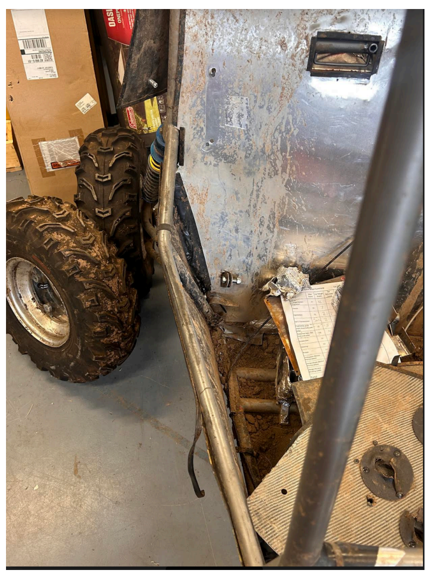


**Figure (24): SIM Angled Outward**

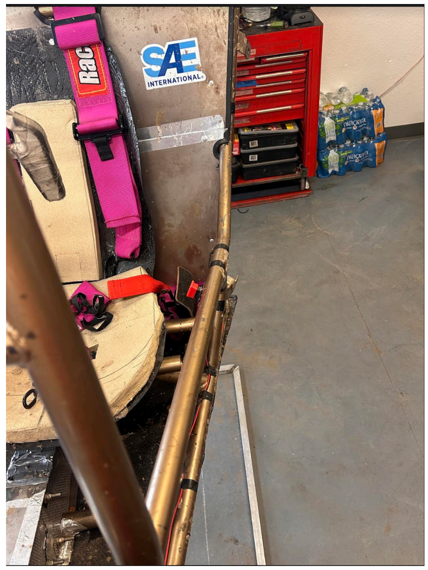



**Figure (25): SIM Angled Inward**

The main difference between angling the SIMs is the amount of room that the driver will have. The wider the SIMs are the more comfortable the driver will be, which is an important factor to think about considering the driver will be driving an endurance race for four hours. Additionally, to pass tech inspections the driver's arms need to have three inches of clearance from the SIMs.

## *4.3 Selection Criteria*

The selections made by the team were based on ergonomics and spacing. Making the components such as suspension, pedals and driver positioning as optimal as possible was the main deciding factor. Most of the decision-making process is defined by the rulebook, so creative freedom for design concepts are very limited therefore the selections that were made are defined in the concept selection portion below.

## *4.4 Concept Selection*

### 4.4.1 Front Braced vs Rear Braced Frame

The main deciding factor in choosing the rear-braced frame was the ease of benchmarking. Previous years cars built by NAU are still located in the machine shop and can still be easily analyzed and all of the cars from years past are rear braced.

### 4.4.2 In-Board vs Out-Board Brakes

Originally the team wanted to attempt at doing in-board brakes because this would mean the car would be able to have four identical hubs. However, once the discussion of packaging the front gearbox, brakes, and steering came up it was clear that in-board brakes were going to overcomplicate the front end of the car. In conclusion, the team decided to do out-board brakes with the intent of keeping manufacturing less complicated.

### 4.4.3 Hanging Pedals vs Floor-Mounted Pedals

The frame team decided that hanging pedals would benefit both the driver and the overall design of the frame. It would benefit the driver because it is easier to push the pedals upward since the driver is sitting slightly lower than the pedals. It also allows the driver to be lower in the seat making the overall center of mass lower, making turning easier and less susceptible to tipping.

### 4.4.4 Inward vs Outward Angled SIMs

Inward-angled SIMs pictured in Figure 25 allow for a more narrow overall design but compromise the comfort of the driver. While the SIMs need to be three inches from the driver's arms if they are slightly wider it will allow the cockpit to have a little more room for the driver which will make a big difference in comfort, especially for the endurance race. For these reasons, the frame team will continue forward with outward-angled SIMs similar to Figure 24.

### 4.4.5 Current State CAD

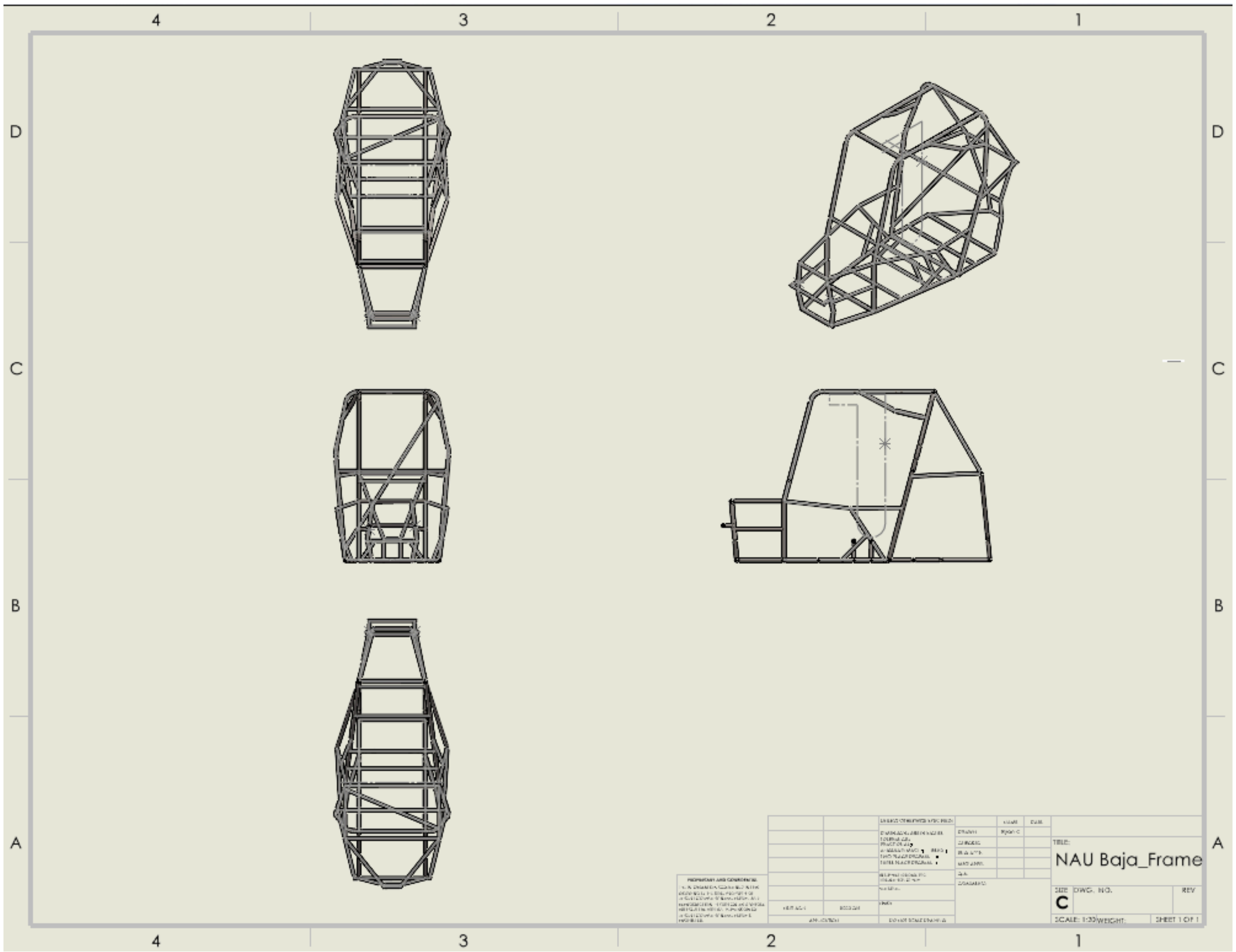



**Figure (25): Current State CAD**

# CONCLUSION

This report covered the research and decision-making conducted by the chassis subteam of the NAU 2025 SAE Baja team. The purpose of the project is to design, fabricate and perform in a competition with other teams that also designed all-terrain vehicles under the same constraints defined by SAE. As the chassis team, the top priority is to make sure that the vehicle is safe and within the specified guidelines and customize the frame to the needs of other subteams. The team has done research and analysis of the design choices that were made and have changed designs accordingly. After conducting these analyses and prototyping the frame the team is preparing to begin fabrication since the entire team has to wait for the frame to be finished to begin mounting the other components of the vehicle.

# 5 REFERENCES

[1] "Lincoln Procedure Handbook of Arc Welding," pdfcoffee.com. Accessed: Sep. 18, 2024. [Online]. Available: https://pdfcoffee.com/lincoln-procedure-handbook-of-arc-welding-pdf-free.html

[2] W. D. Callister and D. G. Rethwisch, Materials Science and Engineering. Hoboken, NJ: Wiley, 2015.

[3] D. Mevawala, S. Mahesh, D. Patel, and D. Kapadia, "Simulation of Roll Cage of an all-terrain vehicle considering inertia, using transient multi-body analysis," IOSR Journal of Mechanical and Civil Engineering, vol. 11, no. 5, pp. 23–26, 2014. doi:10.9790/1684-11532326

[4] N. Baja, 2021 SAE Baja final proposal, https://ceias.nau.edu/capstone/projects/ME/2021/20F01_SAEBaja/OneDrive_1_4-28-2021/Final%20Proposal%20Report%20.pdf (accessed Sep. 18, 2024).

[5] M. Muralidaran and A. Krishnamoorty, "Effect of preheating temperatures on impact properties of ...," http://http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=8&IType=9, https://www.researchgate.net/publication/320189184_Effect_of_preheating_temperatures_on_impact_properties_of_chromoly_alloy_steel_4130_weld_using_gas_metal_arc_welding (accessed Sep. 18, 2024).

[6] Design with Ajay, "Designing a Roll Cage in Solidworks," Youtube. Accessed: Jun. 01, 2024. [Online]. Available: https://youtu.be/vjM-H6xu2ts?si=HBionJ-QVCNiZjxR

[7] Simulation Tech Hub, "Static Structural Analysis in Ansys." [Online]. Available: https://youtu.be/VhO-huASNrE?si=aqqtRn_9xsXpL-Wm

[8] R. Budynas and J. K. Nisbett, Shigley's Mechanical Engineering Design.

[9] E. Oberg, F. Jones, H. Horton, and H. Ryffel, Machinery's Handbook.

[10] Design and Optimization of Mini Baja Chassis, https://d163axztg8am2h.cloudfront.net/static/doc/60/b1/3e31507d86e44fec86f512c78939.pdf (accessed Sep. 13, 2024).

[11] Jacoan a et al., "Design, analysis and optimization of all terrain vehicle chassis ensuring structural rigidity," Materials Today: Proceedings, https://www.sciencedirect.com/science/article/pii/S221478532101083X?casa_token=OOKu_XnhK_kAAAAA%3ACi5WwZOoy-s__X5aaGlxqUhczHmivqmwLgPFa5YmWvjP7l3h0XIudO7if_2f9bLwrBItDSYAzec#s0035 (accessed Sep. 13, 2024).

[12] "Plastic-deformation analysis in tube bending," International Journal of Pressure Vessels and Piping, https://www.sciencedirect.com/science/article/pii/S0308016100000612?casa_token=nqfAucx08

EcAAAAA%3A507Zo7nTUOZ9l7jJ1XmqJ6anE1FqjuSwtohs6hw_DqfR2iGFVKiu5NHfrNXnEj-q0cRcOjBf_N4#FIG7 (accessed Sep. 13, 2024).

[13] “SAE Baja Series Resources,” Baja Sae, https://www.bajasae.net/cdsweb/gen/DocumentResources.aspx (accessed Sep. 13, 2024).

[14] Akhilesh Kumar Singh et al., “Techniques to Improve Weld Penetration in Tig Welding (a review),” Materials Today: Proceedings, https://www.sciencedirect.com/science/article/pii/S2214785317301451 (accessed Sep. 13, 2024).

[15] T. Stolarski, Y. Nakasone, and S. Yoshimoto, Engineering Analysis with ANSYS Software, Second. Elsevier Ltd, 2018.

[16] J. Reimpell, H. Stoll, and J. Betzler, 6 - Chassis and vehicle overall, Second. Elsevier Ltd.

[17] A500/A500M Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes, 2023. doi: 10.1520/A0500_A0500M-23.

[18] J. Shrehari and R. Srinivasan, “ANALYSIS OF ROLL CAGE AND VARIOUS DESIGN PARAMETERS OF AN ALL TERRAIN VEHICLE (BAJA),” ESAT Publ. House, vol. 6, pp. 65–69, 2017, doi: 10.15623/ijret.2017.0602010.

[19] S. Jacob, V. Thiruvarasan, S. Surrendhar, and R. Senthamizh, “Design, analysis and optimization of all terrain vehicle chassis ensuring structural rigidity,” in Materials today, Elsevier Ltd, 2021, pp. 3786–3790. doi: 10.1016/j.matpr.2021.02.023.

[20] S. P. Varandekar and S. A. A. Razzak, “Static and Modal Analysis of All Terrain Vehicle Roll-Cage,” Int. J. Eng. Res., vol. 8, no. 02.

[21] A. Fallahi, Introduction to Simulations (FEA), (Sep. 21, 2021). Accessed: Sep. 15, 2021. [YouTube]. Available: https://youtu.be/CQ9Dff4TOfs?si=WuHKTIcpfvXpW6lN

[22] B. Garner, Bentley Garner Shares Tips for Successfully Welding Chromoly Tube, (May 23, 2017). Accessed: Sep. 14, 2024. [YouTube]. Available: https://youtu.be/K4FYkW1Z3QA?si=KbIXkBj3VQyHTwV9

# 6 APPENDICES

## *6.1 Appendix A*

| |
|---|
| **B.3.2.17 Roll Cage Spec sheet filled out** |
| **B.3.2.16 Primary members steel OD, ID requirements** |
| **B.3.2.16 Alternate Material requirements** |
| **B.3.2.3 Secondary members OD, ID requirements** |
| **B.3.2.15 Welding samples requirements** |
| **B.3.2.1 Straight (40in) and bent members (33in unsupported, <30 deg length** |
| **B.3.2.5 Lateral cross member and CLC <=8in requirements** |
| **B.3.2.6 RRH Continuous vertical members & +/- 20 degree verticality** |
| **B.3.2.7 LDB max 5in from top & bottom of roll cage** |
| **B.3.2.12 FBM max 45 deg. from vertical, FBMup & FBM low joints** |
| **B.3.2.9 LFS must extend from RRH to past driver's heels** |
| **B.3.2.12.1 Gussets required if RHO and FBMup are not continuous** |
| **B.4.2.4.3 Safety harness tubes are in RRH plane from one side to the other** |
| **B.3.2.13.2 Rear bracing structural triangle connecting points A & B (within 2in)** |
| **B.3.2.8 RHO & RRH dimension and placement guidelines** |
| **B.3.2.10 SIMs run 8in-14in above lowest point of the seat** |
| **B.3.2.11 UST connect to LFS members securely below the seat** |
| **B.3.3.1 Roll cage clearance for the largest driver (6in helmet) (3in torso & limbs)** |
| **B.4.2 Min. 5 point harness with 3in webbing with single metal buckle** |
| **B.4.2.4.2 Shoulder webbing laterally placed 6in-9in** |
| **B.12.2 Lap and anti-sub mounting tabs (double shear) >=0.09in thick & >=1.3125in of weld length** |
| **B.4.5 Must have a conventional seat (65-90 degree back angle) with back & bottom plane** |
| **B.4.5.3.2 Seat has 4 mounting points on the bottom and 2 on the back plane** |

| |
|---|
| **B.12.2 Seat tabs >=0.125in thick, fastener of 0.25in dia. spacers <=0.5in thick** |
| **B.4.2.6.2 Anti-Sub belt angle 0-20 deg aft of the chest line** |
| **B.4.2.4.1 Mount shoulder belts at or below driver's shoulders =<4in** |
| **B.10.3.3.1 Cockpit kill switch is within easy reach of a restrained driver** |

**Table(1): Engineering Requirements**