# Bear Cat Solar Cat (BCSC) Chassis Team

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by

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# Abstract

Our senior design project focuses on the development of a lightweight, aerodynamic, and structurally sound chassis for a solar-powered vehicle competing in the American Solar Challenge. The objective is to design a chassis that optimizes strength-to-weight ratio while ensuring driver safety, manufacturability, and integration with the vehicle's aeroshell, solar panels, and electrical systems.

Utilizing SolidWorks CAD modeling and finite element analysis (FEA), we evaluated various materials and structural configurations to achieve an optimal balance between durability and weight. The chassis must comply with American Solar Challenge regulations, including crashworthiness and roll cage requirements, while also accommodating the vehicle's solar array, battery pack, aeroshell, and other subsystems. This chassis is to be fabricated and handed off to the 2025-26 BCSC Mechanical Team for the design and addition of further mechanical systems such as brakes, steering, and suspension.

# Problem Statement

As the 2024-25 Solar Club Mechanical team we were tasked with the continuation of design, analysis, and fabrication of the Bearcat Solar Club chassis and sub-components started by a previous senior design group. This includes a full redesign and build for the chassis as well as the calculations necessary to get next year's mechanical team going on new aspects such as the breaking and suspension system. Previously, the chassis design was overengineered and too complicated to tie into the other aspects of the solar car. The BCSC team still requires additional design work, modifications to existing design, analysis/calculations of designs, as well as fabrication. Utilizing SolidWorks' CAD and FEA capabilities, we will complete the design and analysis ensuring a robust, lightweight, structurally sound chassis which will form the foundation of the solar car the club plans to race in summer of 2026.

# Research

## Background of the Problem

As a whole, the goal for the BCSC is to design and fabricate a car solar car fit for competition in the American Solar Challenge (ASC) and Formula Sun Grand Prix (FSGP) events. The ASC event is a nationwide cross-country time/distance rally event where teams compete on a 2,000-mile course (6). On the other hand, FSGP is a closed course F1 style race that tests the limits of the teams' solar cars handling, braking, and acceleration (6). With the completion of all the mechanical aspects needed in the solar car, they will be able to participate in both events in mid-2026.

The specific tasks we have been assigned as the 2024-25 Mechanical Team is to redesign the chassis for the electrical and aerospace components to mount to. This was previously designed by another senior design group, but this design was thrown out by the club due to it being over-engineered and incapable of fitting other systems. We also chose this as our project because we are interested in automotive design and development, having to design a car essentially from scratch is an added incredible experience.

We are doing this research to not only help finish the solar car for the race, but to also learn more about the automotive engineering design stages. Being able to start so early on in this challenge has allowed us to grasp many of the challenges we could face after graduation in this field of work.

## Applicable Standards

- 7.1.A Single Occupant (ASC 2024 Release C (7))
- 9.1 Solar Car Dimensions (ASC 2024 Release C (7))
- 9.2 Driving Configuration (ASC 2024 Release C (7))
- 9.3 Ground Clearance (ASC 2024 Release C (7))
- 9.5.A Eye Height (ASC 2024 Release C (7))
- 10.3.A Occupant Cell (ASC 2024 Release C (7))
- 10.3.B Occupant Seats (ASC 2024 Release C (7))

- 10.3.C Occupant Space (ASC 2024 Release C (7))
- 10.4 Fasteners (ASC 2024 Release C (7))
- 10.5 Brakes (ASC 2024 Release C (7))
- 10.3.A.15 Occupant Cell (Electrek FSGP 2023 (1))

## State of the Art

Current state or the art includes many other colleges participating in the ASC, most notable of which is the Kansas University Solar Car which we have taken a great deal inspiration from (5). Kanas University has stood out from other colleges because of the transparency they provided in each of their process steps. Another great resource we were able to get our hands on is the Appalachian State Solar Car (1). Each mechanical specification is described in detail with photos, which helped tremendously when we have questions in our design stage.

Furthermore there are also the previously successful solar car collegiate projects that have won either the ASC or the FSGP. The winners of the 2024 ASC were the University of Michigan, with the top 10 teams, both finishers and non-finishers data posted below (2).

| Team | Base Route Completed | Official Miles | Official Time | Checkpoint | Base Miles | Loop Miles | Penalty Miles | Avg. MPH |
|---|---|---|---|---|---|---|---|---|
| #2 - Michigan | Yes | 2095.5 | 56:36:17 | ✅ ✅ ✅ ✅ ✅ | 1558.3 | 561.2 | 24 | 37.51 mph |
| #92 - ETS | Yes | 2004.5 | 59:32:40 | ✅ ✅ ✅ ✅ ✅ | 1562.3 | 451.2 | 9 | 33.82 mph |
| #17 - Illinois State | Yes | 1504.3 | 60:23:08 | ✅ ❌ ✅ ✅ ✅ | 1554.3 | 0.0 | 50 | 25.87 mph |
| #22 - Illinois | No | 1565.8 | 60:36:23 | ✅ ✅ ✅ ✅ ✅ | 1486.6 | 96.2 | 17 | 26.28 mph |
| #5 - Florida | No | 1465.8 | 60:27:42 | ✅ ❌ ❌ ✅ ✅ | 1491.8 | 0.0 | 26 | 24.71 mph |
| #1 - Purdue | No | 1310.6 | 56:36:36 | ❌ ❌ ❌ ✅ ✅ | 1285.8 | 32.8 | 8 | 23.29 mph |
| #12 - Texas A&M | No | 565.7 | 46:33:37 | ✅ ❌ ❌ ❌ ❌ | 592.7 | 0.0 | 27 | 12.79 mph |
| #786 - Western Michigan | No | 146.8 | 6:37:00 | ❌ ❌ ❌ ❌ ❌ | 150.8 | 0.0 | 4 | 22.79 mph |
| #26 - British Columbia | No | 142.1 | 6:38:00 | ❌ ❌ ❌ ❌ ❌ | 142.1 | 0.0 | 0 | 21.42 mph |

**Figure 1 (2): 2024 ASC Results**

With this information in mind, it gives us goals on how to win these races and standards to see how we will match up with other colleges. To clearly win we would need to finish in under 56 hours and stop at each of the 5 checkpoints along the way (2).

This brings us to our first state of the art being University of Michigan's Solar Car and their team. They have shown that overwhelming determination and hard work outweigh any adversity faced on the race day. When their solar car happened to breakdown, they had another teammate fly out that same night with spare parts in a suitcase and fix the issue at 4 am (7). This student organization just raced its' 17th car since its founding in 1989. They have won the ASC 10 times since then (7). What makes this car so great is the chassis design and safety in the roll cage. They had an incident in the FGSP where the driver tipped and rolled around a bend, flipping the car, but the driver remained unharmed after the incident due to how they designed the car (7). They have a very sleek and slender solar car design, with a small base and cage pictured below with the team.

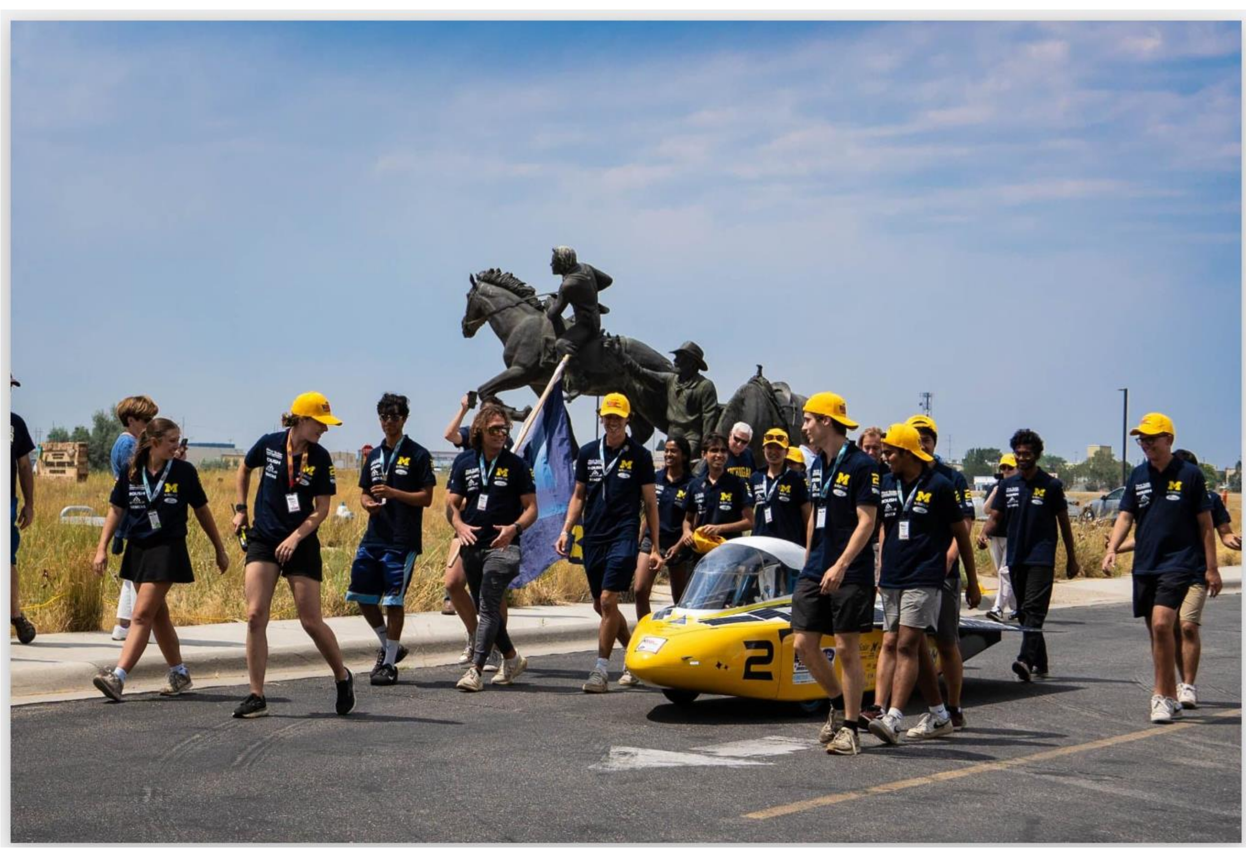


**Figure 2 (7): University of Michigan's Solar Car**

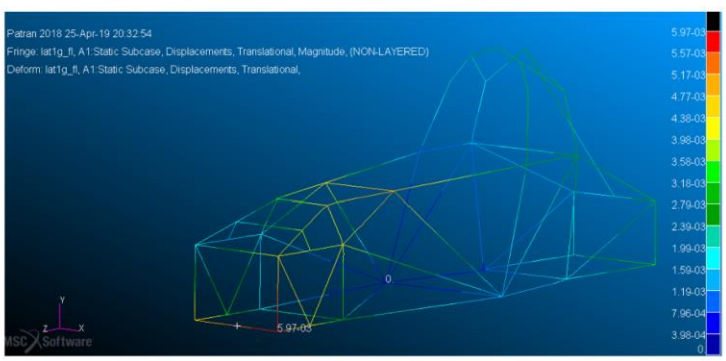
Pros:

- Roll cage safety
- Slender for speed
- Durability in rest of the chassis to withstand flips
- Smaller design, lightweight

Cons:

- Slender design
- Easy to flip over
- Low to ground for less visibility
- Only 1 wheel in front for less turning radius / stability

Another great resource and outstanding solar car we have taken inspiration from in the Kansas University Solar Car from 2021. This applies particularly well to our current project because in each of their documentation steps for mechanical design, they focused on a lot of the chassis, pictured below in FEA analysis and in a rendering (3).




Early FEA of Chassis

**Figure 3 (3): University of Kansas's FEA Analysis**

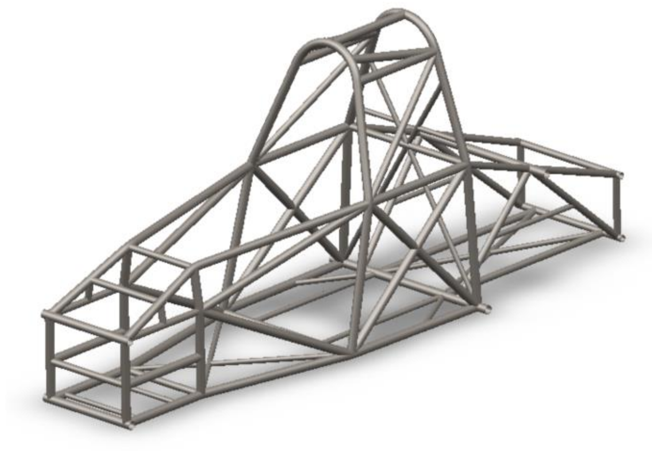


**Figure 4 (3): University of Kansas's Chassis Model**

This tremendously helps us picture what a fundamentally sound chassis design looks like, and we were able to pull much inspiration from this. They also mentioned other key design aspects such as material. They used 4130 Chromoly Steel with a density of 0.284 lb/in^3, ultimate tensile strength of 97200 psi, yield strength of 63100 psi, and a Poisson's ratio of 0.29 (3). We chose this as a part of our state of the art because along with all of the documentation they provided, the design is very similar to our last year's chassis and the FEA analysis they provided can help us determine what we should consider keeping or changing when making our own chassis.

Pros:

- Easy to analyze in FEA
- Easier to manufacture
- Higher tensile and yield strength
- Many members to increase safety
- Many mounting points for electrical and aerospace teams

Cons:

- Material sensitive to cracking

- Less ductile material
- Material difficult to weld
- Too many members (overengineered)

Another previously mentioned collegiate project is the Appalachian State Solar Car from 2015. With incredible feats such as driving 218 laps at the 2017 FSGP in Austin, Texas placing $2^{nd}$, driving 414 laps at the 2016 FSGP in Pittsburg International Complex placing $3^{rd}$, and placing $6^{th}$ in the American Solar Car Challenge (4). Their car and specifications are pictured below on the top of page 9.

We took this as one of our state-of-the-art projects because of their accomplishments and the material that they used to construct the chassis, which is 1" OD 6061-T6 aluminum. This is a great lightweight material that is easy to obtain and use for fabrication.

## SPECS

**Solar Array:** 391 cells covering 6m2, 22.5% efficient SunPower C60 monocrystalline, 1200 W

**Batteries:** 210 Boston Power Swing 5300 Li ion batteries, 42 lb, 4.1 kWh capacity

**Motor:** Single rear mounted 5 kW peak Mitsuba, M2096-III 3 phase AC synchronous in hub motor

**Body Material:** PrePreg Fiberglass composite sandwich with ¼"thick Nomex honeycomb core

**Frame:** 1"OD 6061-T6 thin walled aluminum tubular space frame

**Suspension:** 3 wheel vehicle, double wishbone control arm (front), single sided control arm (rear)

**Tires:** 18.5" diameter. 100 psi Bridgestone Ecopia slick tires

**Brakes:** Regenerative brake (rear), hydraulic activated disk brakes (front), parking brake

**Figure 5 & 6 (4): Appalachian State Solar Car and Specs**

Pros:

- Cheap material to obtain
- Easier to weld material
- Corrosion resistant material

- Versatile design
- Lightweight

Cons:

- Lower material tensile and yield strength
- Material prone to cosmetic issues
- Material strength reduction at high temperatures
- Thin aluminum can break or bend
- Safety concerns

## End User

The end user for the chassis fabrication will be the Bearcat Solar Club team themselves, so that they can race by 2026 with a legal and formidable car. In the solution we are going to provide, we will have a mechanically solid chassis fabricated that values everyone's opinion and satisfies all necessary requirements from both the club and ASC regulations. In the past, other chassis designs didn't work out due to lack of communication, over-engineering, and failure to prepare.

We are going to combat the previous mistakes by consistently communicating with the club president and other teams within the club to start off on the right foot. If we are able to meet consistently with other trades such as the Aerospace team, Electrical team, and the financial team, we will be able to receive extra input that can help out those teams later down the road.

With the over-engineered previous design, there were far too many members and cross-members for each of the other teams to include their necessities. In this lack of space, the design was deemed unusable by the engineering lead and the club president.

There was a failure to prepare in past years by not doing the correct initial research. The past groups did not find the correct initial inspiration from the right sources, which are successful other collegiate solar car teams, leading the design to not match expectations. There was also a misconception that more is better safety wise which isn't exactly the case.

# QFD

## Customer Features

Based on our talks with the solar car team, our advisor, and our personal research we were able to surmise the following list of customer features:

- Adherence to competition guidelines
- Spacing
- Weight
- Chassis Stability
- Manufacturability
- Safety/Structural Integrity
- Cost
- Weight Distribution
- Comfort/Space for Driver
- Craftsmanship

## Survey Methodology and Results

The data below was collected via a survey sent out to the UC Solar Car Club. Although overall sample size is low, we were able to ensure that those who have the most stake in this project including the club president, and all team leads gave their responses to the survey. Our group believes that this precise pool of responders will be me more than sufficient in providing us with the proper guidance of what customer features are essential for our final solar car chassis design.

| | | Importance of the Feature | | Satisfaction with the feature in last year's chassis design | |
|---|---|---|---|---|---|
| **Customer Feature** | **Total Surveyed** | **Average Rating (1-10)** | **Standard Deviation** | **Average Rating (1-10)** | **Standard Deviation** |
| Adherence to competition Guidelines | 12 | 9.83 | .37 | 7.42 | 1.32 |
| Spacing | 12 | 7.83 | 1.67 | 4.92 | 2.18 |
| Weight | 12 | 7.58 | 1.11 | 6.58 | 1.61 |
| Chassis Stability | 12 | 8 | 1.58 | 6.5 | 1.66 |
| Manufacturability | 12 | 8.25 | 1.96 | 4.75 | 1.69 |
| Safety/Structural Integrity | 12 | 8.58 | .95 | 6.92 | 1.32 |
| Cost | 12 | 7.42 | 2.63 | 7.17 | 1.14 |
| Weight Distribution | 12 | 7.75 | 1.3 | 4.83 | 1.86 |
| Comfort/Space for Driver | 12 | 7.25 | 2.09 | 5.42 | 1.61 |
| Craftsmanship | 12 | 8.25 | 1.23 | 5.64 | 1.49 |

**Figure 7: Survey Results**

## Engineering Characteristics

| Customer Features | Engineering Characteristic |
|---|---|
| Adherence to competition Guidelines | Ensure all measurements adhere with 2024 ASC guidelines |
| Spacing | Ensure all subassemblies fit comfortably around chassis design |
| Weight | Select a lightweight material, minimize total structural members |
| Chassis Stability | Incorporate proper # of supporting beams to chassis frame at optimal locations |
| Manufacturability | Simplify design compared to last year (Less overall supporting members in design) |
| Safety/Structural Integrity | Ensure all structural members can withstand minimum forces determined by our factor of safety factor of safety |
| Cost | Keep total material usage to a minimum, select cheapest material which can still withstand desired output forces |
| Weight Distribution | Design chassis so weight is distributed evenly throughout frame including location with battery pack |
| Comfort/Space for Driver | Include ample headspace and leg room for driver to be comfortable when racing for extended periods. |

| | |
|---|---|
| Craftsmanship | Final assembly is rigid, all welds are smooth and complete |

**Figure 8: Customer Features and Engineering Characteristics**

# Product Objectives

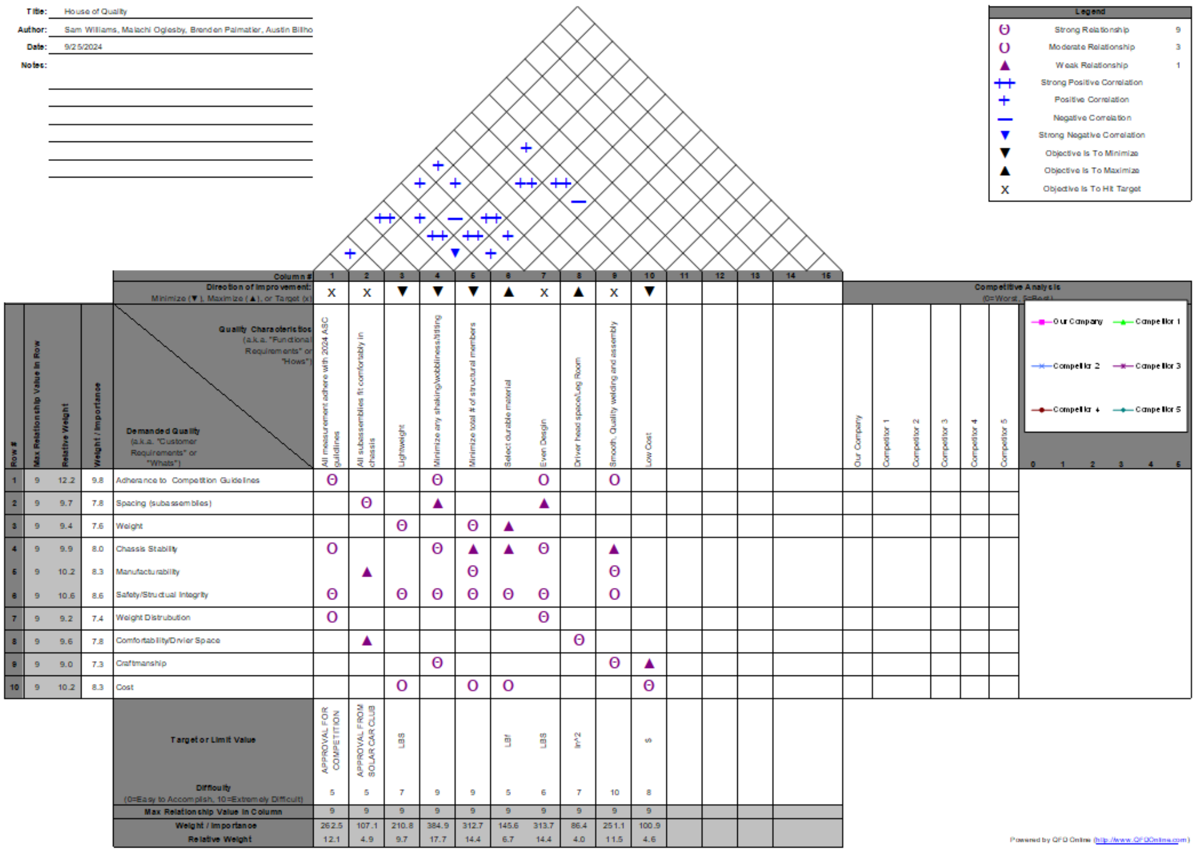



**Figure 9: Product Objective Matrix**

Below is our customer features with its corresponding engineering characteristic ranked in order of importance based on our House of Quality. This list will be the order in which we prioritize various design features for our final concept.

1. Chassis Stability (17.7%)
    - Incorporate proper # of supporting beams to chassis frame at optimal locations

2. Manufacturability (14.4%)
    - Simplify design compared to last year (Less overall supporting members in design)

3. Weight Distribution (14.4%)
    - o Design chassis so weight is distributed evenly throughout frame including location with battery pack

4. Adherence to Competition Guidelines (12.1%)
    - o Ensure all measurements adhere with 2024 ASC guidelines

5. Craftmanship (11.5%)
    - o Final assembly is rigid, all welds are smooth and complete

6. Weight (9.7%)
    - o Select a lightweight material, minimize total structural members

7. Safety/Structural Integrity (6.7%)
    - o Ensure all structural members can withstand minimum forces determined by our factor of safety factor of safety

8. Spacing (4.9%)
    - o Ensure all subassemblies fit comfortably around chassis design

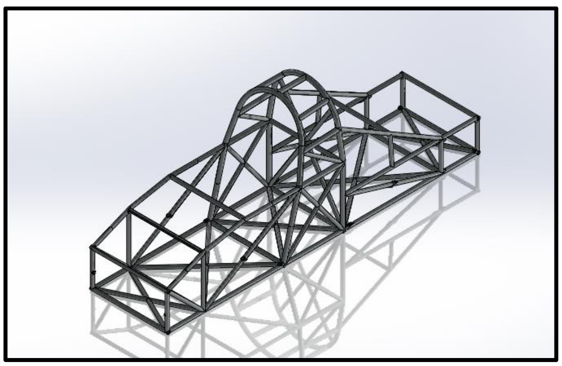
9. Cost (4.6%)
    - o Keep total material usage to a minimum, select cheapest material which can still withstand desired output forces

10. Comfort/Space for Driver (4%)
    - o Include ample headspace and leg room for driver to be comfortable when racing for extended periods.

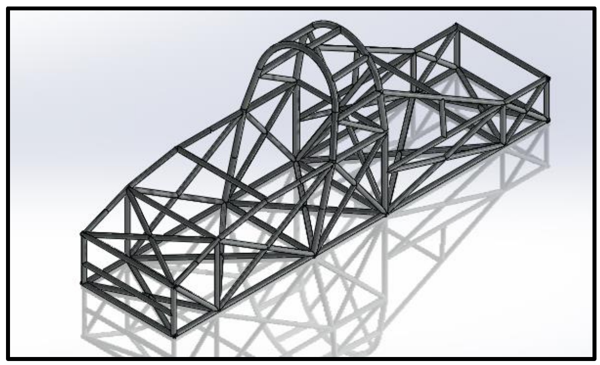
# Concepts

## Concept 1: Overall Simplified Model

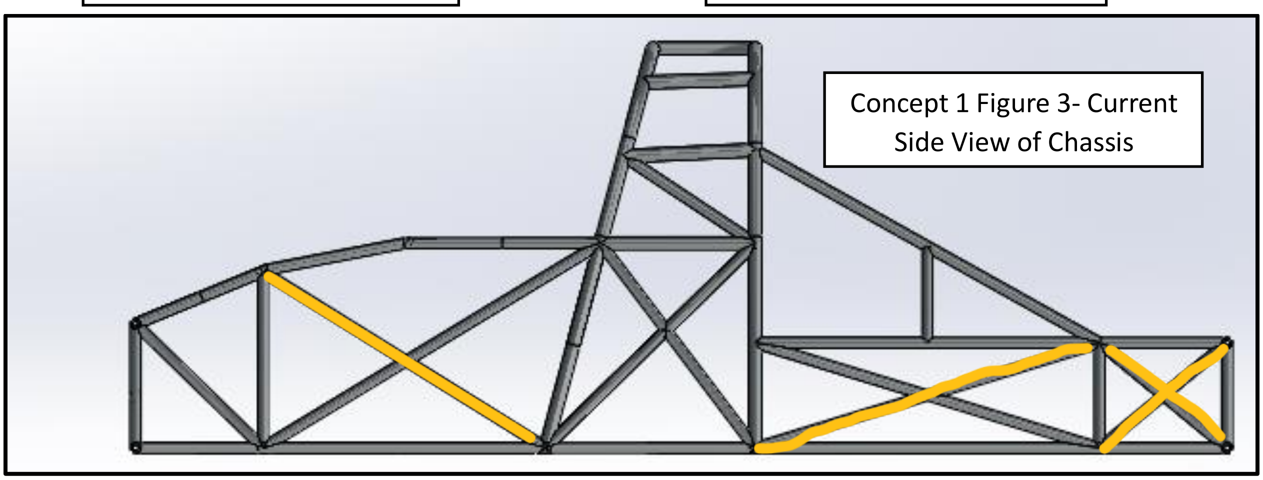
This concept's goal is to completely reduce the number of members that make up the chassis and give a very reliable, sturdy, and light chassis that isn't too complicated. This model removes a lot of the unnecessary cross-sectional areas but maintains the structural integrity of this model and most importantly keeps the structure of the roll cage to protect the driver. Furthermore, this model demonstrates the importance of achieving minimal weight while not sacrificing structural integrity. Highlighted in yellow are the members being removed.



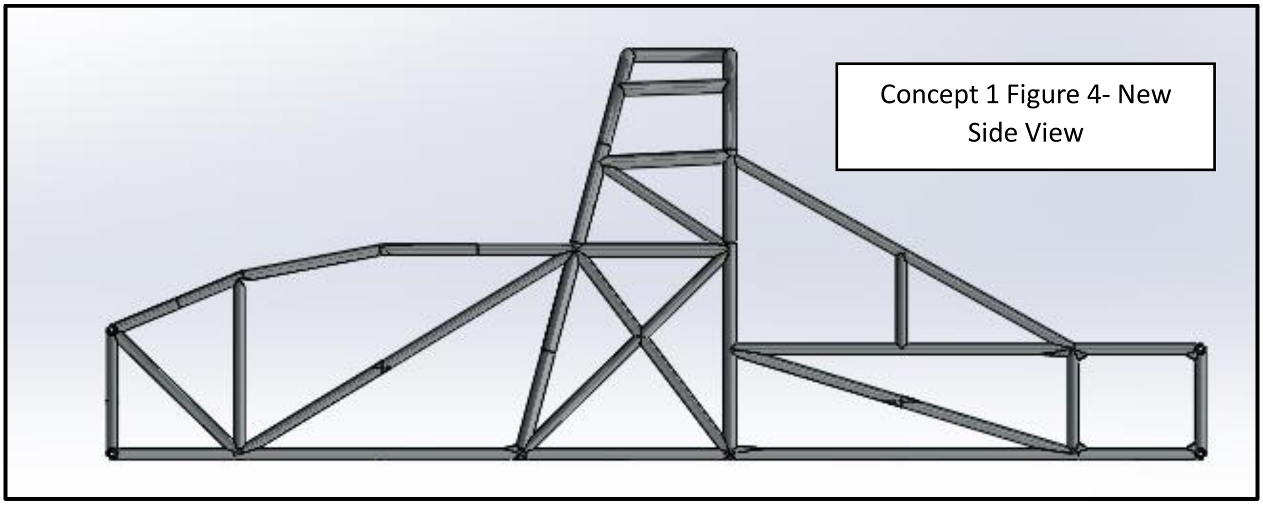
Concept 1 Figure 1- New Isometric View



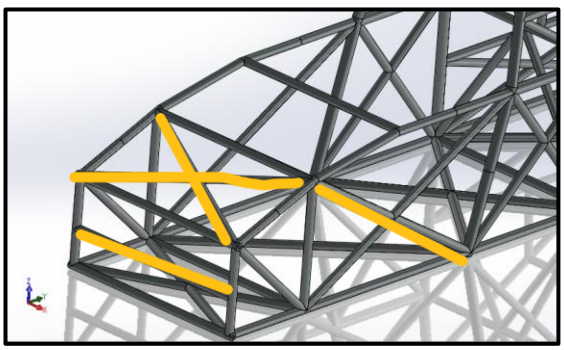
Concept 1 Figure 2- Current Isometric View



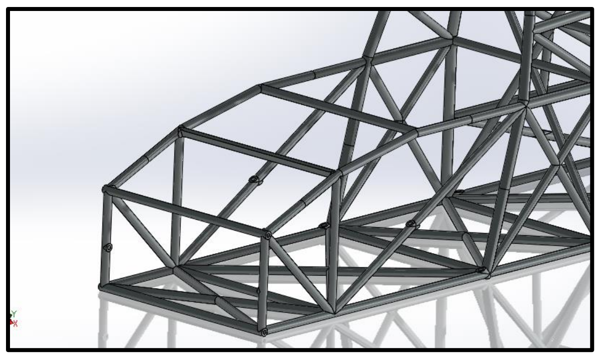
Concept 1 Figure 3- Current Side View of Chassis



Concept 1 Figure 4- New Side View



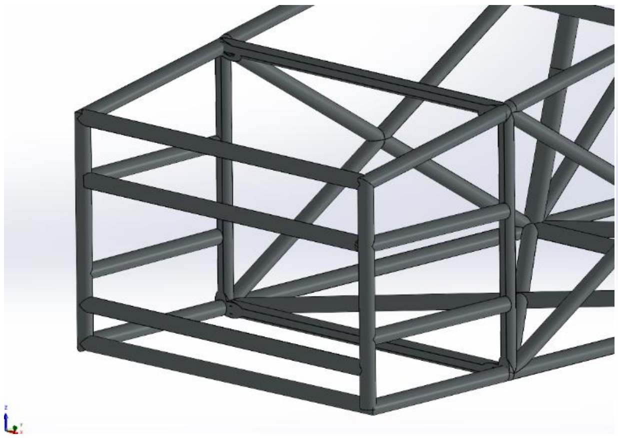
Concept 1 Figure 5- Current Top Angled View



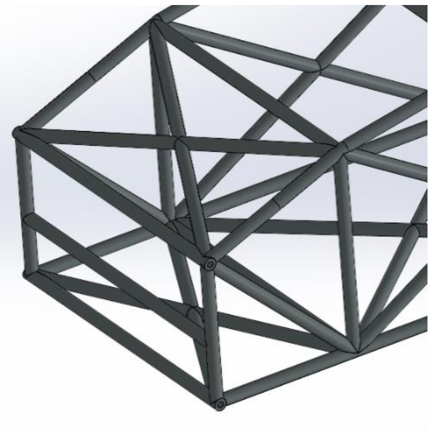
Concept 1 Figure 6- New Top Angled View

## Concept 2: Simplified Front Frame

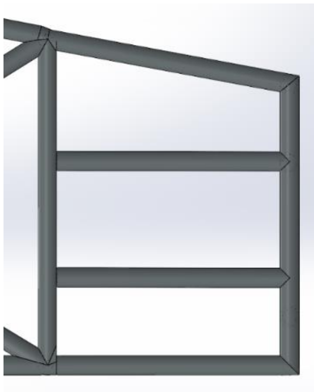
The idea behind the second concept was to simplify the front chassis frame to include provisions for mounting the suspension/wheel hub assembly. After surveying the Bearcat Solar Car Executive Team and Mechanical lead, it was deemed that the current design was too difficult to mount external components to. With this simplified design, it includes horizontal mounting points which will satisfy teams that work directly with sub-components. In addition to mounting provisions, this design has removed cross members that increased the structural rigidity of the car, as to limit the crumple zone. Removing these cross members allows the frame to crumple in a front-end collision, reducing the amount of force directed at the driver of the vehicle, making it safer for the operator.



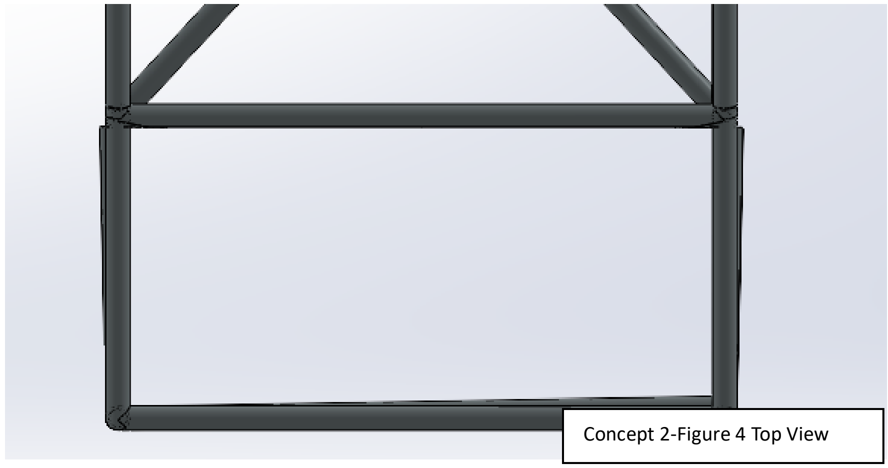
Concept 2-Figure 1 Isometric view of front chassis



Concept 2-Figure 2 Isometric view of current chassis



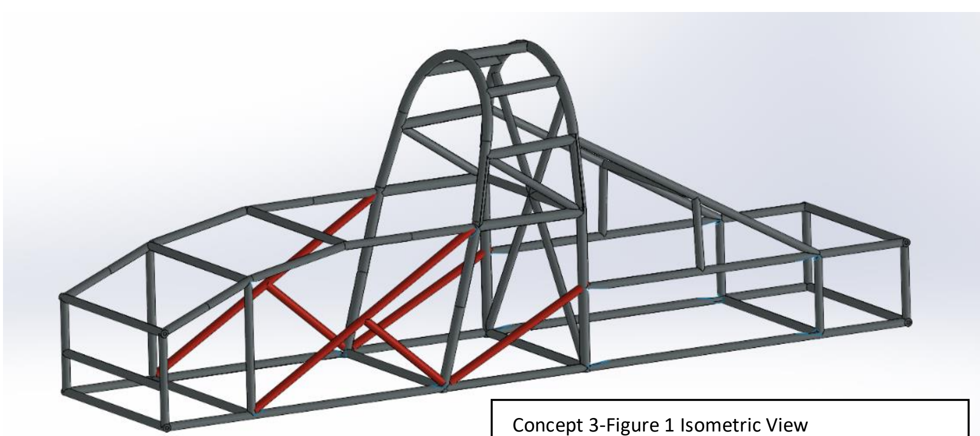
Concept 2-Figure 3 Side View



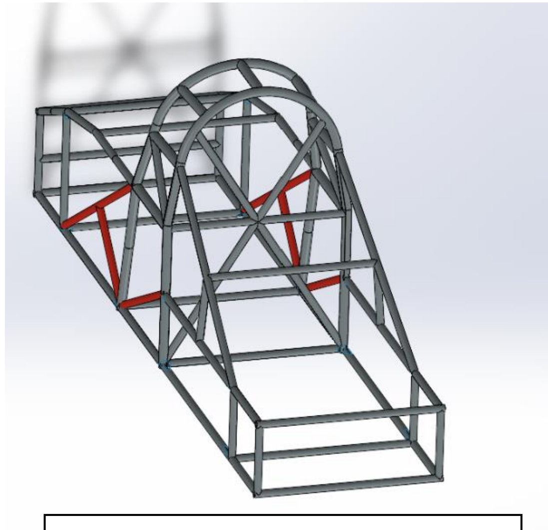
Concept 2-Figure 4 Top View

## Concept 3: Alternative Chassis Simplification Design

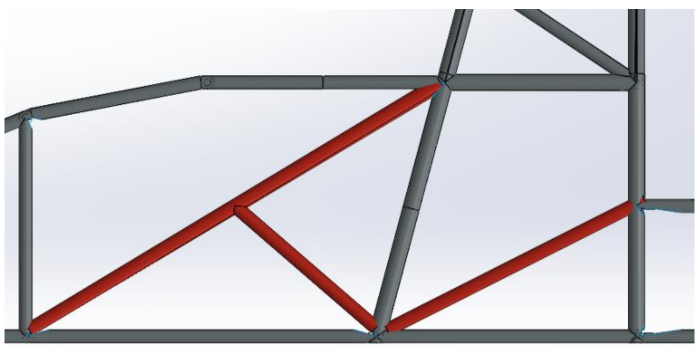
Based on feedback provided by members of the Bearcat Solar Car Club, it was deemed that the previous design would be too complicated to manufacture, as there were places where four structural members would meet, and be welded, creating tight tolerances that would stack, and not correctly line up. In this simplification, any place where an "X" was created in the design was removed. The replacement design includes a "T" support highlighted in red in the figures below. This support protects the driver from side impact as well as increases the frames structural integrity. It is likely that during FEA analysis of this chassis, additional supports will be added.



Concept 3-Figure 1 Isometric View



Concept 3-Figure 2 Rear Facing Isometric View



Concept 3-Figure 3 Side Detail

## Chosen Concept:


**Figure 10: Chassis at Tech Expo**

Seen above is our team at the CEAS Expo with our final design for the chassis. We did leave out some of our cross members due to the fact that the club was unsure of the direction they would take with some of their components down the line as we wanted to make this chassis as easy as possible to work on. Also, if anything unforeseen occurred and they wanted to change directions, they wouldn't be locked into one certain design. This chassis was meant to be a blank slate for the club, so as they progress in next years, they can continue in the best direction.

# Calculations

While we are the Chassis team, we were also asked to help with the production and calculations of some other mechanical aspects, being the suspension, steering, and breaking, pictured below.

## Suspension

Front Suspension FBD (A-Arm):

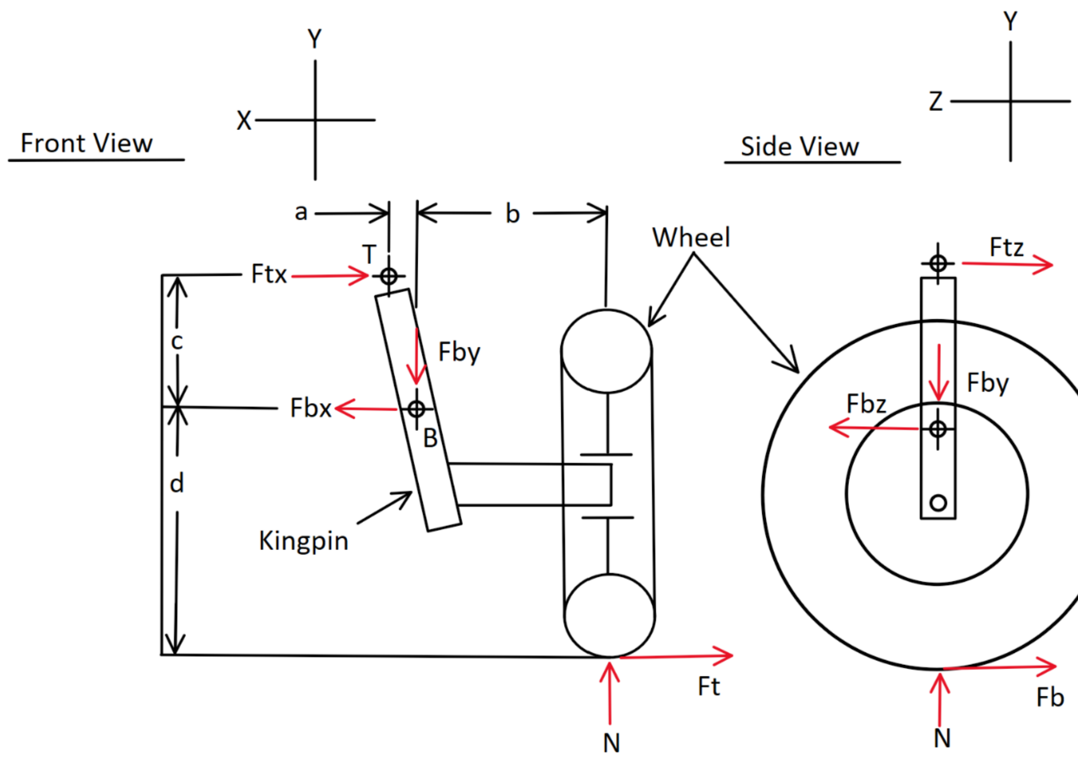



**Figure 11: Front Suspension**

Rear Suspension FBD (MacPherson Strut):

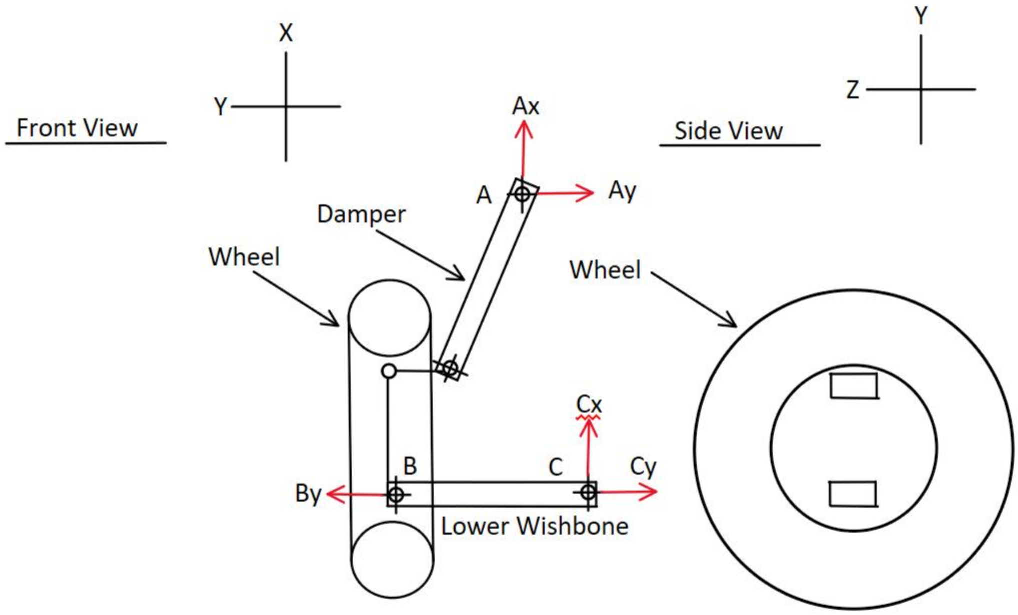



**Figure 12: Rear Suspension**

Assumptions:

- Vehicle is a rigid body, no rotational inertia about wheels
- Steering and tie rods take no loads
- Worst-case/pre-loads not present and Fi = 0
- Distances between members from previous years model

For a static 2G Bump Load

$$N = 2(0.20 \cdot W) = 2(0.20 \cdot 387\ lbs) = 154.8\ lbf$$

For a static 1G Turn on Inner Radius

$$F_t = 0.20 \cdot W = 77.4\ lbf$$

For a 1G Braking Load

$$F_b = 1.25(0.20 \cdot W) = 96.75\ lbf$$

Front View

$$\Sigma F_y = F_{by} = N$$

$$\Sigma M_T = N \cdot b + F_t(c + d) - F_{by} \cdot a - F_{bx} \cdot c = 0$$

$$\Sigma M_B = N \cdot (b - a) + F_t \cdot d - F_{tx} \cdot c = 0$$

Side View

$$\Sigma M_T = F_b \cdot (c + d) - F_{bz} \cdot c = 0$$

$$\Sigma M_B = F_b \cdot d - F_{tz} \cdot c$$

Solving for resultant forces

$$F_{bz} = \frac{1}{c}\left(F_b(c + d)\right) = \left(\frac{1}{3.33\ in}\right)\left(96.75\ lb(20\ in)\right) = 581.08\ lb$$

$$F_{tz} = \frac{1}{c}\left(F_b \cdot d\right) = \left(\frac{1}{3.33\ in}\right)\left(96.75\ lb(16.67\ in)\right) = 484.33\ lb$$

$$F_{by} = N = 154.8\ lb$$

$$F_{bx} = \frac{1}{c}\left(N \cdot b + F_t \cdot (c + d) - F_{by} \cdot a\right)$$

$$= \left(\frac{1}{3.33}\right)\left(154.8\ lb(9in - 5in) + 77.4\ lb(20in)\right)$$

$$= 650.822\ lb$$

Axial Load on Bottom Rod (compressive);

$$F_a = F_{tx} = \left(\frac{1}{c}\right)\left(N(b - a) + F_t \cdot d\right)$$

$$F_a = \left(\frac{1}{3.33}\right)\left(154.81\ lb(4\ in) + (77.41\ lb)(16.33\ in)\right)$$

$$F_a = 565.57\ lb\ in$$

Total Shear Load is the vector sum of Fby and Fx;

$$F_s = \sqrt{(F_{by})^2 + (F_{bz})^2} = \sqrt{(154.8\ lb)^2 + (581.08\ lb)^2}$$

$$F_s = 601.3\ lb$$

Axial Load on Top Rod (compressive);

$$F_a = F_{tx} = 565.57\ lb\ in$$

& the Shear Load on the Top Rod;

$$F_s = F_{tz} = \ 484.33 \ lb \ in$$

The Stress on the Stud;

$$\sigma = \frac{F_a}{A_t} + \frac{32M}{\pi d_r^2}$$

Where 'M' is the bending moment, 'dr' is the minor diameter, and 'd' is the moment arm of the Ball Joint Rod End

$$M = F_s \cdot d$$

$$= (601.3 \ lb)\left(\frac{2.59 \ in}{12 \ in}\right) = 129.78 \ lb$$

Reference: MACHINE DESIGN, by Robert L. Norton, Second Ed., Prentice Hall, 2000

M16x2
Major Dia;
0.62992".
(Nominal OD;
Threads per inch
12.70 th./1"

**Table 14-1 Principal Dimensions of Unified National Standard Screw Threads**
Data Calculated from Equations 14.1—See Reference 3 for More Information

| | | Coarse Threads—UNC | | | Fine Threads—UNF | | |
|---|---|---|---|---|---|---|---|
| Size | Major Diameter $d$ (in) | Threads per inch | Minor Diameter $d_r$ (in) | Tensile Stress Area $A_t$ (in$^2$) | Threads per inch | Minor Diameter $d_r$ (in) | Tensile Stress Area $A_t$ (in$^2$) |
| 10 | 0.1900 | 24 | 0.1359 | 0.0175 | 32 | 0.1494 | 0.0200 |
| 12 | 0.2160 | 24 | 0.1619 | 0.0242 | 28 | 0.1696 | 0.0258 |
| 1/4 | 0.2500 | 20 | 0.1850 | 0.0318 | 28 | 0.2036 | 0.0364 |
| 5/16 | 0.3125 | 18 | 0.2403 | 0.0524 | 24 | 0.2584 | 0.0581 |
| 3/8 | 0.3750 | 16 | 0.2938 | 0.0775 | 24 | 0.3209 | 0.0878 |
| 7/16 | 0.4375 | 14 | 0.3447 | 0.1063 | 20 | 0.3725 | 0.1187 |
| 1/2 | 0.5000 | 13 | 0.4001 | 0.1419 | 20 | 0.4350 | 0.1600 |
| 9/16 | 0.5625 | 12 | 0.4542 | 0.1819 | 18 | 0.4903 | 0.2030 |
| 5/8 | 0.6250 | 11 | 0.5069 | 0.2260 | 18 | 0.5528 | 0.2560 |
| 3/4 | 0.7500 | 10 | 0.6201 | 0.3345 | 16 | 0.6688 | 0.3730 |
| 7/8 | 0.8750 | 9 | 0.7307 | 0.4617 | 14 | 0.7822 | 0.5095 |
| 1 | 1.0000 | 8 | 0.8376 | 0.6057 | 12 | 0.8917 | 0.6630 |

**Figure 13: MACHINE DESIGN**

For the Tensile Stress Area;

$$A_{t5/8} = 0.2260 \ in^2$$

$$\sigma = \frac{565.57 \ lb}{0.2260 \ in^2} + \frac{32 \cdot 129.78 \ lb}{\pi \cdot 0.5069 \ in^2} = 5110.39 \ lb$$

For the Factor of Safety of the Rod Ends at the Estimated Load;

$$\eta = \frac{S_y}{\sigma}$$

$$= \left( \frac{8400\, lb}{5110.39\, lb} \right) = 1.6437$$

Along with the weight shift towards the front of the vehicle during braking, in our future calculations we will need to consider inner wheel cornering force and side weight transfer. The calculated FOS 1.6 exceeds the target value of 1.5.

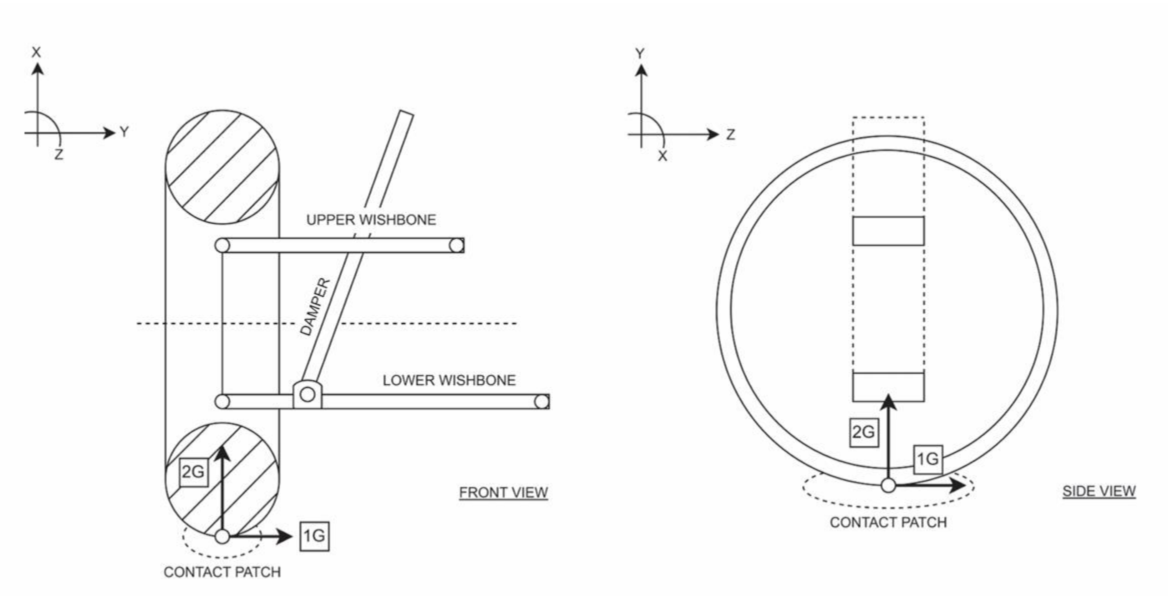



**Figure 14: Front and Side View Suspension**

# Braking

Braking force for front-only brake system

$$F_b = \frac{W}{2} = \frac{407\, lb}{2} = 203.5\, lb_f \backslash$$

Stopping speed on wetted pavement [Required: 4.72 m/s$^2$]:

$$F_f = \mu W = 0.5\left(407\, lb \times \frac{4.448\, N}{1\, lb}\right) = 909.668\, N$$

$$m = \frac{W}{g} = \frac{407\, lb \times \frac{4.448\, N}{1\, lb}}{9.81\, m/s^2} = 184.5399\, kg$$

$$F_f = m\alpha,\ \alpha = \frac{F_f}{m} = \frac{909.668\, N}{184.5399\, kg} = 4.9294\, m/s^2$$

# Steering

## Equations:

$$\textbf{Steering Angle } (\delta) = \tan^{-1}\left(\frac{L}{R}\right)$$

Ackerman Minimum Steering Angle (δ) to make 16m U-Turn:

$$\delta_{inner} = \tan^{-1}\left(\frac{1.3m}{6.5m}\right)$$

$$\delta_{inner} = 11.31°$$

$$\delta_{Outer} = \tan^{-1}\left(\frac{1.3m}{8m}\right)$$

$$\delta_{Outer} = 9.23°$$

# Occupant Cell

**F.3.3.2 Roll Cage Impact:** Roll cage impact scenarios shall have a loading patch no more than 150mm diameter. The roll cage can not exceed yield strength (10.3.A.9). The required load cases are:

1. Combined Loading (5g down, 4g backward, 1.5g lateral)
2. Sideways angled loading (5g at 30 degrees downward from horizontal)
3. Sideways angled loading (5g at 60 degrees downward from horizontal)
4. Sideways horizontal loading (5g at the top of the hoop)
5. Rearward horizontal loading (5g at the top of the hoop)

Each load case should be evaluated when applied to the front and rear roll hoop (10 load cases total). An example of the combined roll cage loading case for the front hoop is included in Figure 6.

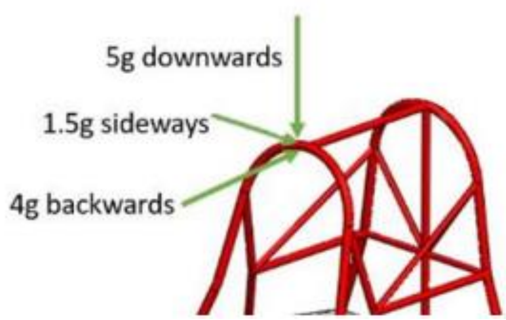



**Figure 15: Load Impact Regulations**

***Assume 4g =** $-\vec{x}$**,** $\mathbf{1.5}g = +\vec{y}$**,** $\mathbf{5}g = -\vec{z}$

**Equations:**

$$F = ma$$

$$\sum F = \sqrt{{F_x}^2 + {F_y}^2 + {F_z}^2}$$

## For Material Type 4130 Steel 1.00" OD 0.12" Wall Thickness

Material Yield Strength: 97,200 psi

Load Case 1: Combined loading (Front Hoop)

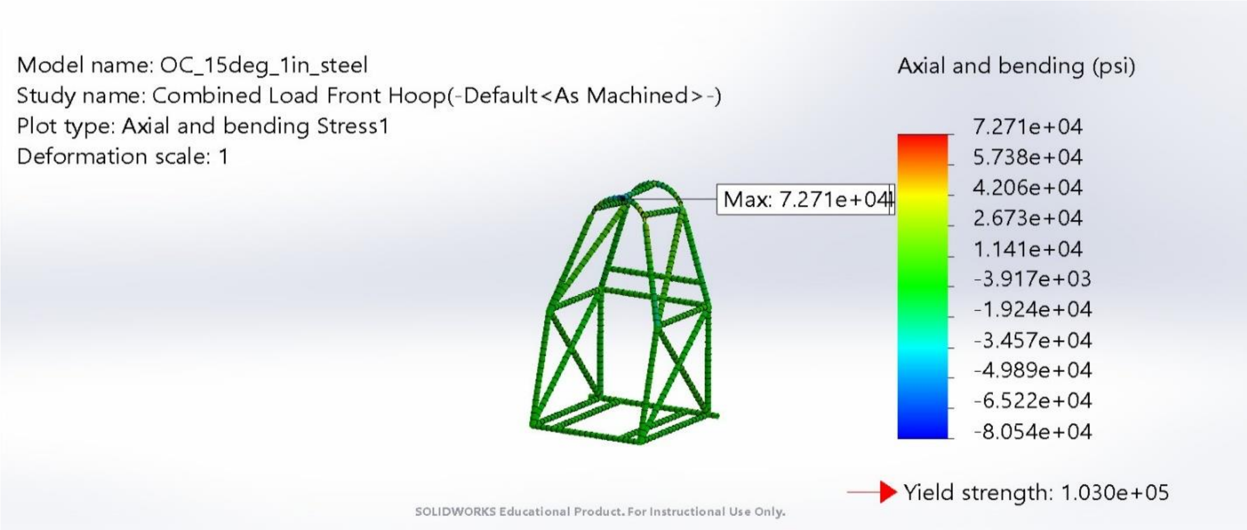



**Figure 16: Max Stress 7.271 X $10^4$ psi**

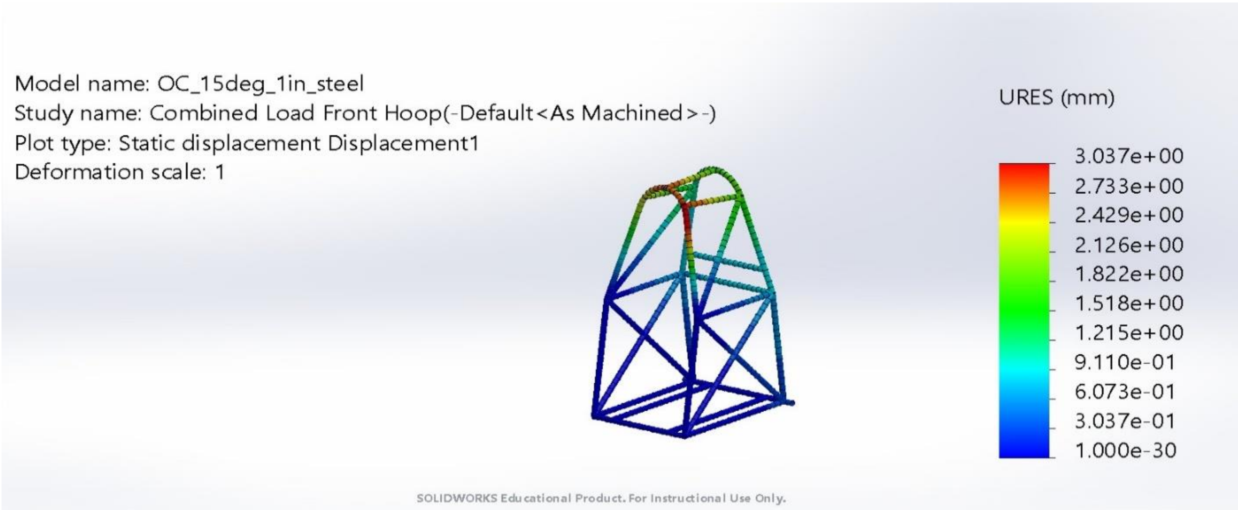



**Figure 17: Max Displacement 3.037 mm**

| Load Case | Stress | Displacement |
|---|---|---|
| 30° | 74,100 psi | 7.803 mm |
| 60° | 63,650 psi | 4.824 mm |
| Combined | 72,710 psi | 3.037 mm |
| Rearward | 49,670 psi | 1.536 mm |
| Sideways | 91,080 psi | 8.966 mm |

Table 1:Stress & Displacement Based on Load Case on Roll Cage (Front Hoop)

(See Appendix for 30°, 60°, Rearward, and Sideways)

Load Case 2: Combined loading (Rear Hoop)

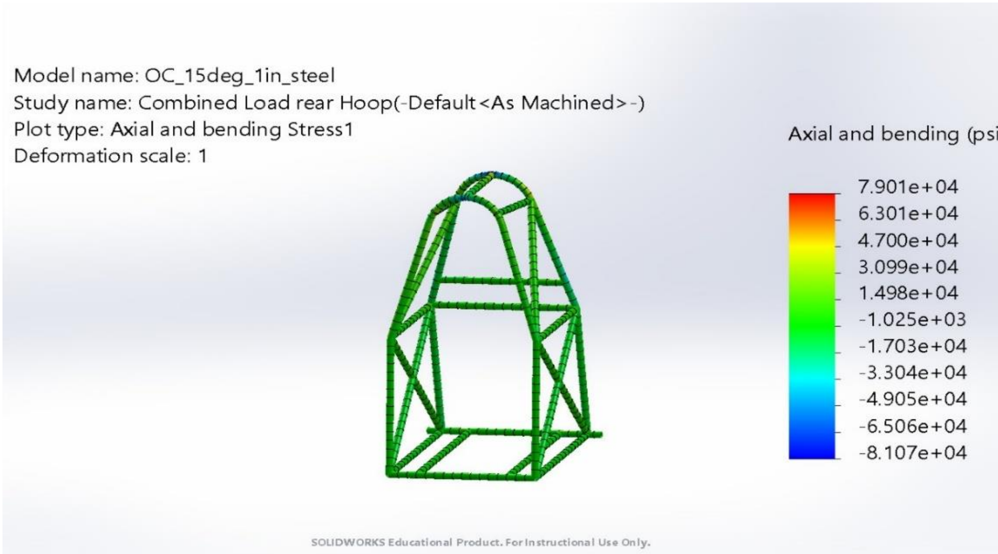



**Figure 18: Max Stress 7.901 X $10^4$ psi**

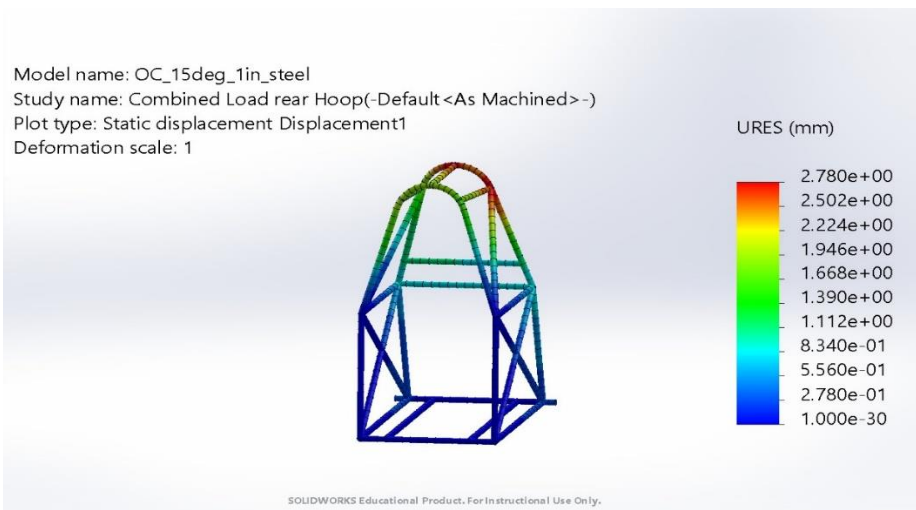



**Figure 19: Max Displacement 2.780 mm**

| Load Case | Stress | Displacement |
|---|---|---|
| 30° | 64,070 psi | 6.307 mm |
| 60° | 54,760 psi | 3.920 mm |
| Combined | 79,010 psi | 2.780 mm |

| | | |
|---|---|---|
| Rearward | 55,500 psi | 1.567 mm |
| Sideways | 73,870 psi | 7.051 mm |

Table 2:Stress & Displacement Based on Load Case on Roll Cage (Rear Hoop)

(See Appendix for 30°, 60°, Rearward, and Sideways)

# Product Fabrication and Assembly

**Figure 20 & 21: Chassis Being Fabricated in Shop**

With the help of UC connections, we were able to outsource the welding of the chassis through Iron Belle Metal Design. We thought this would be the best plan of action for the club considering they wanted to have a frame that would last for years to come. We also wanted to ensure driver safety so given our teams' welding inexperience, we felt outsourcing would be the best course of action.

# Project Management

## Initial Gantt Chart

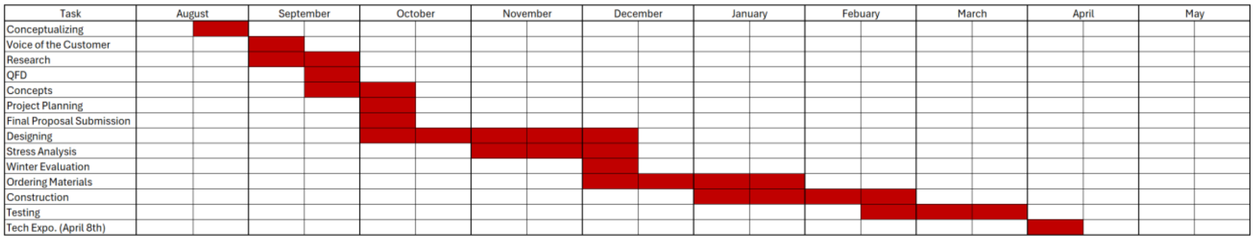



**Figure 22: Initial Gantt Chart**

## Final Gantt Chart

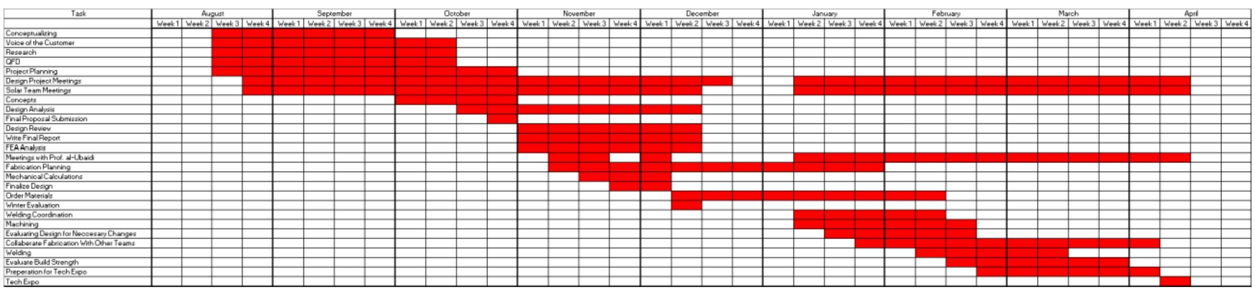



**Figure 23: Final Gantt Chart**

## Initial Budget

At the beginning of the project, we were given a budget of **$2,250** for the material and construction of the chassis. The total initial budget the Bearcat Solar Car Club allocated for all mechanical teams was **$4,650**, with the original breakdown shown below.

| | A | B | C |
|---|---|---|---|
| 1 | **Mechanical Team Budget** | | |
| 2 | **Subteams** | | Items: |
| 3 | Chassis | $2,250 | Rear axle, welding, possible full rebuild |
| 4 | Braking | $200 | Brake fluid, Brake lines, Brake pads, Possible intermediary caliper plate |
| 5 | Suspension | $300 | Rework wheel angle, Possible full rebuild(double a-arm or other well-known design) |
| 6 | Solar Array | $100 | Resturcturing, wire hiding (tubes/pipes) |
| 7 | Steering | $100 | New steering wheel, steering stops |
| 8 | Battery Box | $200 | Outer casing, machining, insulation, fans |
| 9 | Aero | $500 | Reworking molds, Designing rear aerodynamical structure |
| 10 | Other | $1,000 | Storage racks and tool boxes, new tires, tools |
| 11 | | | |
| 12 | Total | $4,650 | |

**Figure 24: Proposed Budget**

## Final Budget

Due to administrative reprioritizing and decisions, including the decision not to submit a car in 2025, the Bearcat Solar Car Club increased our final budget to **$4,200** for materials and fabrication. However, by pursuing alternative vendors to McMaster-Carr, specifically David Hirschberg Steel & Recycling Center, we were able to cut down the cost of materials and shipping to $900. This, alongside our final fabrication cost at Iron Belle Metal Design equaling $2,000, allowed us to finish $1,300 below budget, for a final total cost of **$2,900**.

David Hirschberg
Steel & Recycling Center
Recycle Today for a Better Tomorrow

**Quote**

| Date | Quote # |
|---|---|
| 3/6/2025 | 4307 |

209 Longworth St
PO Box 15815
Cincinnati, OH 45215-0815

(513) 821-0514

Name / Address

UNIVERSITY OF CINCINNATI
PO BOX 210012
CINCINNATI, OH 45221
AUSTIN
513-295-8139

| Rep | Project |
|---|---|
| EJ | |

| Description | Qty | Cost | Total |
|---|---|---|---|
| 1" OD X .120 4130 CHROME MOLY TUBE X 140' | 1 | 875.00 | 875.00 |
| DELIVERY | 1 | 25.00 | 25.00 |
| LEAD TIME 7-10 DAYS | | | |
| PRICING IS BASED ON ALL ITEMS ORDERED. QUANTITY CHANGES MAY RESULT IN PRICE ADJUSTMENTS. | | | |
| | | **Total** | $900.00 |

Quote/Project Proposal

IRON BELLE METAL DESIGN

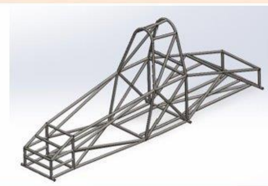
Date ; 3/4/25
Expiration Date 30 days

IRON BELLE METAL DESIGN LLC
4005 Dumont St.
Cincinnati, OH 45226
Phone 513-478-9650
Ironbellemetaldesign@outlook.com

TO UC - Bearcat Solar Car team
Attn : Brenden Palmatier
Austin Billhorn

| Project Name | Shipping Method | Shipping Terms | Project Timeline | Payment Terms | Due Date |
|---|---|---|---|---|---|
| Solar Car Chassis | Delevered | N/A | ASAP | 100% due at completion invoice | ASAP |

| Qty | Description | Line total |
|---|---|---|
| 1 | Car Chassis Fabrication (design per rendering below) Hourly shop rate $100/hour - Est 20 Hours | $2000 |
| | | |
| | Sales Tax | 0 |
| | Total | $2000 |



Quotation prepared by: Jordan Graff

**Figure 25 & 26: Material and Fabrication Quotes**

## Member Responsibilities

Brenden Palmatier: Team Leader/Point of Contact, Lead Engineer

Austin Billhorn: Proposal Creator, Project Manager, Assistant Engineer

Malachi Ogelsby: QFD Creator

Demetrius Smiley: Concept Designer

Sam Williams: Project Management Support

# Summary of Research

In summary, the previous BCSC mechanical team's design was deemed unfit for the needs of the club, so redesigning and fabrication are required. From our research we learned how important choosing the correct material can be, prioritizing safety, and triple checking calculations. The material has one of the greatest impacts on the project due to it being essentially the skeleton of the car, too heavy and it will not be able to move well, too light and safety is at risk. Safety should never be taken lightly as this is a moving vehicle with a designated driver inside who could potentially be injured. Finally, always ensuring the math behind the design can never be overlooked, this goes from FEA analysis to every cut when creating the members. Diving into each of the previous ASC and FSGP winners' solar cars and looking at their old research taught us how to correctly walk through the engineering design and fabrication steps to ensure a great solar car is produced.

Each of our state-of-the-art designs look very different, made up of all different materials and compositions. This goes to show that not one will always be better than another and it is up to the designer to weigh the pros and cons of each to determine what is best for the team. Lightweight, easy to weld, and high tensile/yield strength are just a few of the features we should include in the final design. Among many other things, these are a few of the key features that we need to consider in our design. Lightweight so the car can move swiftly and efficiently. Easy to weld because this will be the main fabrication aspect of this project and many of us have little experience welding. High tensile/yield strengths so the car is fundamentally sound and can manage the added weights of the driver and electrical components.

# 2025 MET Chassis Team Project Handoff

The following below will serve as the official project handoff for the Bearcat Solar Car chassis designed by this team in the Fall 24 and Spring 25 semester. This outlines key details, specifications, and recommendations to ensure a smooth transition to continue development and implementation. These following points provide critical information about the chassis design, materials, testing and next steps, as well as key points of contact for any future questioning.

**Project details:**

- **Chassis design specifications**

- Frame constructed using 4130 Chromoly Steel – 1.00” OD, 0.120” Wall
- Overall dimensions: 109” L X 25” W X 43” H
- Weight: Estimated at 154 lb (from material properties)

- **Fabrication Process:**
  - MIG welded using:
    - Hobart Quantum Arc D2 ER80S-D2 0.030” Wire
- **Testing Outcomes:**
  - All FEAs completed on top hoop loading – 10 cases.
    - Found in: *Mechanical Team/2025 MET SENIORS FILES/BCSC Finalized-3-30/Paperwork/SolarCar load cases – Final*
- **Recommendations for Next Steps:**
  - **Design Weldment tabs and locations for mounting mechanical sub assemblies:**
    - Select optimal locations on chassis frame for tab placement, prioritize accessibility, load distribution and note geometric constraints
    - Perform FEA stress analysis on tab designs to ensure they withstand operating constraints
    - Confirm subassembly mounting positions on the floor pan and chassis to ensure no interference with chassis crossbars (refer to chassis crossbar layout in CAD model).
  - **Model manufacturing changes in CAD model:**
    - Note changes on chassis frame: Hoop geometry, front bulkhead chassis stabilization bars, front mechanical box
    - Run FEA to confirm no yield under expected loads, updating geometry in CAD file

- **Design Floor pan:**
  - Using CAD Model, design single sheet metal floor (Aluminum or light gage steel) to protect driver from road debris and stabilize chassis weldment
  - Choose to either weld or fasten floor pan to chassis
  - Look into designing and laser manufacturing floor pan with provisions to mount electrical and mechanical sub assemblies – provisions with tapped holes or mounting slots to clean up design and add flexibility.

- **Documentation and Resources**
  - **CAD Files:**
    - *(Solid for FEA) Mechanical Team/2025 MET SENIORS FILES/ BCSC Finalized-3-30/Full_Chassis_.12steel_solidModel.SLDPRT*
    - *(Assembly for Design) Mechanical Team/2025 MET SENIORS FILES/ BCSC Finalized-3-30/Full_Chassis_.12steel_asy*
    - ***Backup files located in:*** *Mechanical Team/2025 MET SENIORS FILES/ BCSC Finalized-3-30/Backup Folder*
    - *(Current FEA Files) Mechanical Team/2025 MET SENIORS FILES/BCSC Finalized-3-30/Model with FEA*
    - *(Manufacturing Prints) Mechanical Team/2025 MET SENIORS FILES/ BCSC Finalized-3-30/CUTLIST/Prints For Jordan*

- **Contact information:**
  - Jordan Graff (Iron Belle Metalworks):
    - IRON BELLE METAL DESIGN LLC

- 4005 Dumont St. Cincinnati, OH 45226
- Phone 513-478-9650
- Ironbellemetaldesign@outlook.com

- Brenden Palmatier
  - Palmatier.brenden@gmail.com
  - (937) 856-2694


# References


1. **Electrek Formula Sun Grand Prix 2023 Regulations.** ***ASC & FSGP.*** **[Online] American Solar Challenge, 2023. https://www.americansolarchallenge.org/regulations/2023-formula-sun-grand-prix-regulations/.**

**2. Official Electrek ASC Results.** ***Electrek ASC and FSGP 2024 Home.*** **[Online] Electrek, 2024. https://www.americansolarchallenge.org/2024/asc/results/.**

**3. Srimongkolkul, Michael. KU Solar Car History Part 2.5 – Astra's Car Design. [Online] Word Press, June 28, 2021. https://michaelsri.wordpress.com/2021/06/28/ku-solar-car-history-part-2-5-astras-car-design/.**

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**5. Electrek American Solar Challenge 2024.** ***American Solar Challenge.*** **[Online] ASC, 2024. https://www.americansolarchallenge.org/.**

**6. Foundation, Innovaters Education. American Solar Challenge.** ***ASC 2024 Regulations.*** **[Online] 2024. https://www.americansolarchallenge.org/ASC/wp-content/uploads/2023/11/ASC2024-Regs-EXTERNAL-RELEASE-C.pdf.**

**7. Moore, Nicole Casal. Mechanical Engineering News.** ***Mechanical Engineering University of Michigan.*** **[Online] University of Michigan, July 28, 2024.**

**https://news.engin.umich.edu/2024/07/national-champs-u-michigan-solar-car-team-takes-first-in-american-solar-challenge/.**

# Appendix

| Component | Weight | Method |
|---|---|---|
| Chassis | 206 lbs | Previous Chassis - 850lbs, 2nd iteration design 154 (Raw Material) |
| Battery Box | 42 lbs | Weight Scale, Components may be added |
| Shell/Solar Array | 115 lbs | 10 lbs panels, 1.3x fiberglass weight, similar team design comparison |
| Other | 20 lbs | Misc. weight under 10 lbs |
| Passenger | 177 lbs | Ballast, per regulatory compliance (ASC 9.7,C.2) |
| Front Suspension | 35 lbs | Estimated weight of two front tires and wheel hub, less brake calipers and rotors |
| Rack and Pinion | 10 lbs | Estimated weight of aluminum steering system |
| Shocks and Subs | 10 lbs | Estimated weight of aluminum subcomponents and front suspension attatchments |
| Rear Suspension | 30 lbs | Estimated weight of two rear tres and left wheel hub, less brake calipers and rotors |
| Shocks and Subs | 10 lbs | Estimated weight of aluminum subcomponets and rear suspension attachments |
| Motor Hub | 20 lbs | Weight of motor hub for RWD design |
| **Total** | **675 lbs** | 560 lbs unsprung, 115 lbs sprung weight |

**Figure 27: Solar Car Component Weight Breakdown**

Load Case 3: Sideways Angled (30-deg Front)

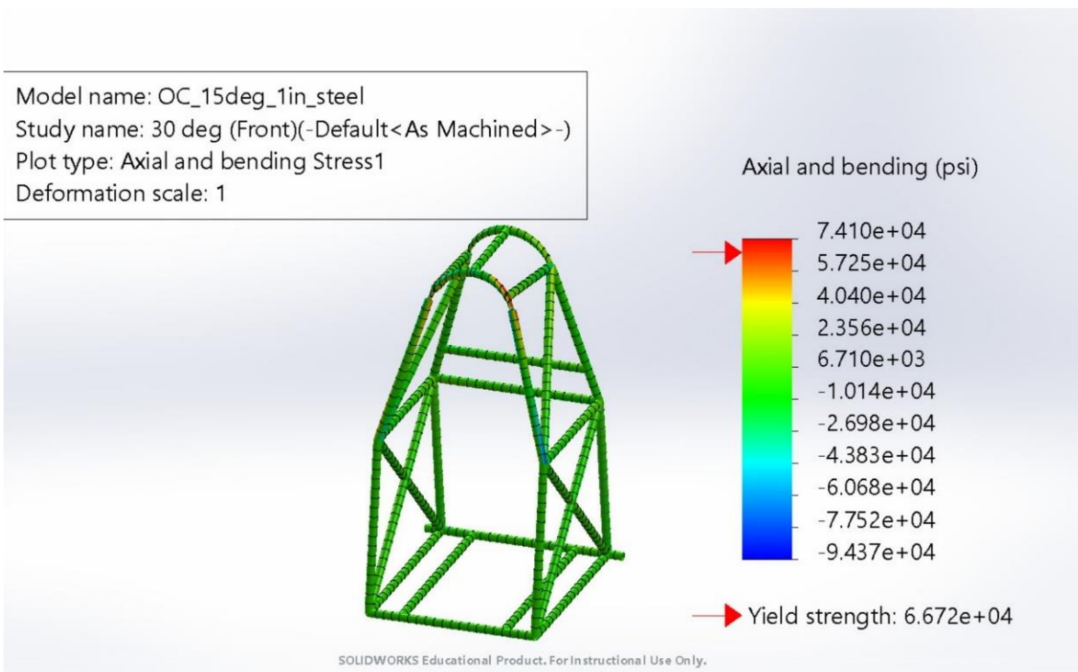


**Figure 28: Max Stress 7.410 X $10^4$ psi**

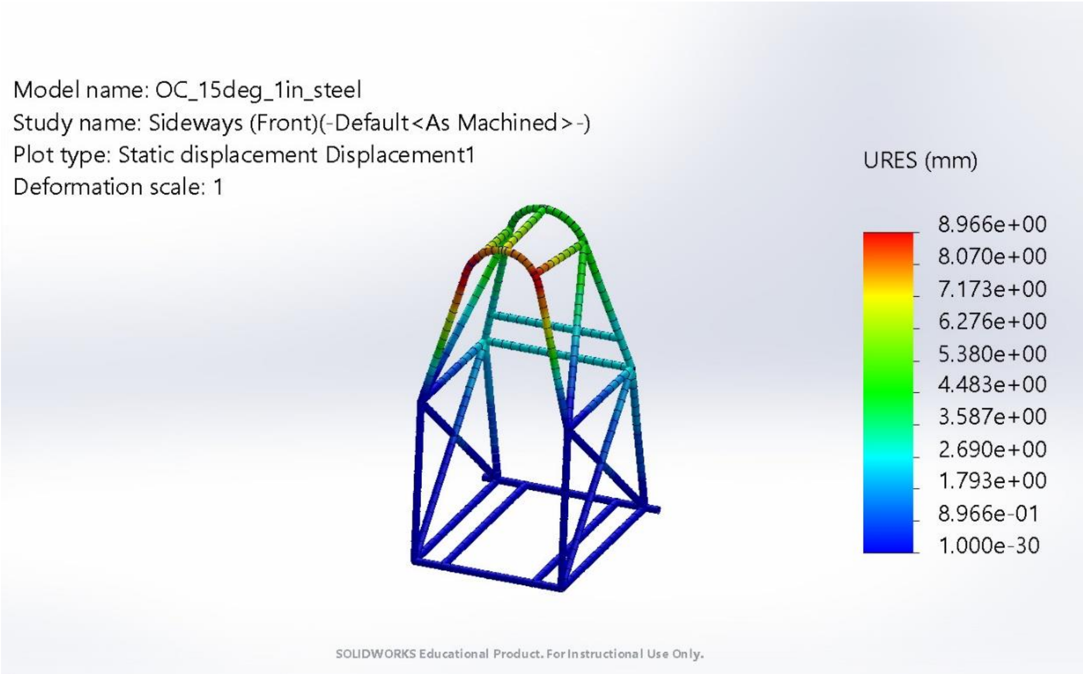


**Figure 29: Max Displacement 7.803 mm**

Load Case 4: Sideways Angled (30-deg Rear)

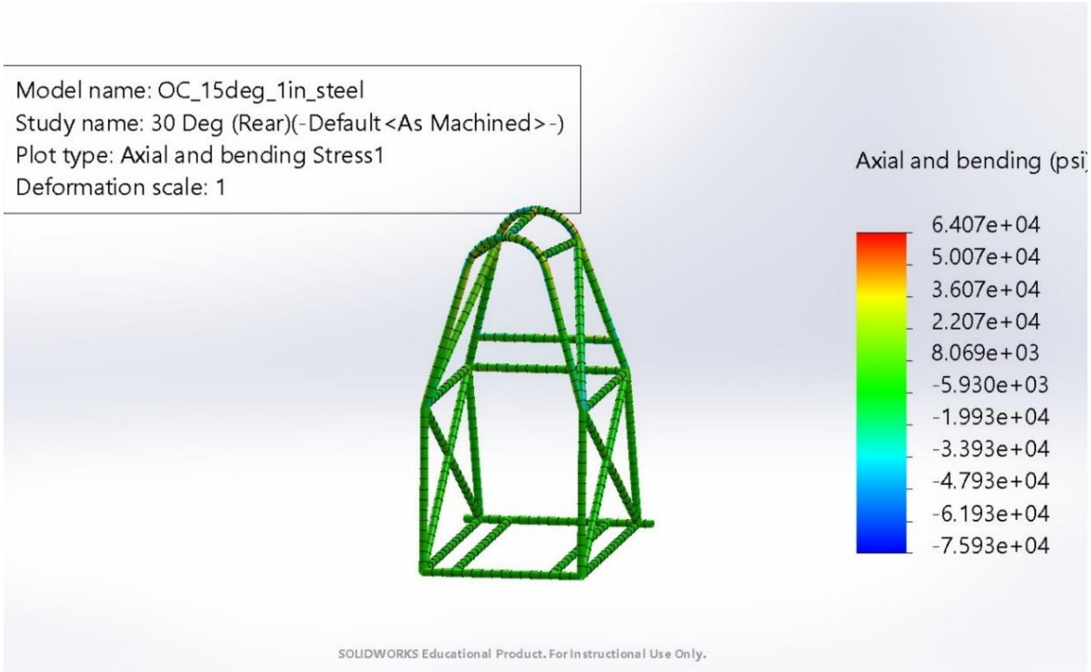


**Figure 30: Max Stress 6.407 X $10^4$ psi**

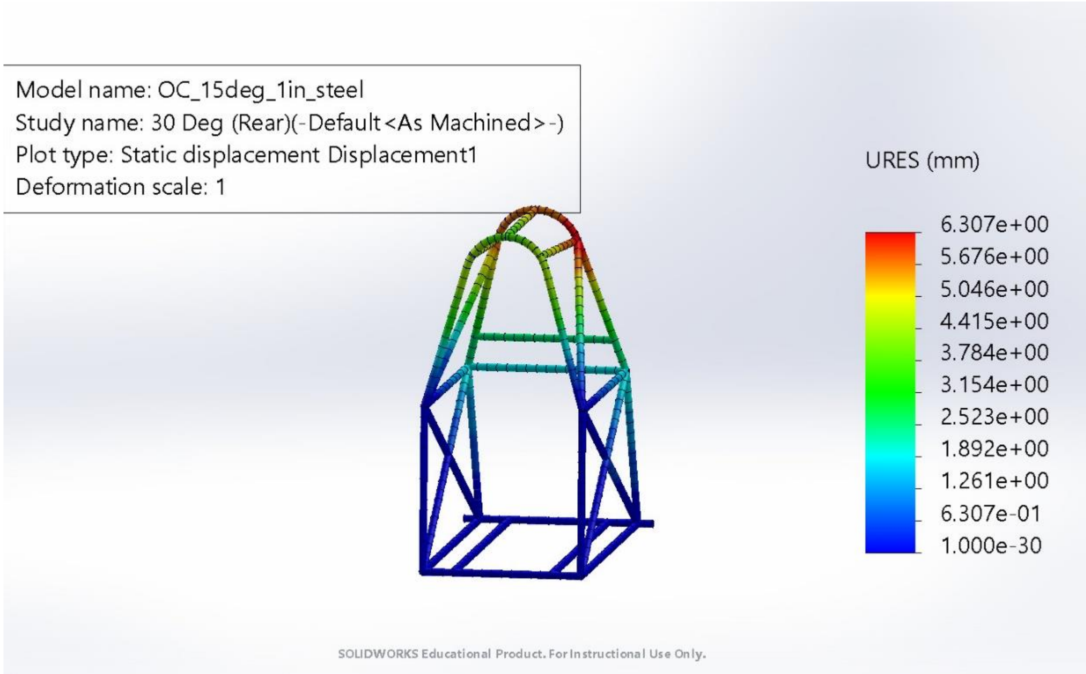


**Figure 31: Max Displacement 6.307 mm**

Load Case 5: Sideways Angled (60-deg Front)

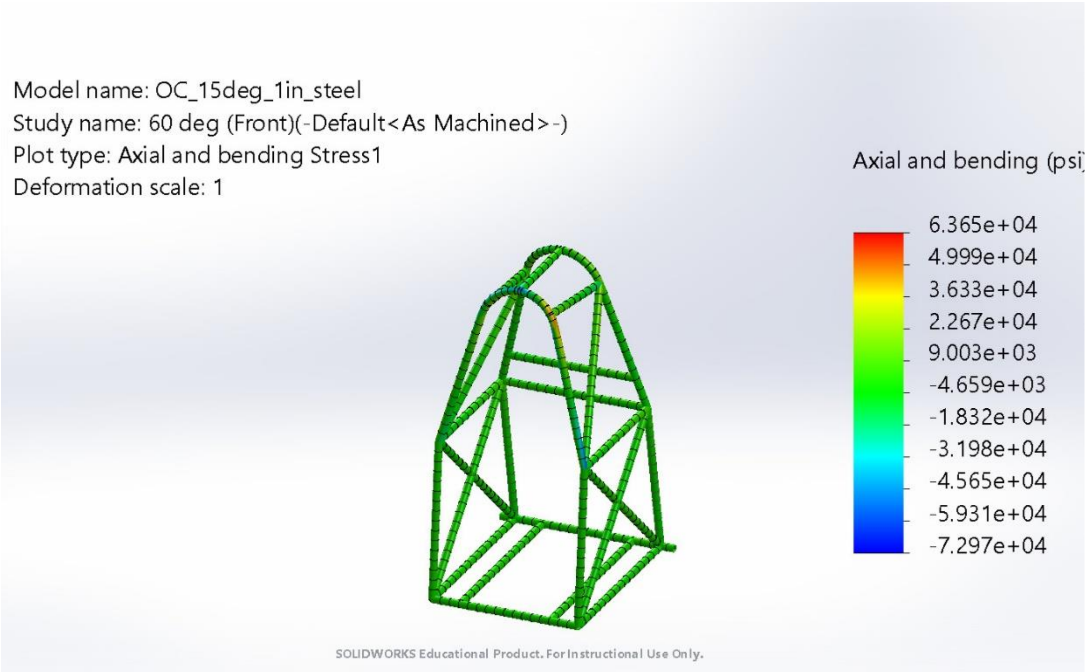


**Figure 32: Max Stress 6.365 X $10^4$ psi**

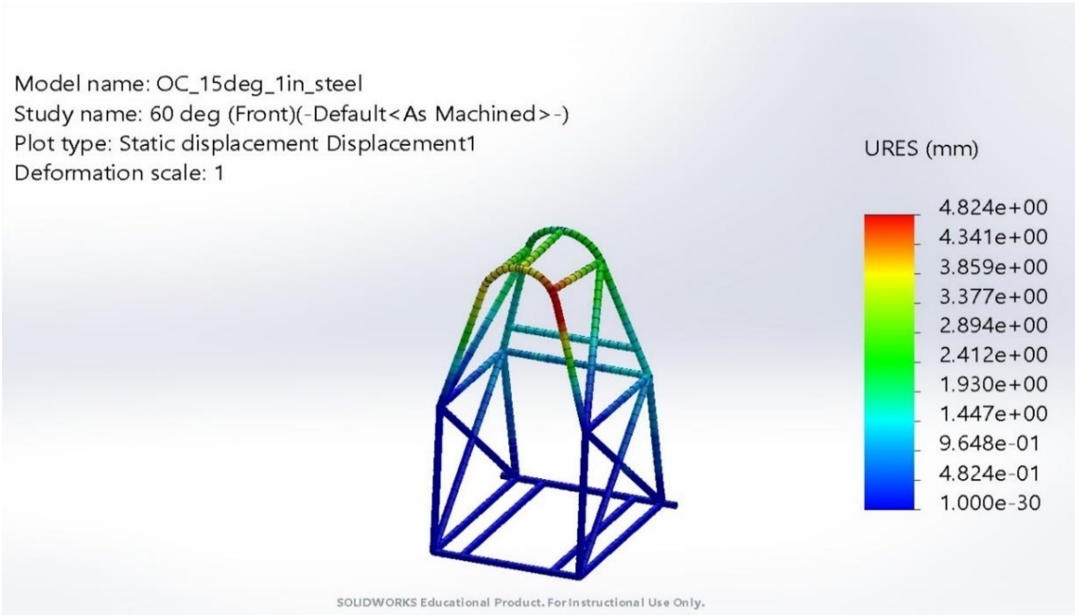


**Figure 33: Max Displacement 4.824 mm**

Load Case 6: Sideways Angled (60-deg Rear)

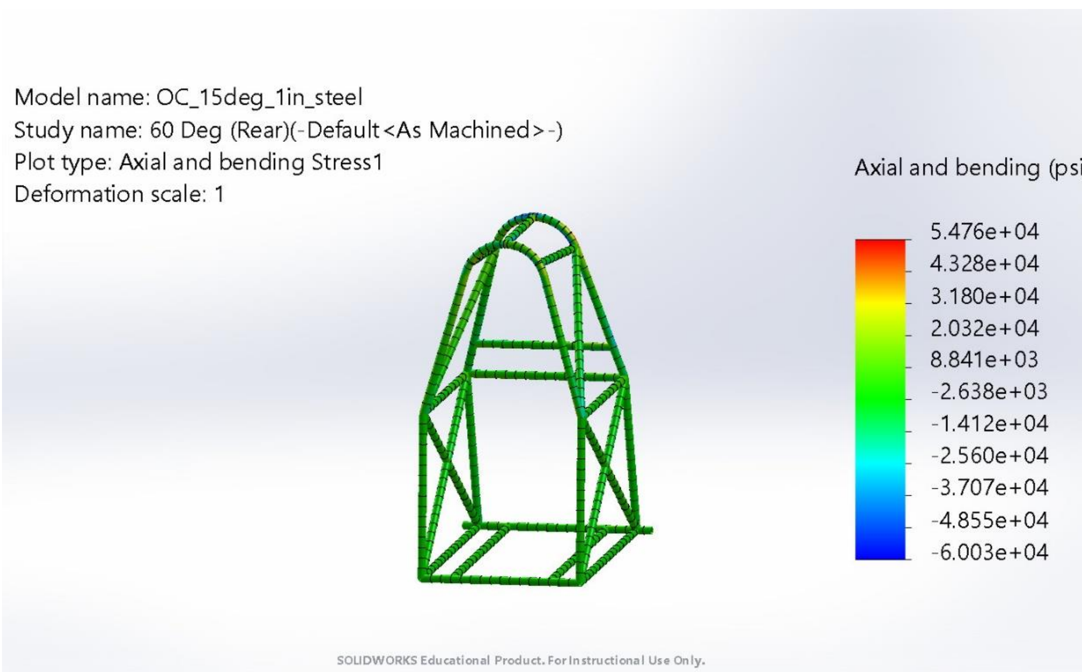


**Figure 34: Max Stress 5.476 X $10^4$ psi**

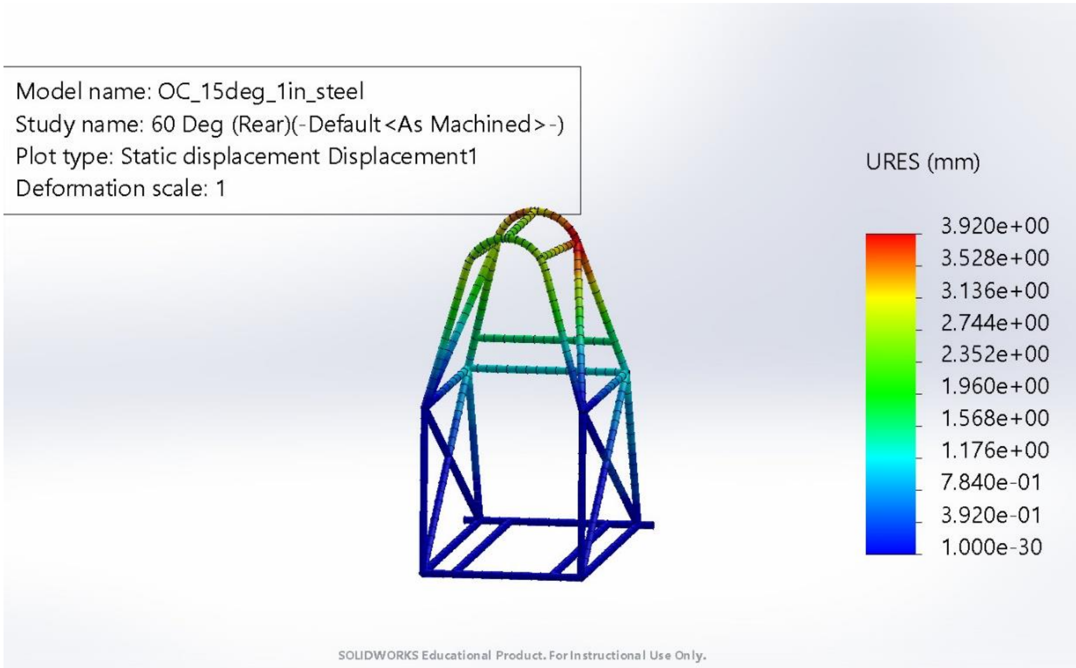


**Figure 35: Max Displacement 3.920 mm**

Load Case 7: Sideways Horizontal (Front)

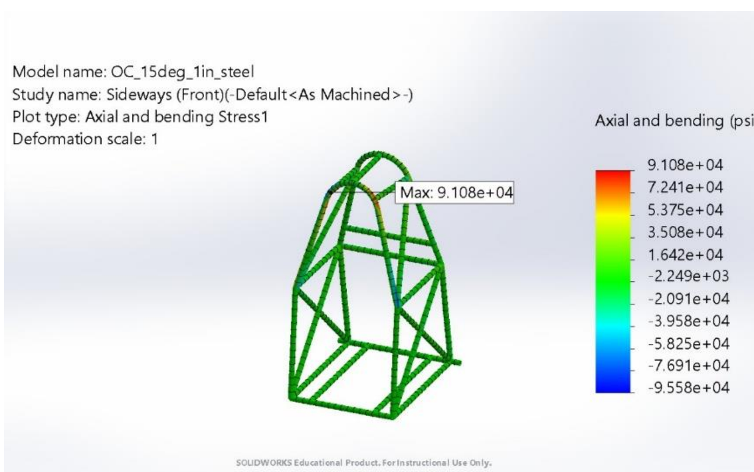


**Figure 36: Max Stress 9.108 X $10^4$ psi**

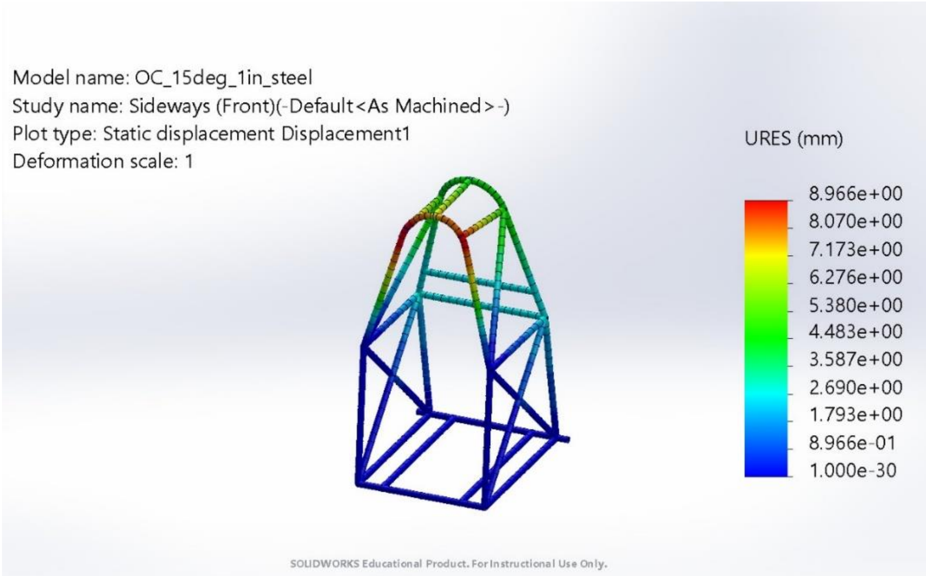


**Figure 37: Max Displacement 8.966 mm**

Load Case 8: Sideways Horizontal (Rear)

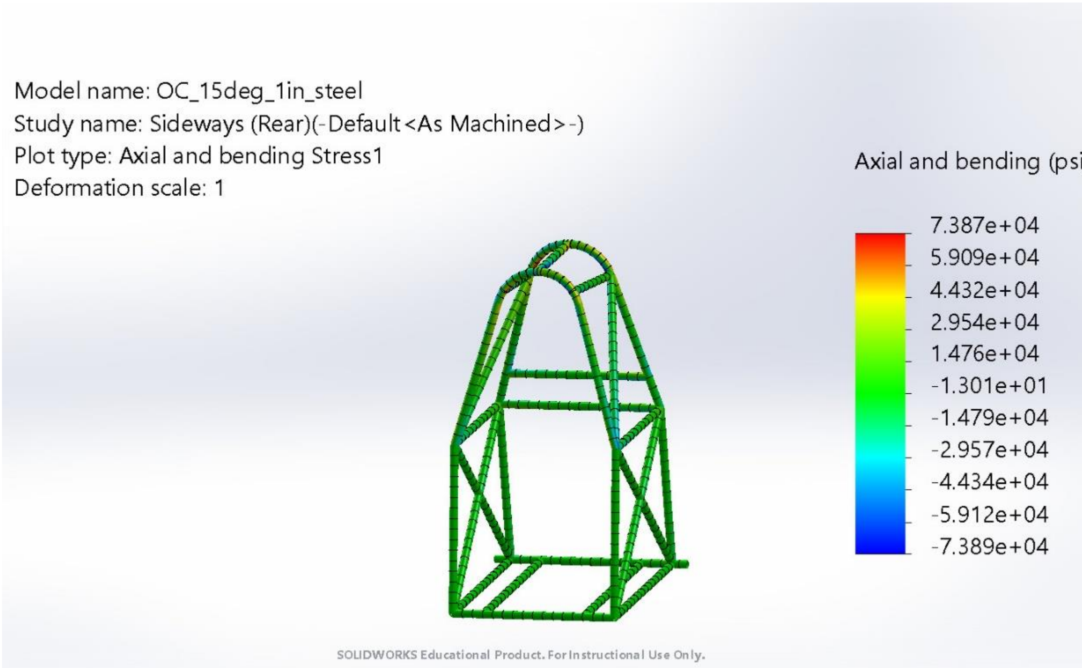


**Figure 38: Max Stress 7.387 X $10^4$ psi**

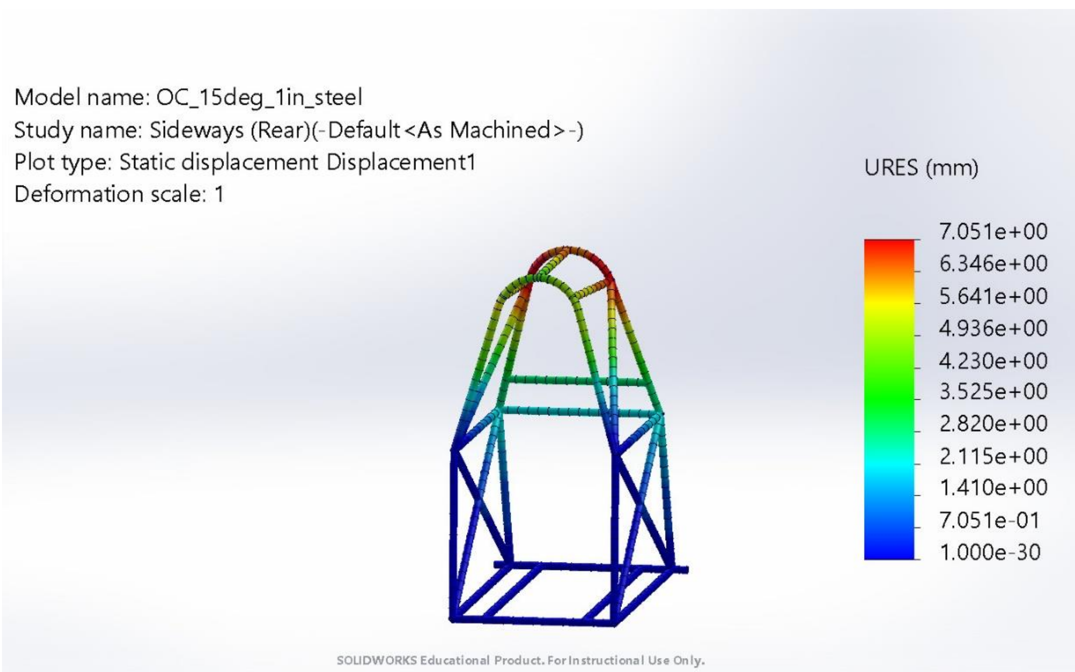


**Figure 39: Max Displacement 7.051 mm**

Load Case 9: Rearward Horizontal (Front)

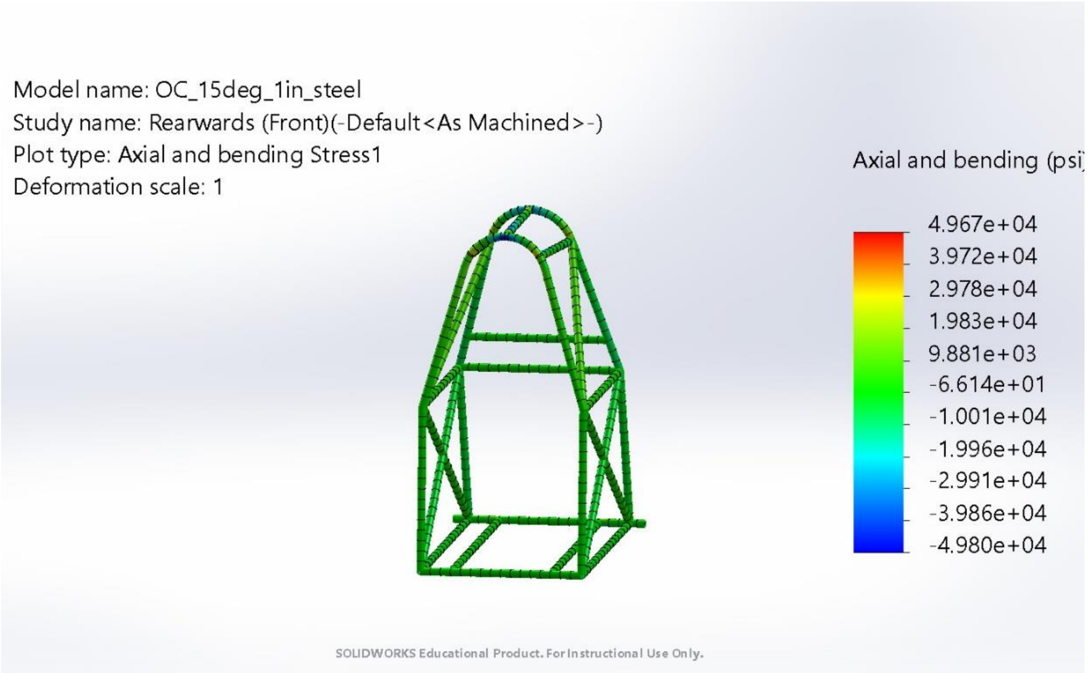


**Figure 40: Max Stress 4.967 X $10^4$ psi**

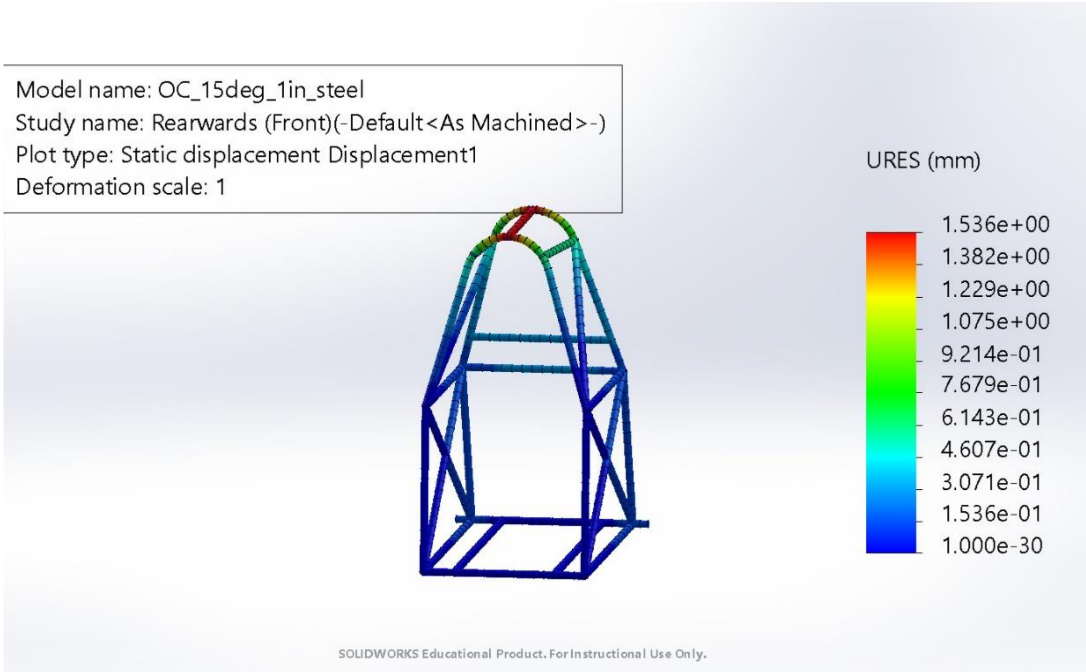


**Figure 41: Max Displacement 1.536 mm**

Load Case 10: Rearward Horizontal (Rear)

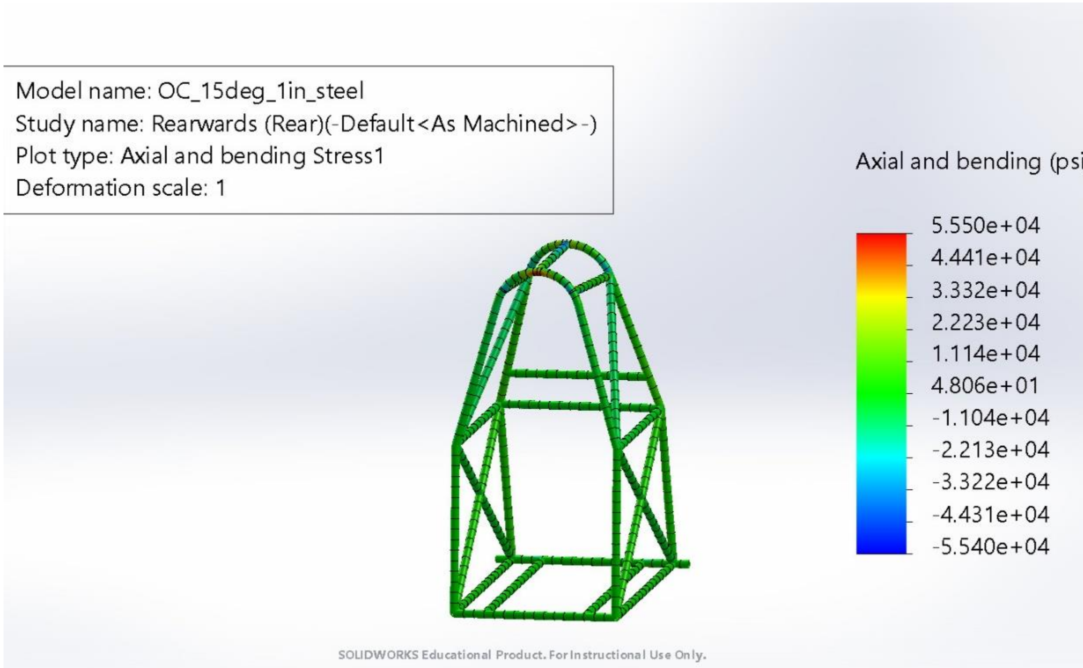


**Figure 42: Max Stress 5.550 X $10^4$ psi**

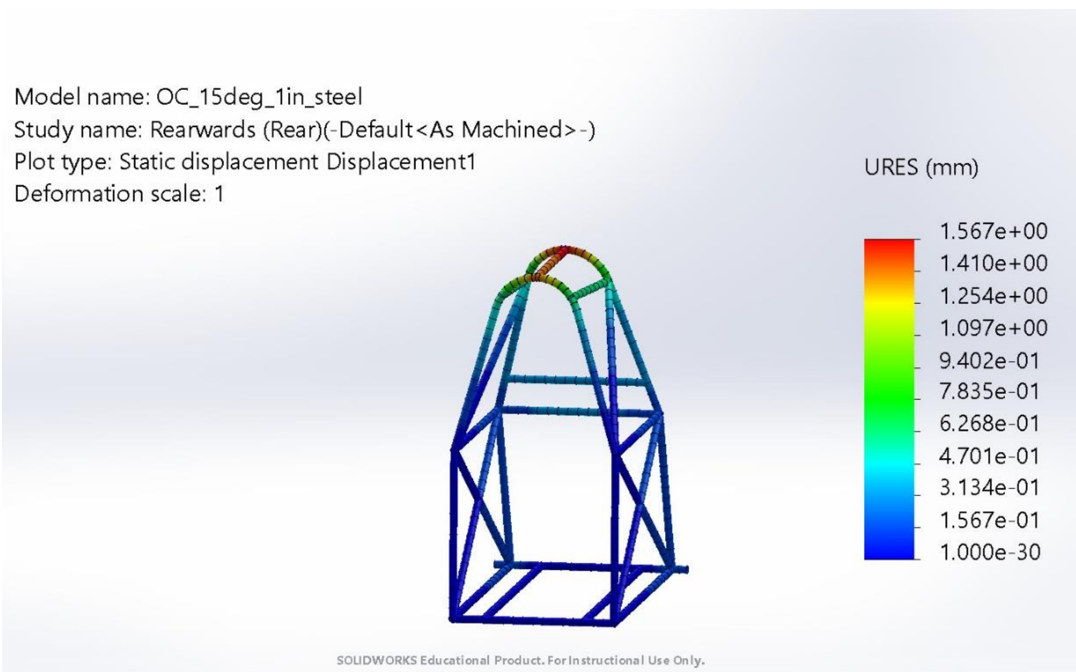


**Figure 43: Max Displacement 1.567 mm**