Utility Terrain Vehicle (UTV)

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
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Bachelor of Science

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by

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Problem Statement

Continue the design and fabrication of the UTV that was started by a prior senior design group. The UTV still requires additional design work, modification to existing design, and analysis of all involved designs, as well as much of the fabrication. Utilizing CAD tools, we will complete the design and analysis portion. We will also utilize basic manufacturing processes to fabricate the UTV.

Research

Background of the Problem

Over the years, Utility Terrain Vehicles (UTV) have become increasingly common for professional and recreational usage. UTVs can trace their origins back to the Willys Jeep of the 1940's, but more recently, the 1988 Kawasaki Mule, which was one of the first UTVs marketed specifically for farm and other commercial use (1). They allow the user to traverse various terrains and they assist in the moving of heavy items and equipment from one place to the next. Their designs have been improved dramatically, but the cost continues to rise. A price tag of at least $7,000 is to be expected and many UTV models can easily surpass $10,000 (1). Our goal is to design a basic and easily maintained, affordable UTV for everyday usage to increase worker productivity, while also decreasing the chance of injury due to physical strain.

This UTV is needed for the transportation of maintenance equipment and personnel. Maintenance workers fix a plethora of issues in all different locations around manufacturing plants, construction sites, universities, stadiums, and office complexes. These workers can walk upwards of 13,000 steps per day, which is 30% more than recommended for the average person (2). Our target audience needs a product that can reliably and practically transport them and their tools/parts around to the location of their tasks to limit strain on their bodies. A small, yet durable UTV with a bed that can effectively carry a couple maintenance crew members and their equipment is the perfect solution to this problem. (3)

There are many different UTVs boasting assorted designs currently on the market today. Common features on UTVs today include all wheel drive, roll cage, and off-road tires (4). Some UTVs are quite minimalistic, some are high tech and extremely rugged. Our target audience for this finished product is maintenance crews. Therefore, we do not necessarily need incredibly expensive, fast, and high-tech designs for off-road usage, we need more dependable, easily repaired, and practical designs for driving workers and tools around manufacturing facilities and job sites to perform work.

We have divided our UTV design into four main components: the drivetrain, suspension, braking system, and chassis. Our main goal for this vehicle is to provide maintenance crews with a practical and useful asset that can withstand the environments of factories and/or outdoor job sites. Since maintenance crews are usually relatively handy and knowledgeable about how things work, we aim to make our UTV easily modifiable or repaired. Most all the parts used on the UTV are going to be off the shelf (OTS) parts, which will make it easier for a maintenance worker to fix and manipulate.

Applicable Standards (3)

- Four or more wheels (ANSI/OPEI B71.9-2016)
- Intended to transport persons and cargo (ANSI/OPEI B71.9-2016)
- Non-straddle seat (ANSI/OPEI B71.9-2016)
- Controlled by pedals and steering wheel (ANSI/OPEI B71.9-2016)
- Top speed of at least 25 mph (ANSI/OPEI B71.9-2016)
- Maximum of 80" in overall width (ANSI/OPEI B71.9-2016)
- Maximum of 4000 lbs. in gross vehicle weight rating (ANSI/OPEI B71.9-2016)
- Minimum cargo capacity of 350 lbs. (ANSI/OPEI B71.9-2016)

State of the Art

The frame or chassis is the base structure of any car or vehicle. Your vehicle no matter what it is can only be as strong as the base structure. Having a solid and sturdy frame can make or break a design especially in our application of a maintenance UTV. The frame oversees carrying thing line engine, drivetrain, and even the people sitting in the vehicle. There are two main ways you can implement your frame in a vehicle. The first way is to have a body-on-frame design where the body and frame are created separately and then put together. The second way is to have a unibody design which is a body and frame created as one sound structure.

In "Figure 1" shown below is an example of a vehicle that is body-on-frame. The earliest cars utilized a simple frame that resembled a horizontal ladder to which wheels were then attached. A large seating cabin, or body, then sits on top of the horizontal frame (5). This same concept is used today in a lot of different applications.

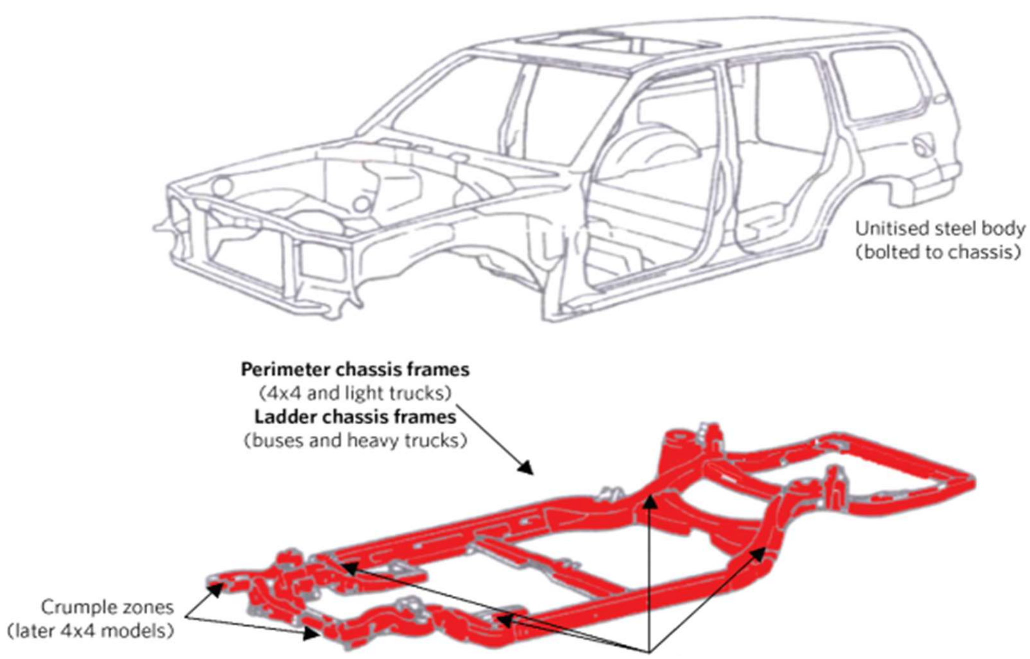


Figure 1: Body on Frame

There are a lot of advantages of having a design with body-on-frame. Most of the applications for this is used in larger vehicles like trucks and large SUVs. The vehicles that still use this concept usually are taller and have more ground clearance, offering true off-road capabilities (5). You will have more flexibility in your vehicle because the frame is separated making it easier to have different tires on different levels of terrain. Another advantage is the ability to redesign and modify vehicles that are separate body and frame. This makes most all repairs much cheaper and more affordable when it comes to a body or frame repair.

There are some disadvantages to this design. Body-on-frame design are always going to be heavier than a unibody config. This ultimately makes your overall weight increase, and your fuel consumption will be greater. It is more likely to tipping because of the need for a higher ground clearance which then moves your center of gravity (CG) higher.

Another way to do the frame and body of a vehicle is a unibody configuration. Unibody vehicles are a cage-like housing that merges the frame with the body in a single piece (5). In “Figure 2” shown below you can see an example of a unibody frame where the frame and body are integrated into one assembly. Most all modern cars and SUVs are made in this way now. Also, UTV and ATVs are almost all made this way mainly because they are smaller vehicles, and it would almost be over killed to do a body-on-frame.

Figure 2 Unibody config (7)

There are a lot of advantages for having a unibody configuration. They are much lighter than the body-on-frame design because they are integrated together, this in theory gets you a much better fuel economy. One of a big advantage that could apply directly to a UTV is the lower center of gravity which will help with a more rigid frame which is lower probability to rolling and tipping. Another big advantage that made a big impact on the change to unibody is the higher crash safety testing scores. This is because the body and frame are designed so the impact of collision is evenly distributed which in turn makes the force of the collision less.

There are some disadvantages to a unibody system. One of the big one is the customization you can do to the framing. Also, they will not have a better carrying weight limit. Another big disadvantage would be the ability to change configs for new models. When you want to change a design for a new year you will have to change a lot more of the chassis design in a unibody config compared to a body-on-frame.

End User

The ideal end user will be employed in roles such as facility maintenance and construction. The end user will use the UTV to transport items such as tools or construction materials over long distances. The age range of the end user is ideally 18 to 65 years old. They will be able bodied men and women. The end user will possess some minor mechanical knowledge and a state issued driver's license.

Summary of Research

In conclusion of my research, I have found that a UTV is a very important part to a company's success. The ability to get to point A to B with the right tools and equipment fast is very helpful to the flow of any operation. I have figured out that it is feasible to do a unibody chassis for our UTV. Even though it would be nice to have the better advantage for modifications for a body-on-frame config, but our UTV is not going to be that high off the ground and won't need that type of frame. I learned that we have some very important guidelines and standards to design by. The minimum cargo capacity is 350lbs which directly impacts the design of the framing. Also, the max weight and width of the vehicle is another thing I will have to keep an eye on to make sure it doesn't exceed the standards. Ultimately, I have a very good idea on how to move forward with this and create an effective set of concepts.

Quality Function Deployment

Customer Features

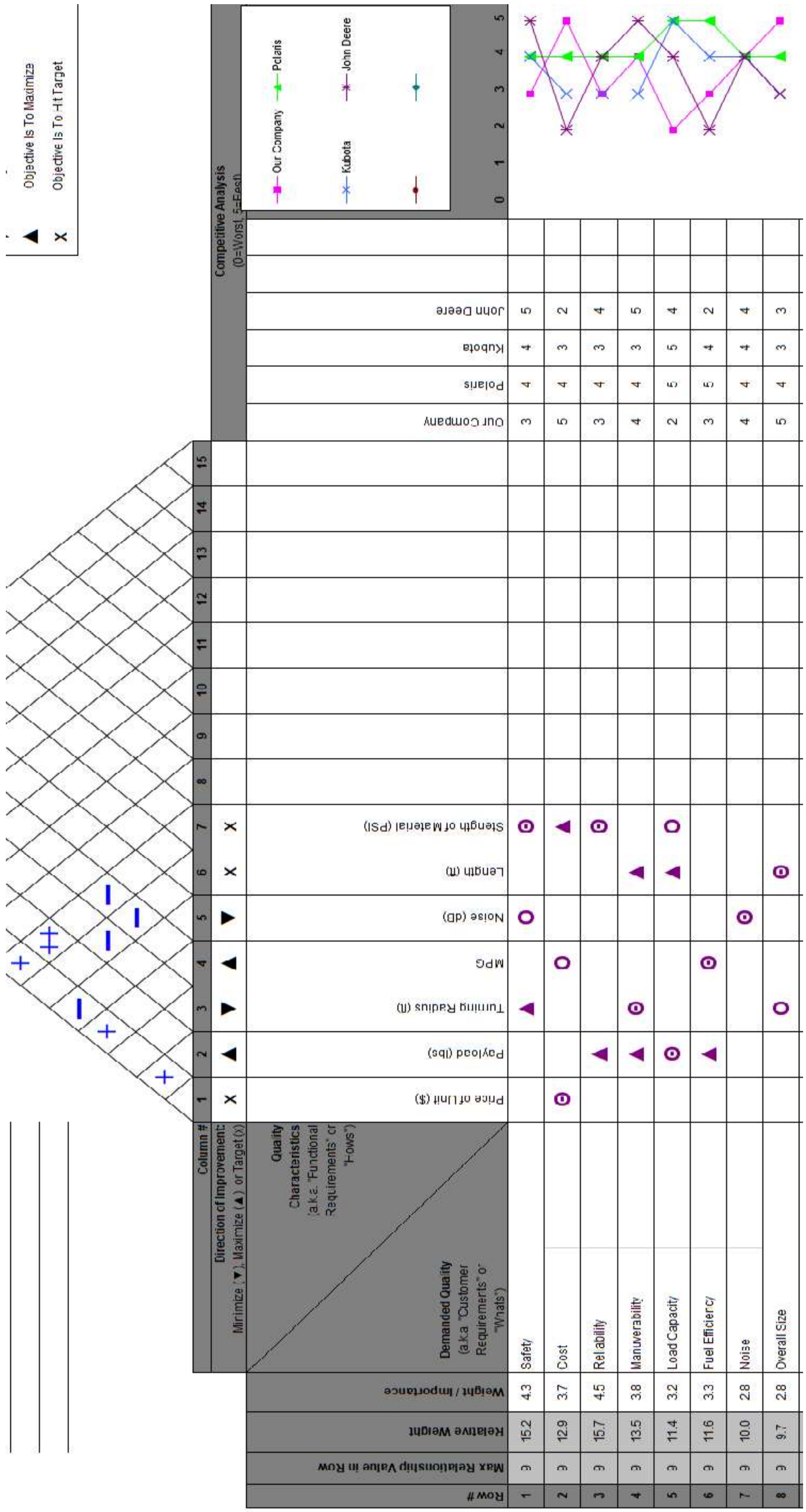
Our group conducted a survey on the importance of certain features of a UTV. We surveyed 31 people who work in either a maintenance role or in the construction industry. We used the results of this survey to create the table below.

Customer Features	Average Score
Safety	4.32
Cost	3.68
Reliability	4.45
Maneuverability	3.84
Load/Capacity	3.23
Fuel Efficiency	3.29
Noise	2.84
Overall Size	2.77

Engineering Characteristics

Using our data found via our survey, we decided upon the engineering characteristics below
1) Material Strength (psi)
2) Unit cost ($)
3) Life of product (miles)
4) Turn Radius (ft)
5) Payload (lbs.)
6) Fuel Efficiency (mpg)
7) Noise (dB)
8) Length (ft)

House of Quality



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Price of Unit ($)	Payload (lbs)	Turning Radius (ft)	MPG	Noise (dB)	Length (ft)	Strength of Material (PSI)	Our Company	Polaris	Kubota	John Deere
Column #					1	2	3	4	5	6	7				
Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)					x	▲	▼	▲	▼	x	x				
1	9	15.2	4.3	Safety			▲		O		⊙	3	4	4	5
2	9	12.9	3.7	Cost	⊙			O			▲	5	4	3	2
3	9	15.7	4.5	Reliability		▲					⊙	3	4	3	4
4	9	13.5	3.8	Manuverability		▲	⊙			▲		4	4	3	5
5	9	11.4	3.2	Load Capacity		⊙				▲	O	2	5	5	4
6	9	11.6	3.3	Fuel Efficiency		▲		⊙				3	5	4	2
7	9	10.0	2.8	Noise					⊙			4	4	4	4
8	9	9.7	2.8	Overall Size			O			⊙		5	4	3	3

Target or Limit Value	8,000	500	12	15	94	5	36,000
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	2	7	7	6	2	1
Max Relationship Value in Column	9	9	9	9	9	9	9
Weight / Importance	116.5	143.0	166.0	143.0	135.5	112.6	324.8
Relative Weight	10.2	12.5	14.5	12.5	11.9	9.9	28.4

Product Objectives

Based on our House of Quality the engineering characteristics are listed below in order of importance, with the first on the list being most important. We will prioritize these characteristics according to their percentage of importance.

1) Strength of Materials (28.4%)
- Select strong metals and plastics for framing/siding
2) Turning Radius (14.5%)
- Include smooth, reliable suspension and steering column
3) MPG (12.5%)
- Limit unnecessary weight
4) Payload (12.5%)
- Install space for tool/equipment storage
- Install supports at crucial weight bearing locations
5) Noise (11.9%)
- Equip some sort of muffler
6) Price (10.2%)
- Eliminate unneeded expenses
7) Length (9.9%)
- Remain mindful of size of frame

Concepts Drawings

Concept 1:

In my first concept I would have a unibody frame that will have more of a box concept to handle the loading of the vehicle. This will make welding and cutting of the metal tubing much easier since we won't have a lot of different angles and difficult corners to deal with. As far as loading goes it isn't the strongest way to design a vehicle, but it also isn't the worst. Since our UTV isn't supposed to be towing or carrying excessive amounts of loads I believe it will not be a big barrier to overcome with this concept. For a UTV application a box design is common but if you go more towards an ATV you see a lot more different types of shapes than just a box shape. Another advantage with a box shaped configuration is the ability to put a trunk in the back to hold maintenance crew tools and equipment. Shown below (Figure 3) is a model of the concept. As you can see most of the members are about 90-degree joints making it a more box shape instead of having angles like 30/60 or 45/45 degrees.

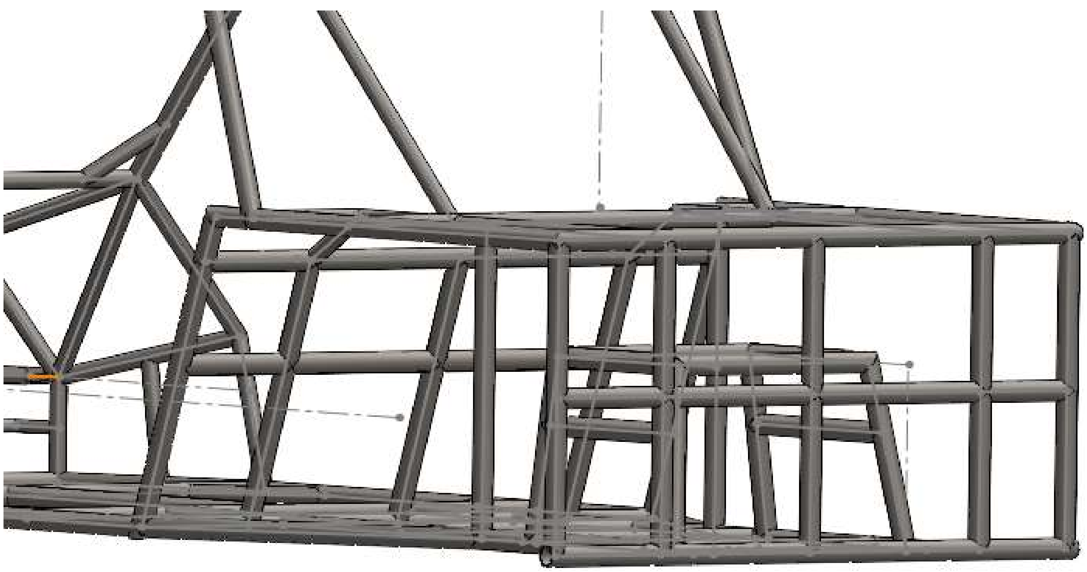


Figure 3: Concept 1

Concept 2:

In the second concept I plan on using a more triangle shaped unibody frame. This is a more robust configuration that can take a greater amount of load and could be more aerodynamic. As far as loading goes triangles are the best shape to carry a load for example most all bridges use triangles because they can take the most load out of any other shape. There are some disadvantages to this configuration though as well. First, it can be much harder to weld and manufacture because of the angles and different type of cuts needed. Also, it would be harder to add on a trunk as shown in *Figure 4&5* below you can see that the back of the UTV would almost come to a point instead of the first config have a more box shape.

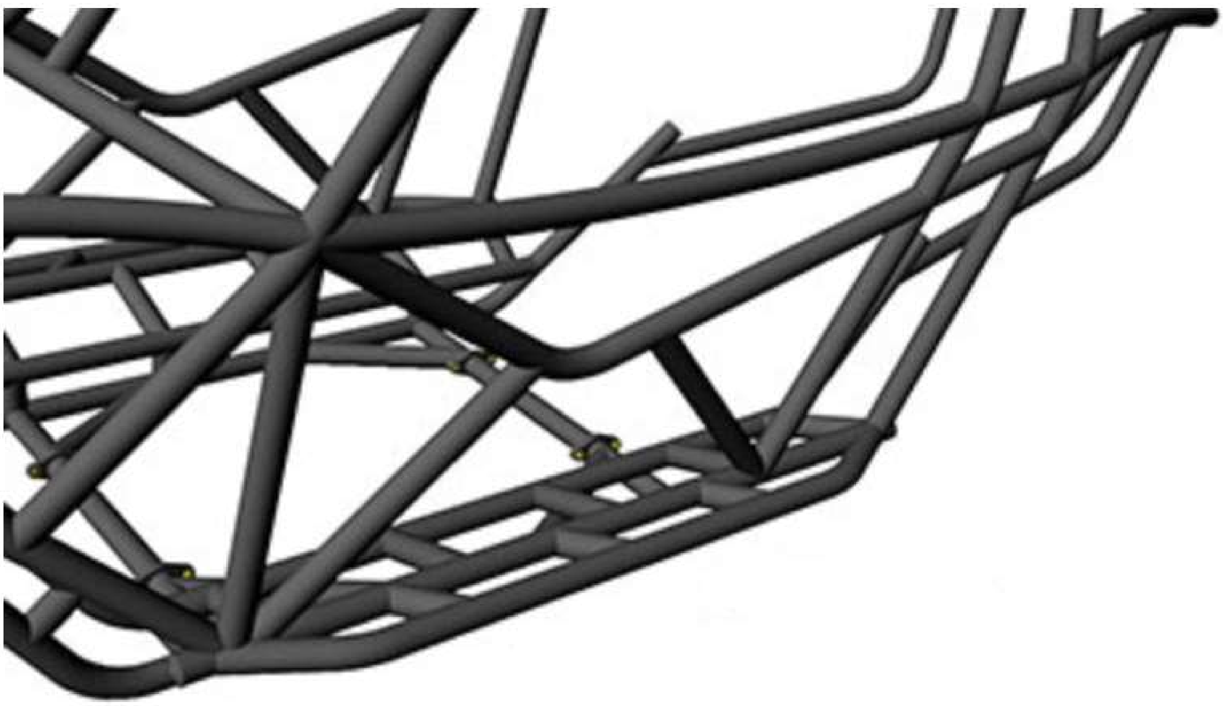


Figure 4: Concept 2

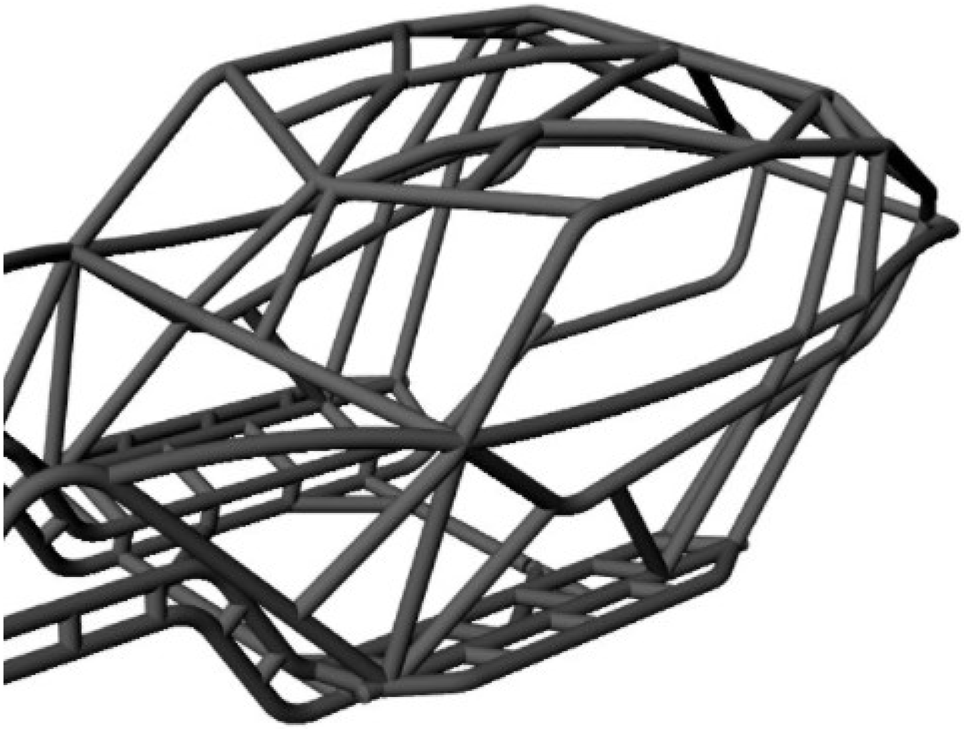


Figure 5: Concept 2

Concept 3:

The third concept would be to use square tubing instead of circular tubing. There will be advantages and disadvantages to using square tubing over round tubing. An advantage is that it is much easier to measure and define spacing and gaps because of the flat edges you can measure to. Whereas, in round tubing there is no flat edges on the surface, so it sometimes gets hard to make accurate measurements. Another advantage is the weldability would be a little bit more manageable with the square tubing but it’s not a huge factor for picking which one is better because they are both manageable welding. The last and one of the most important factors that square tubing has an advantage is the cost. Round tubing is a couple times more in price than square and you will ultimately have more scrap using round tubing as well. But one thing that is a disadvantage of square tubing is that it is not as strong as round tubing if you assemble and weld everything correctly. Figure 6 shown below shows the round steel tubing on the left and the square tubing on the right.

Figure 6: Concept 3

Project Management

Project Budget Limit

Given the purchased components that the group already has, and the frame already having been built, we set a budget limit of $8,000 to complete the project. However, we may be able to complete the project for only $5,000. As mentioned in the research portion, UTVs typically cost at least $7,000, if not $10,000+, so completing the project for $5,000 would be a great achievement and help accomplish our goal of creating a reliable and practical UTV that is also affordable.

Key Milestones

Remaining Components Put on Order	11/15/21
Components Arrive	01/15/22
Assembly Start	01/15/22
Finish Assembly	02/30/22
Test	03/10/22

Design

Design Selection

In the design selection phase for the frame there was a lot of trial and error that went into finalizing the design of the frame. We were given a model of the UTV from a previous team that designed what they wanted the vehicle to look like (shown in Figure 7 below). Most of this design is already put together via the form of the frame coming from a go-cart frame. The back half of the UTV is the big design part of the project. As you can see the other team had a box shaped rear end with a cage where the differential sits and the suspension mounts. Also, they put some more reinforcement in the front of the cage to help with impact testing.

Figure 7: Old frame from former team

For my design I had to consider that we are making this UTV for a much different application than the previous team accounted for. The other group designed for a more off-road recreational use for the vehicle whereas we are going with a more maintenance crew utility vehicle that can get works from place to place faster and carry some tools and equipment that will be used by the employees. Shown below in Figure 8 is an overview of the new design of the frame. One of the big problems with the frame was there is a couple different sized pipes in the design model, and it was very hard to work with and figure out the FEA's. So, I went in and redid all the piping and made it more consistent to what we are going to do and make it a standard pipe size that we are going to use.

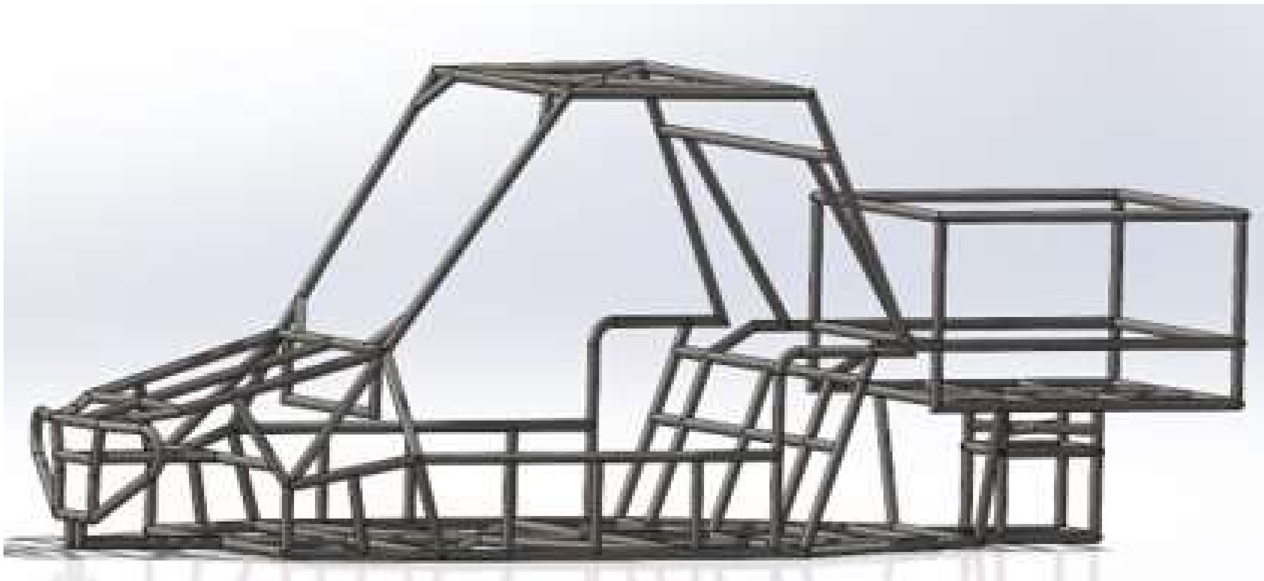


Figure 8: New Frame

When I started designing I decided to scratch the whole back side of the old UTV design. I designed a rear end to account for a trunk bed (as shown in Figure 9 below). Another big part of the design was figuring out the mounting of the suspension to the frame. We had to figure out the type of suspension we needed to accommodate our application and total weight of the vehicle. So, when we figured that out we noticed that our suspension was sticking out of the frame a good amount and I need to tweak and refine the design to make sure the wheels do not stick out too far.

Figure 9: New/Old Rear end

For the front and sides of the UTV frame design I made some more changes. In Figure 10 below you can see the mounting pipes for the suspension in the nose have changed and tightened to help with the tire width issue. Also, you can see in the floor of the cabin I added some cross members to add some rigidity to the frame when two grown people sit in the cabin. Another big change that improved the analysis immensely was the side impact bars that helped connect the front of the frame to the back. Another thing I added was a frame for the dash of the vehicle because before there was nowhere to mount the steering shaft and all the electronics.

Figure 10: New/Old Front end

Design Analysis

In the analysis of the frame, I focused on 5 major tests and FEA's. These consisted of front/rear impact, side impact, static loading, torsional stiffness, and roll over. My analysis of the cage was done in SolidWorks 2021 simulation study. It uses finite element analysis by beams to allow us to figure out the Factor of Safety (FOS), total deformation/displacement, and Von-Misses stress. In most of the roll cages used in SAE Baja UTV/ATV's AISI 1020 DOM Steel piping is used, and I am using an inch diameter piping. The tensile strength of this material is 55ksi and the yield strength is 65ksi.

Front Impact

For the front impact I have made a local connection plate connected to the front grill of the frame to make an easier distributed load. I have put fixture points at the rear and front suspension points. For the back fixtures I made them totally constraint but in the front I locked the side-to-side motion and up and down motion and left the in and out motion to be unconstraint to simulate a realistic collision. This allows me to get an accurate representation of a front collision deforming the front of the cage. It is assumed that the vehicle has front collision with another stationary vehicle, considering our vehicle is moving at maximum speed of 30mph. In the below list is the variables used to construct this test. We put a distributed load of 1600 pound force on the front of the vehicle (shown in Figure 11 below).

- Velocity = 30mph
- Standard load = 4G
- Weight of Frame = 400 lbs.
- Impact time = 0.342 sec
- Force = 1600 lbf

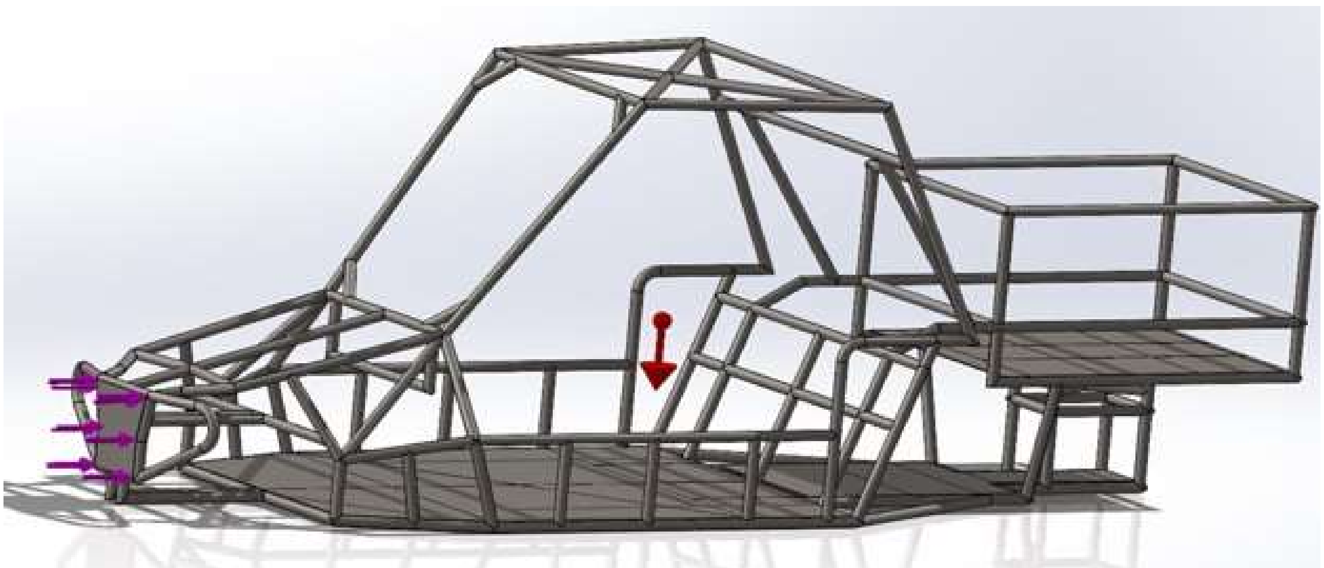


Figure 11: Front Impact loading

In this FEA I figured out that the FOS for the frame will be around 3.3 which is very reasonable and safe for this application (shown in Figure 12 below). We found that there will be very little deformation with a max of 0.04 in (shown in Figure 13 below). Lastly, we figured that the max stress for this test was around 11ksi which is far under the physical properties of the material (shown in Figure 14 below).

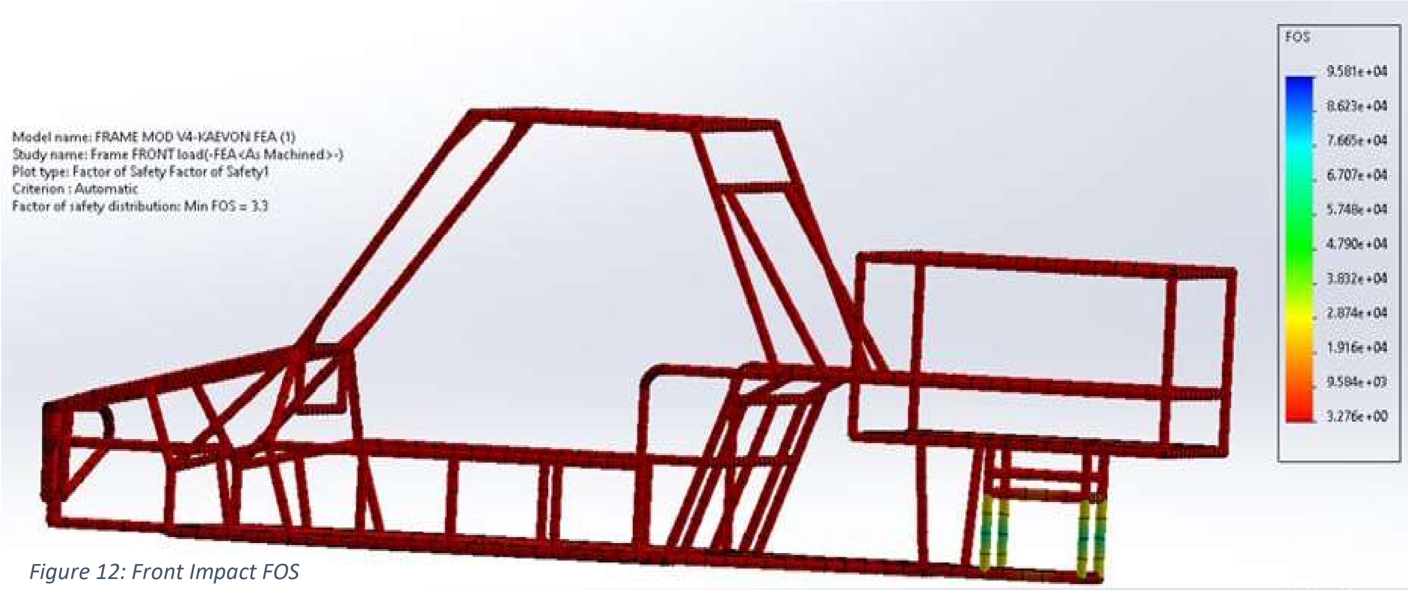


Figure 12: Front Impact FOS

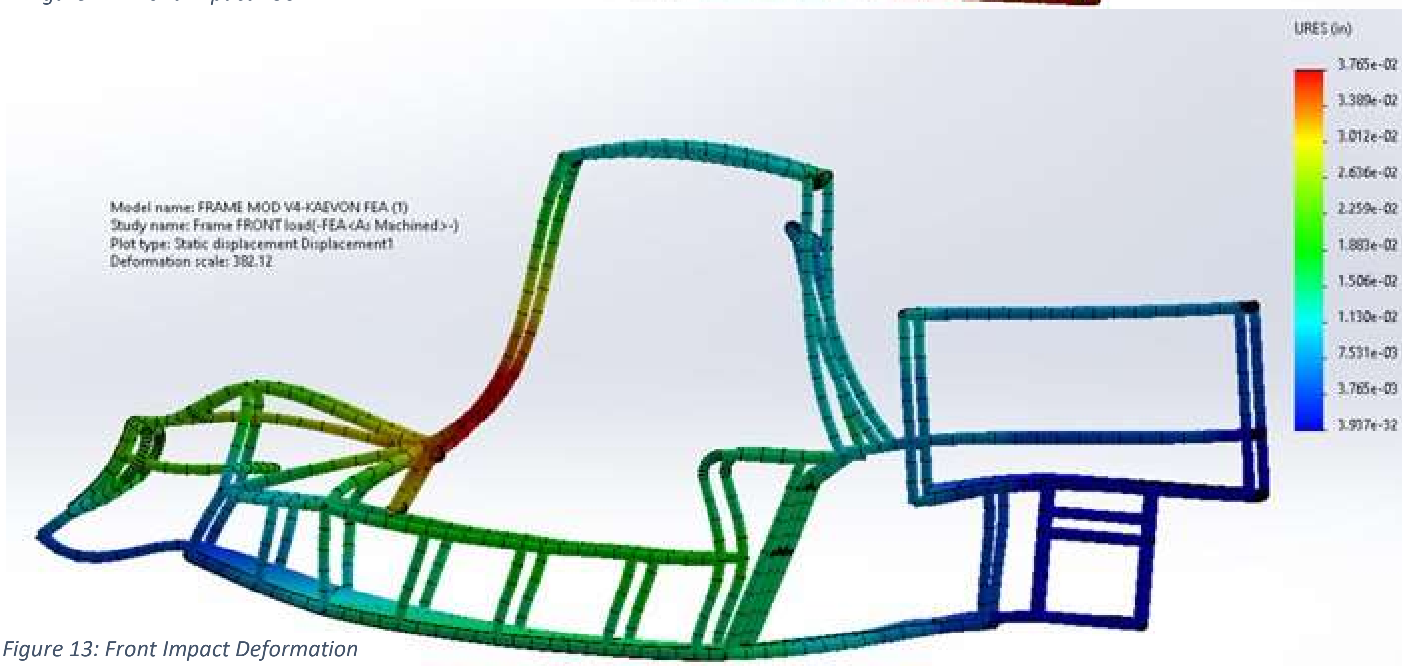


Figure 13: Front Impact Deformation

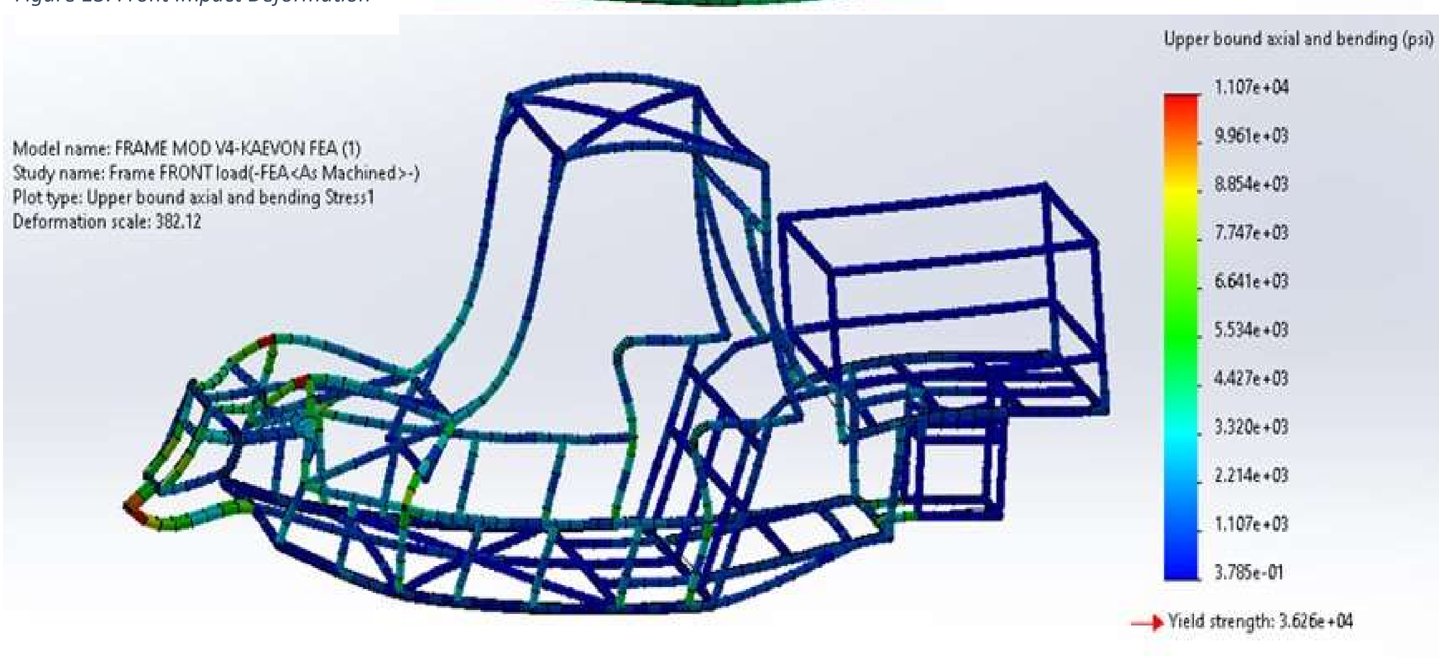


Figure 14: Front Impact Von-Misses Stress

Side Impact

For the side impact I have made a local connection plate connected to the side bar to make an easier distributed load. I have put fixture points at the rear and front suspension points that are fully constraint in all directions. This allows me to get an accurate representation of a side collision deformation. In the below list is the variables used to construct this test. We put a distributed load of 800-pound force on the front of the vehicle (shown in Figure 15 below).

- Standard load = 2G
- Weight of Frame = 400 lbs.
- Impact time = 0.683 sec
- Force = 800 lbf

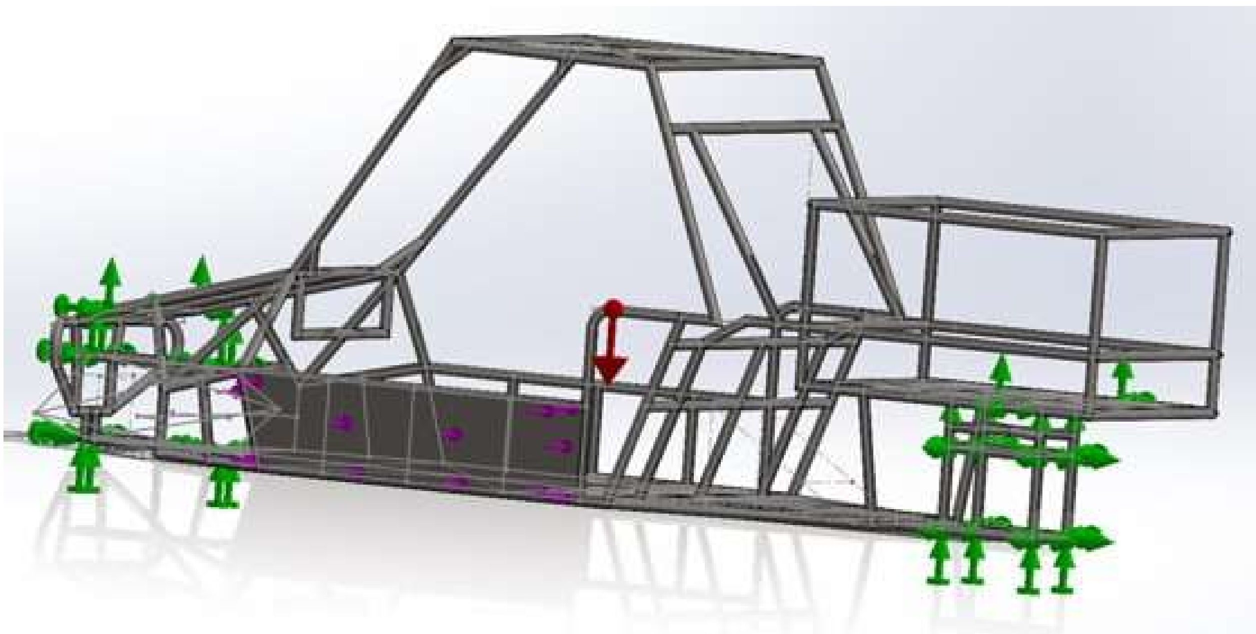


Figure 15: Side Impact Load

In this FEA I figured out that the FOS for the frame will be around 8 which is very safe for this application (shown in Figure 16 below). We found that there will be very little deformation with a max of 0.01 in (shown in Figure 17 below). Lastly, we figured that the max stress for this test was around 5ksi which is far under the physical properties of the material (shown in Figure 18 below).

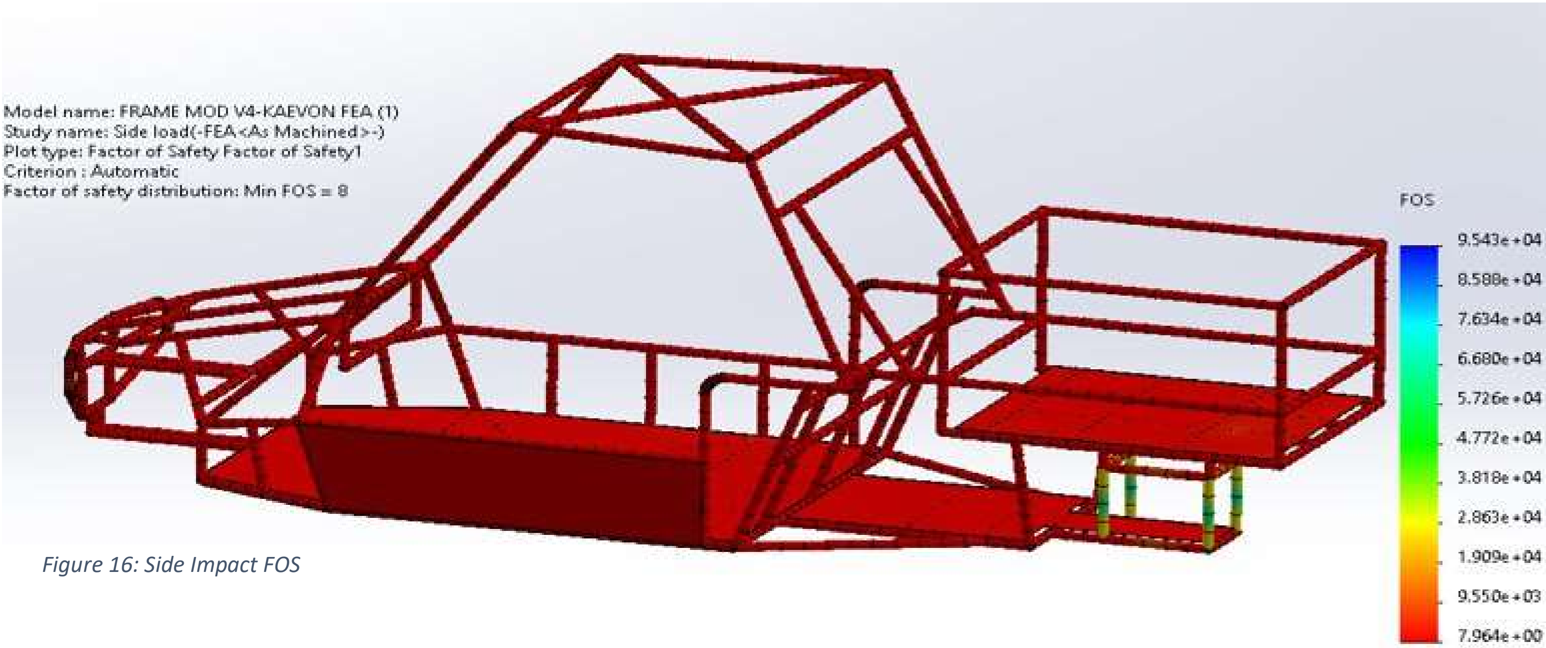


Figure 16: Side Impact FOS

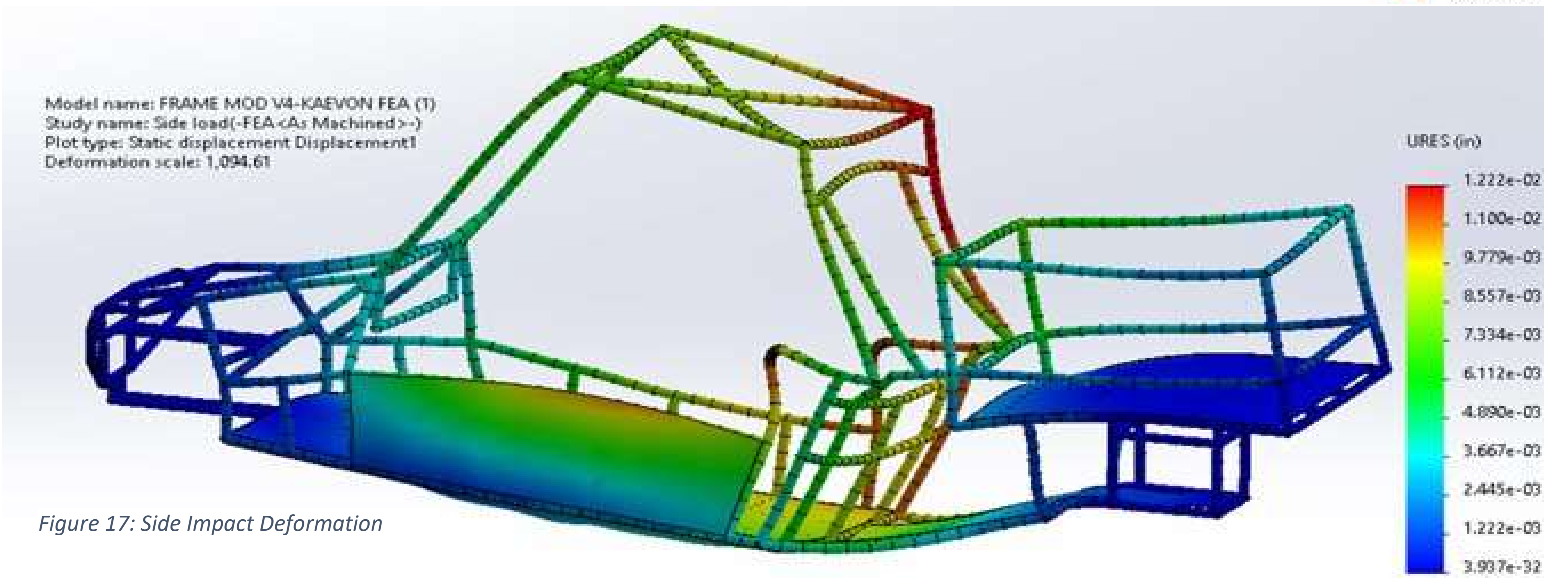


Figure 17: Side Impact Deformation

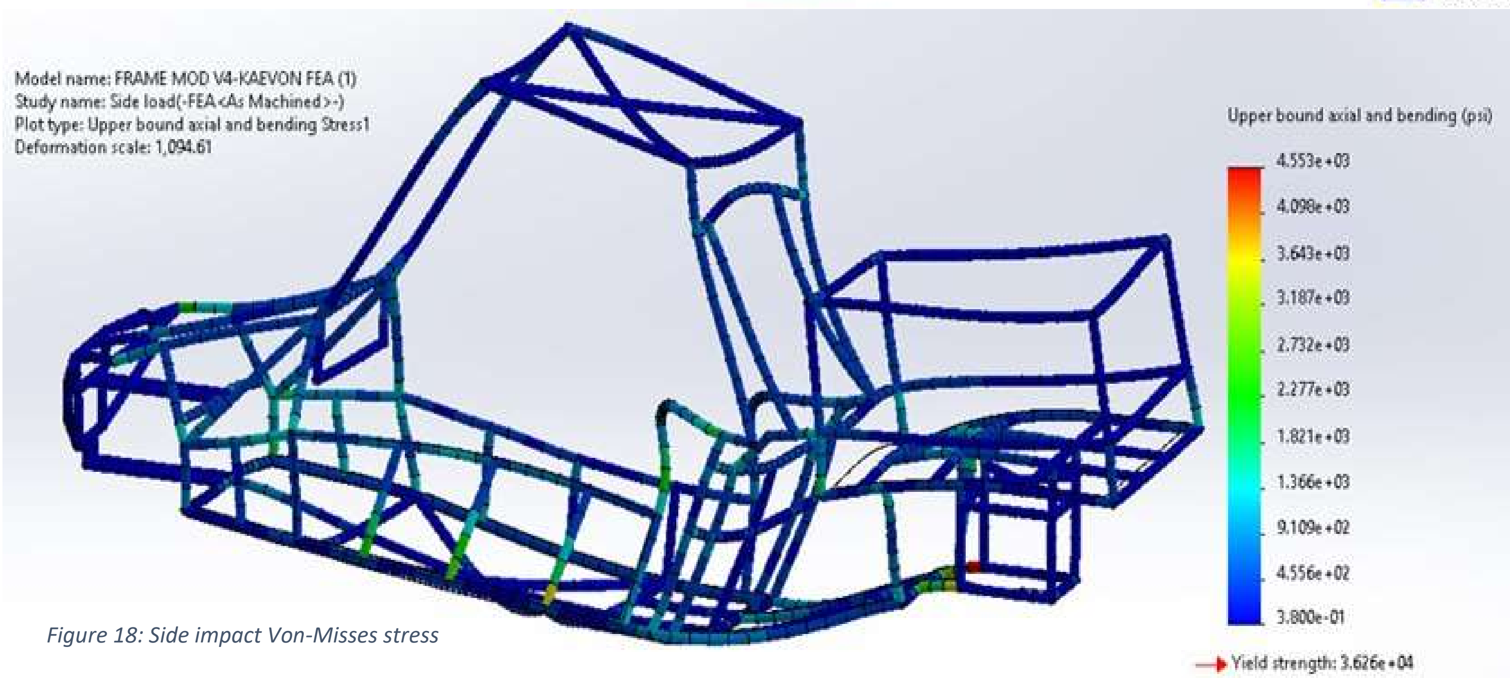


Figure 18: Side impact Von-Misses stress

Static Load

For the static loading I have made a local connection plate connected to the floor of the cabin, engine block, and where the trunk is. This allows a very accurate distributed load. I have put fixture points at the rear and front suspension points that are fully constraint in all directions. We put a distributed load of 500-pound force in the cabin of the vehicle, 300lbf on the engine block plate, and 350lbf in the trunk (shown in Figure 19 below).

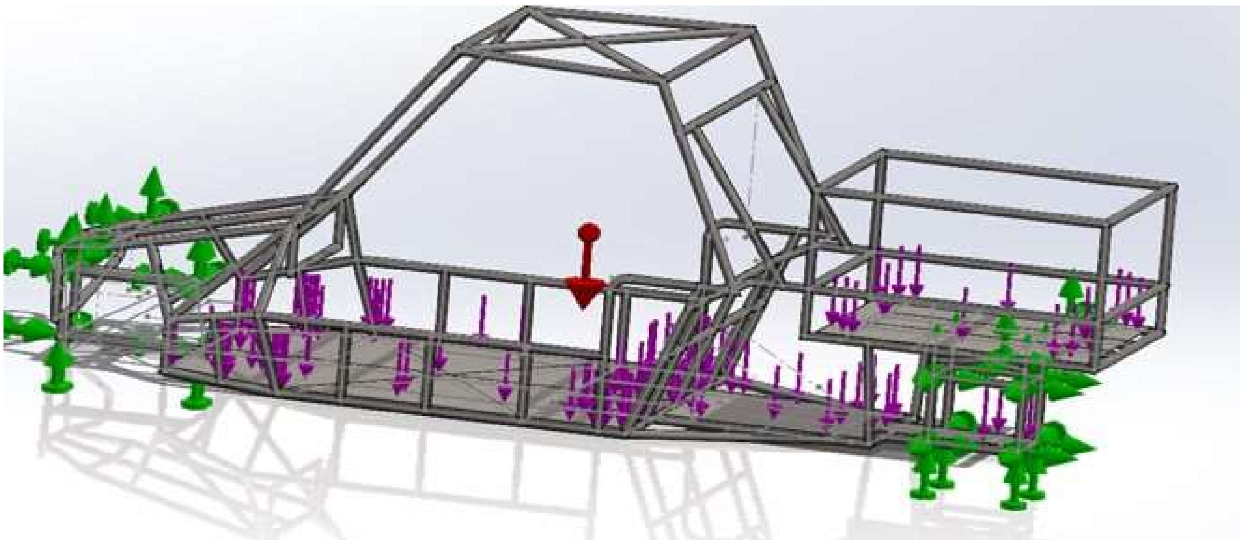


Figure 19: Static Load

In this FEA I figured out that the FOS for the frame will be around 3.6 which is very safe for this application (shown in Figure 20 below). We found that there will be very little deformation with a max of 0.05 in (shown in Figure 21 below). Lastly, we figured that the max stress for this test was around 10ksi which is far under the physical properties of the material (shown in Figure 22 below).

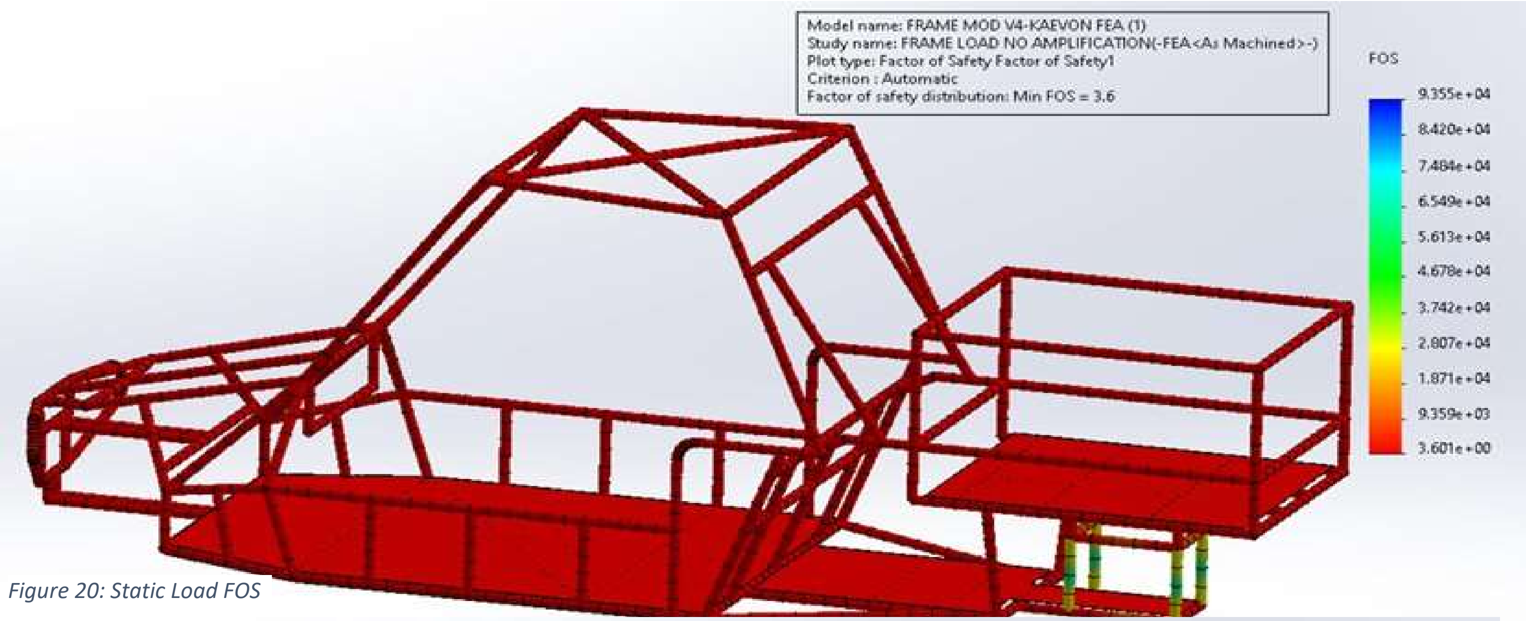


Figure 20: Static Load FOS

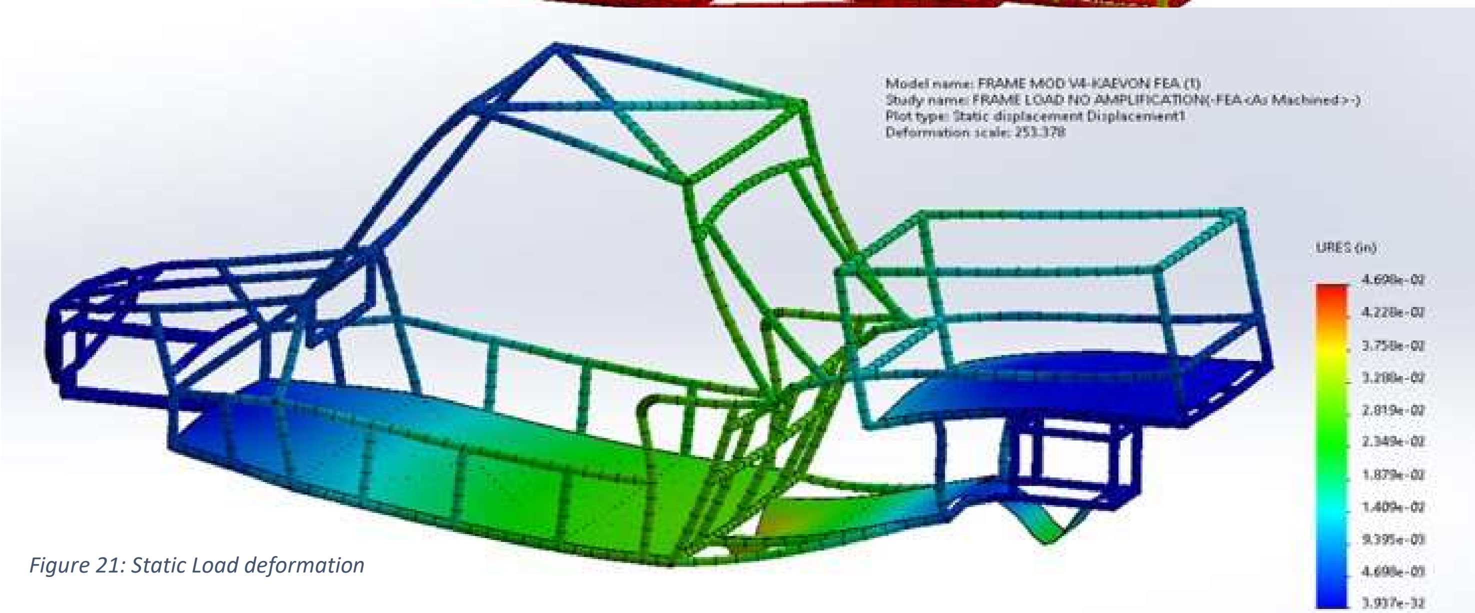


Figure 21: Static Load deformation

Figure 22: Static Load Von-Misses stress

Front Impact

For the torsional load I have made to truss members on each side of the front suspension to act like the suspension when the vehicle is under torsional loading. I have put fixture points at the rear and front suspension points. For the back fixtures I made them totally constraint but in the front I locked the vertical motion up and down and left all the other direction unconstraint to simulate a torsional load. This allows me to get an accurate representation of a cage under torsional deformation. In the below list is the variables used to construct this test. We put a distributed load of 400 lbf on the end of each truss going in opposite directions (shown in Figure 23 below).

- Standard load = 1G
- Weight of Frame = 400 lbs.
- Tire width = 50in or 4.166 ft
- Torque = 1666.67 ft. lb.
- Angular deformation = 0.3827
- Torsional Stiffness v= 4354.68 ft. lb./deg
- Impact time = 1.37 sec
- Force = +400 lbf and -400 lbf

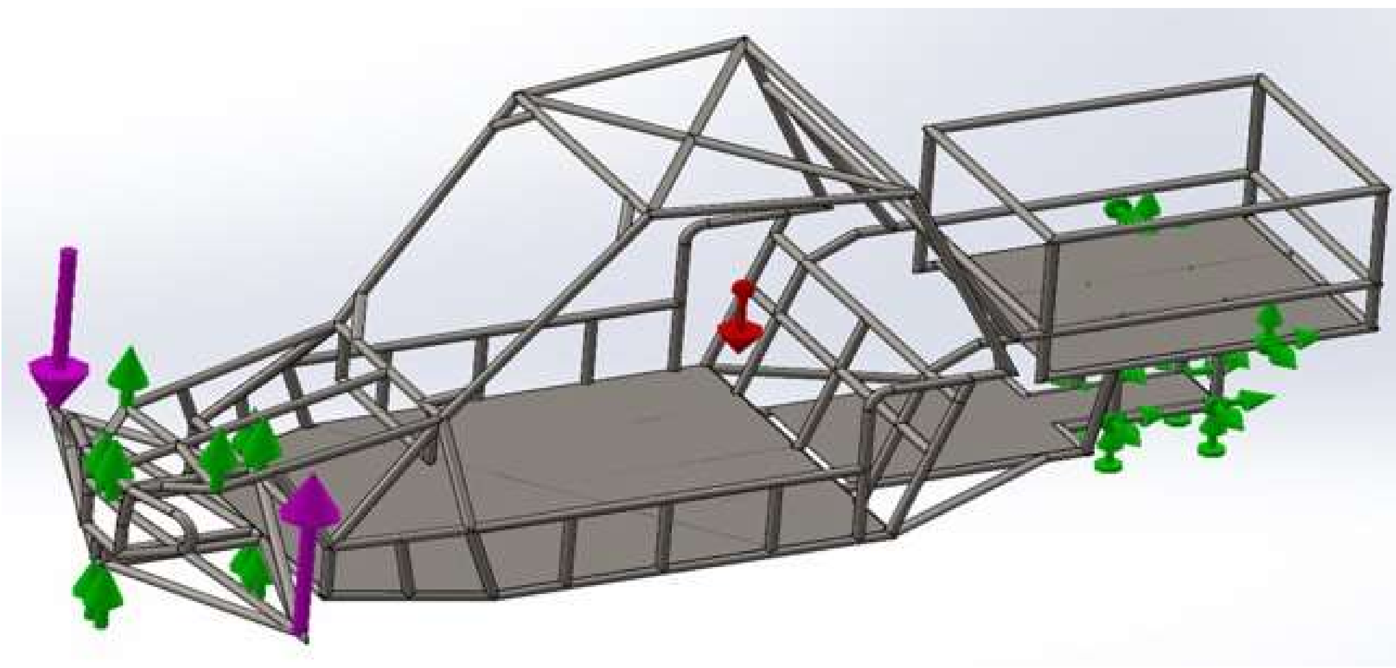


Figure 23: Torsional Load

In this FEA I figured out that the FOS for the frame will be around 1.3 which is good for a torsional test at max torque (shown in Figure 24 below). We found that there will be a deformation with a max of 0.17 in (shown in Figure 25 below). Lastly, we figured that the max stress for this test was around 27ksi which is under the physical properties of the material (shown in Figure 26 below).

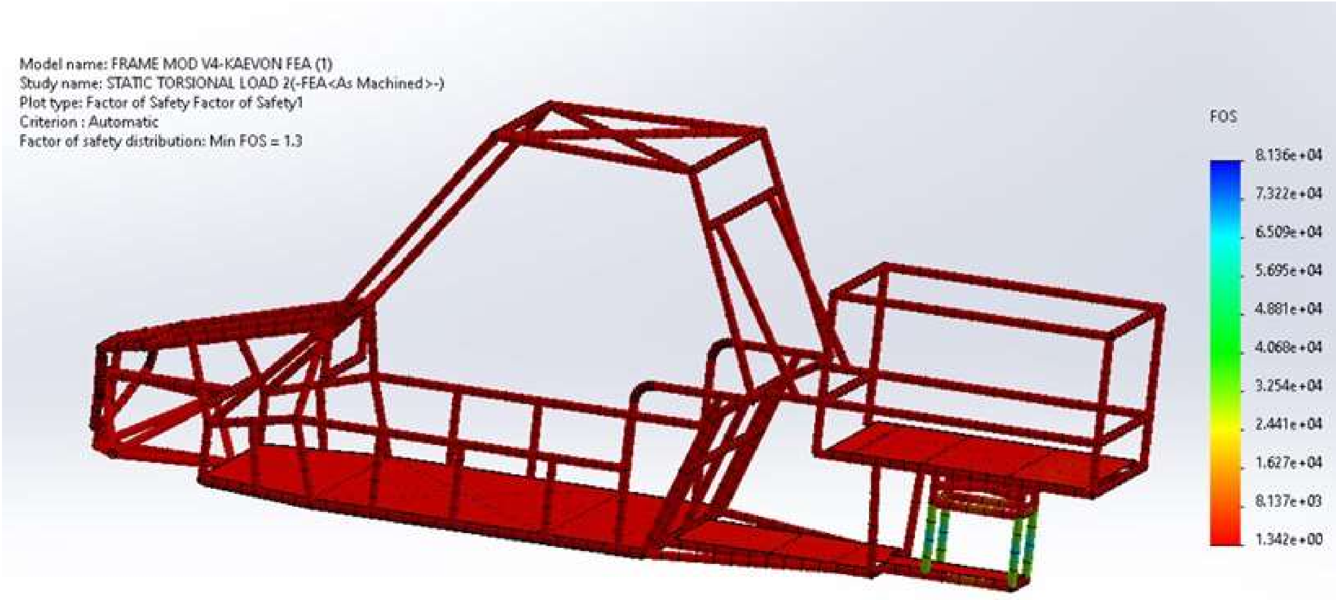


Figure 24:Torsional Load FOS

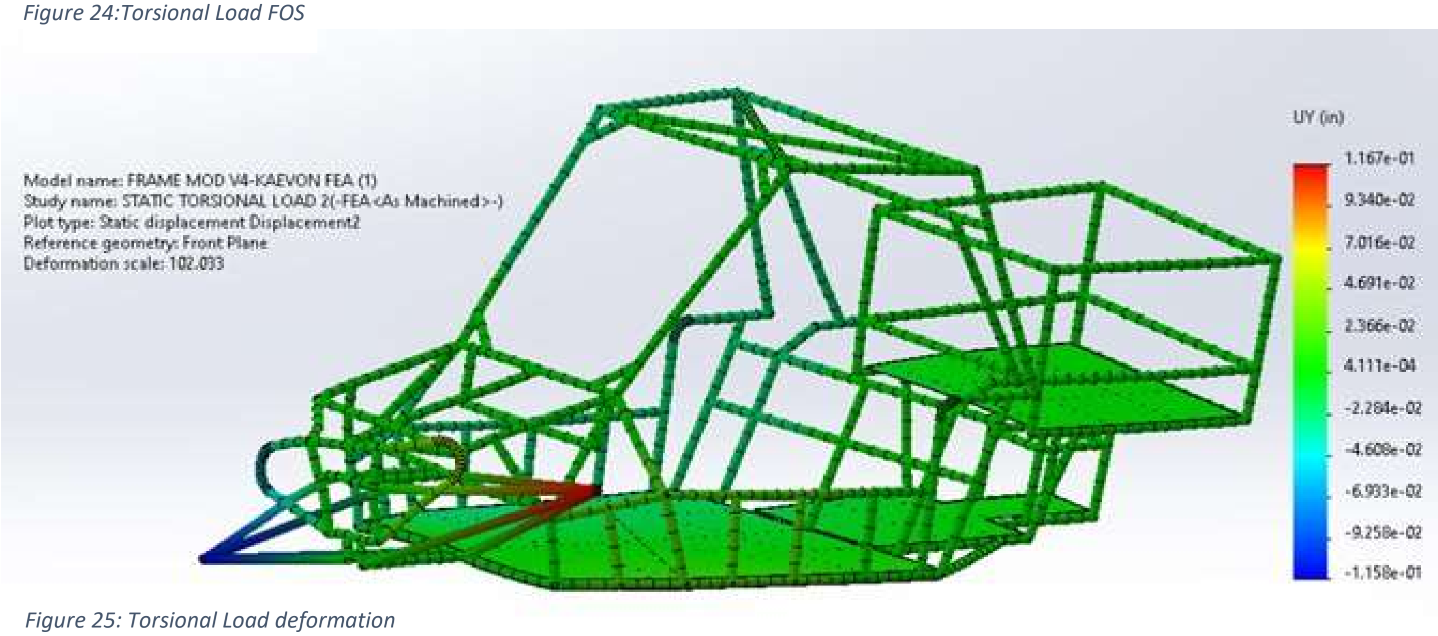


Figure 25: Torsional Load deformation

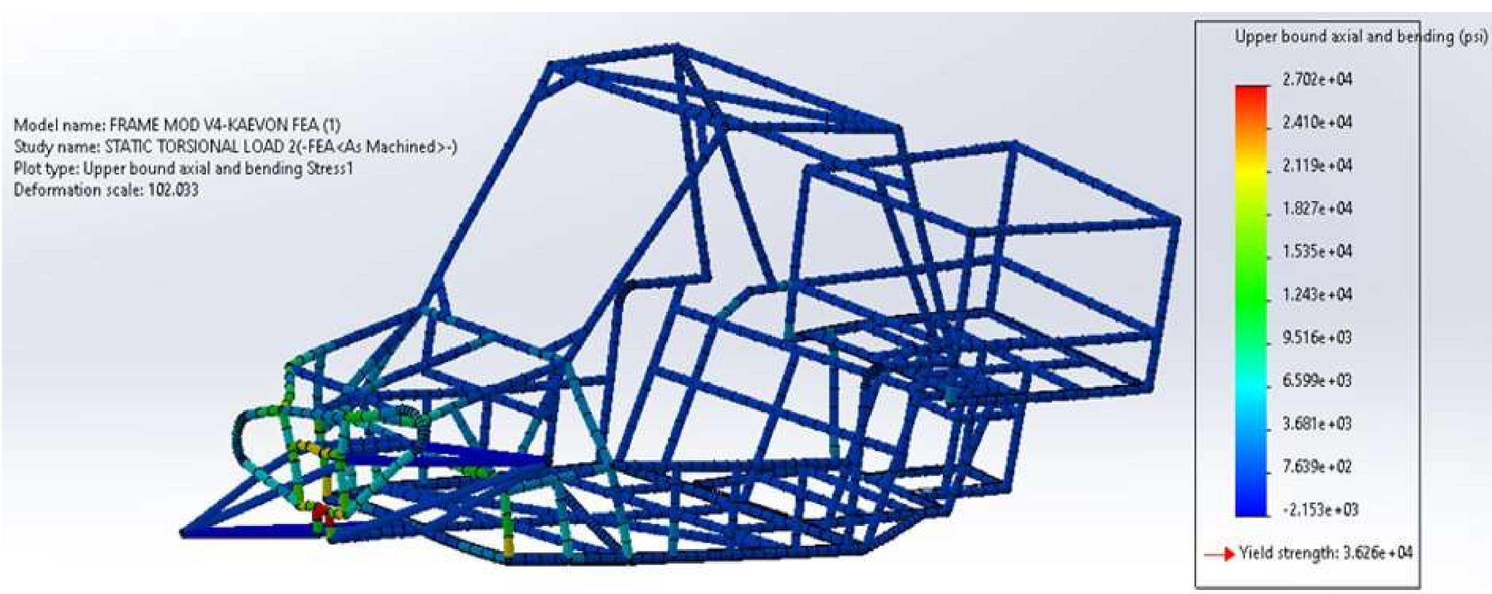


Figure 26: Torsional Load Von-Misses stress

Static Load

For the roll over loading I have made a local connection plate connected to the top of the UTV. This allows a very accurate distributed load. I have put fixture points at the rear and front suspension points that are fully constraint in all directions. We put a distributed load of 700 lbf on the top to represent the UTV flipping on its head (shown in Figure 27 below).

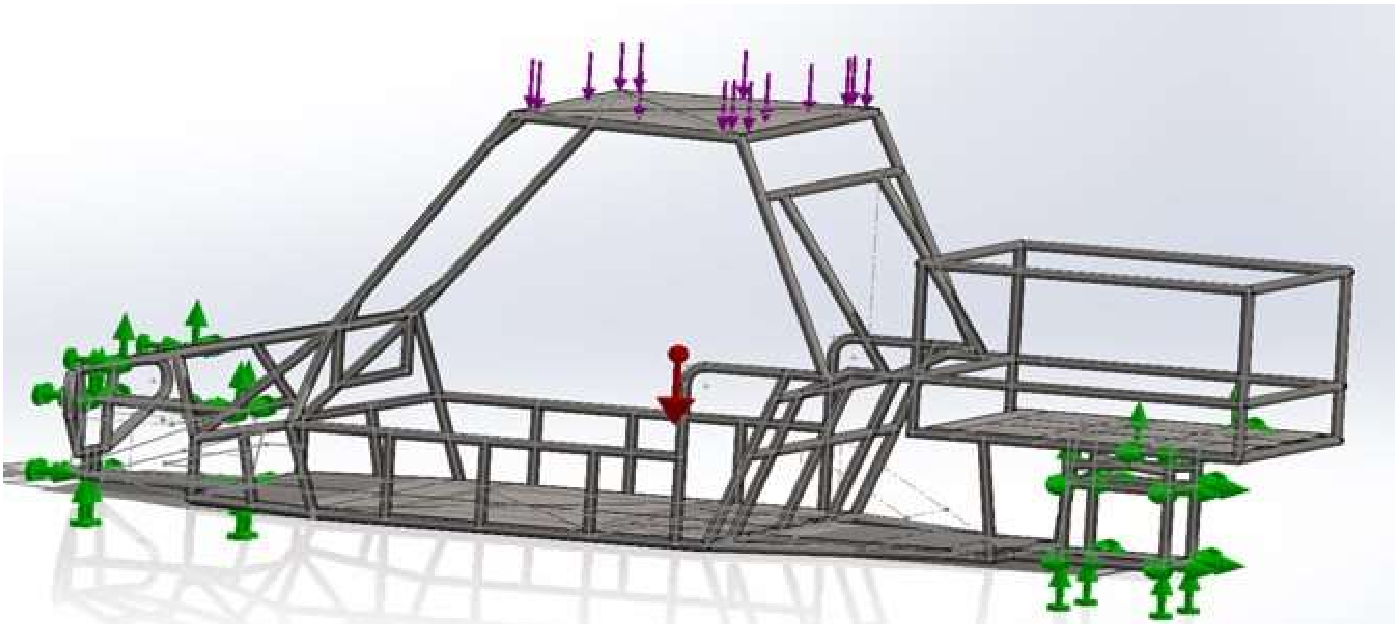


Figure 27: Roll Over Load

In this FEA I figured out that the FOS for the frame will be around 4.1 which is very good for a UTV (shown in Figure 28 below). We found that there will be a deformation with a max of 0.05 in (shown in Figure 29 below). Lastly, we figured that the max stress for this test was around 9ksi which is far under the physical properties of the material (shown in Figure 30 below).

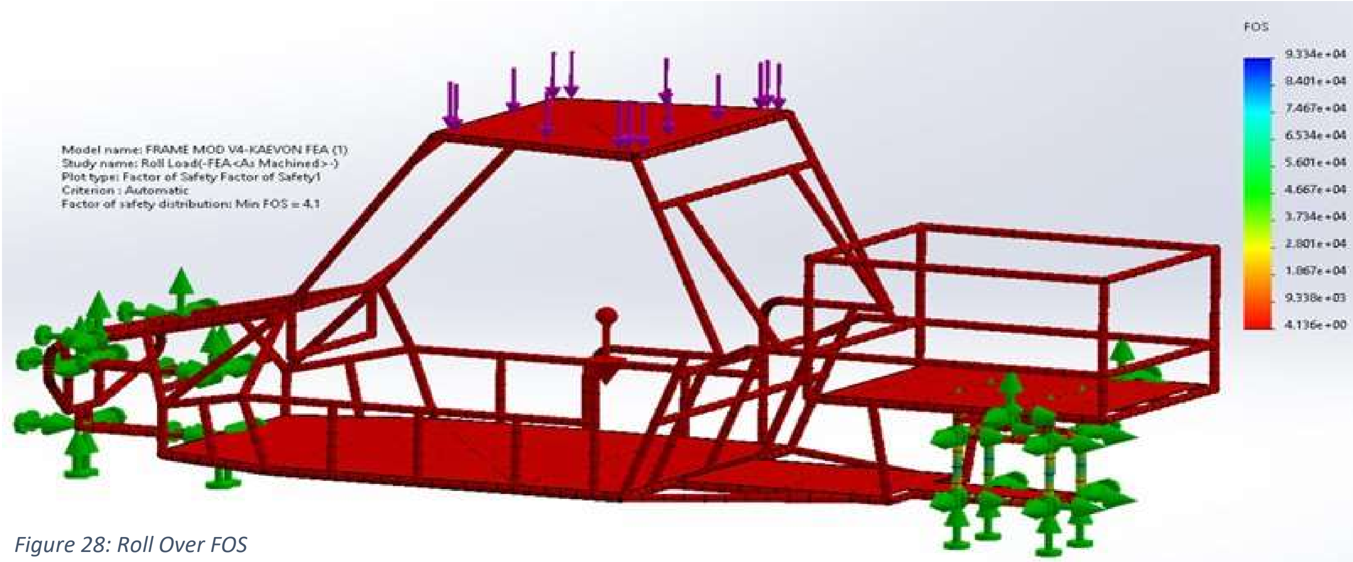


Figure 28: Roll Over FOS

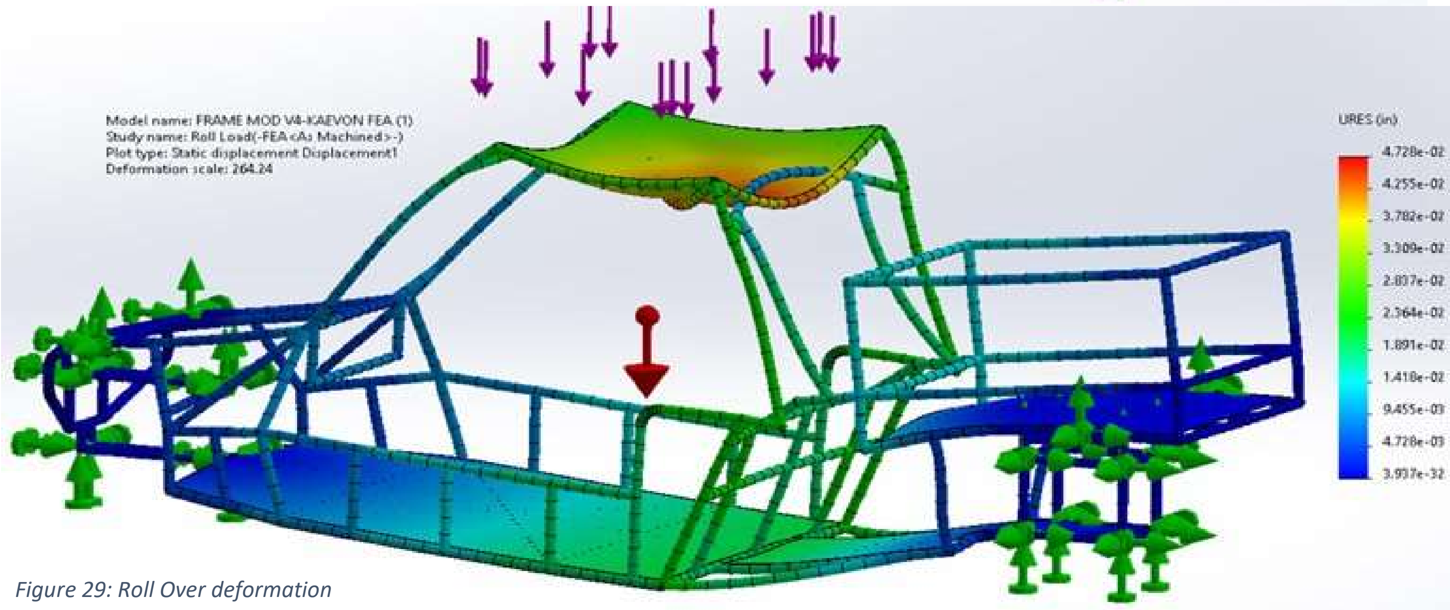


Figure 29: Roll Over deformation

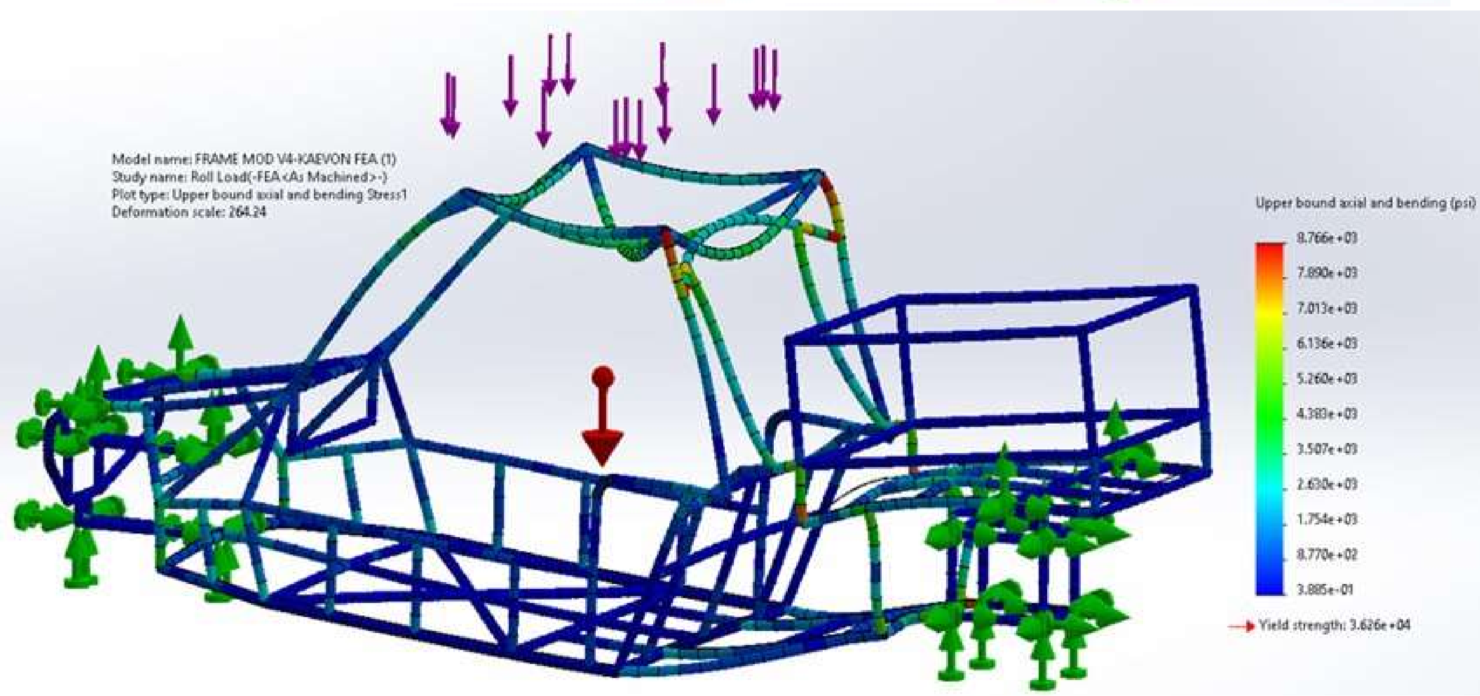


Figure 30: Roll Over Von-Misses stress

Calculations

These were the calculations I have used throughout this process of analysis on our frame. Some of these calculations were repeated for multiple stages.

Front/Rear Impact

Velocity = 30 mph = 44 ft/s

Standard load = 4G

Weight of frame = 400lbs

$$\text{Impact time} = \frac{\text{V}}{a} = \frac{44\ \text{ft/s}}{4*(\frac{32.2ft}{s^2})} = 0.342s$$

$$\text{Force} = \frac{\text{mV}}{\Delta t} = \frac{\left(\frac{400\text{lbs}}{32.2}\right)*\left(\frac{44ft}{s}\right)}{0.342s} = 1600\ \text{lb}_f$$

Side Impact

Standard load = 2G

Weight of frame = 400lbs

Impact time = 0.683s

Force = 801 lb_f

Torsional Stiffness

Standard load = 1G

Weight of frame = 400lbs

Track width = 50in or 4.1667ft

Torque (τ) = rF = 400lbs * 4.1667ft = 1666.667 ft. lb.

$$\text{Angular def} = arctan\left(\frac{vertical\ deflection}{moment\ arm}\right) = \arctan\left(\frac{0.167in}{0.5*(50in)}\right) = 0.3827$$

$$\text{Torsional Stiffness} = \frac{\tau}{angular\ def} = \frac{1666.667}{0.3827} = 4354.68\frac{ft.\ lb.}{deg}$$

Analysis Conclusion

In my analysis I have figured out that this will be a feasible design for our team to move forward with. I made sure to do testing and analysis based on many different sites as far as roll cages go for UTV's and ATV's. In the table below it will show you all tests and FES's results that will prove that this frame design is robust and able to withstand the application we are using it for. Every test was under the safe limit by a very reasonable amount. This simulation was very useful for designing the frame and helping us make changes where changes were needed.

No.	Test Type	Standard Load	Von-Misses Stress (psi)	Deflection (in)	FOS
1	Front/Rear Impact	4G	11,070	0.0377	3.3
2	Side Impact	2G	4,553	0.0122	8
3	Static Loading (AMP)	3G	25,890	0.1265	1.4
4	Static Loading	1G	10,070	0.4698	3.6
5	Torsional stiffness	1G	27,020	0.1167	1.3
6	Roll Over	1G	8,766	0.0473	4.1

Bill of Materials

Below in *Figure 31* is our full project Bill of Materials.

Part Name	Manufacturer Part Number	OEM Part Number	Quantity	Price	Link	Totoal Price
POLARIS - NUT	7547237	164103	16	$2.90	http://www.ad	$46.40
POLARIS - RIM, FLAT BLACK, 8 inch wide	1520263-463	164104	4	$133.92	http://www.ad	$535.68
POLARIS - VALVE, RIM	1525017	102703	4	$2.90	http://www.ad	$11.60
POLARIS - NUT, CASTLE	7547337	123952	4	$2.18	http://www.ad	$8.72
POLARIS - PIN, COTTER	7661404	102708	4	$2.18	http://www.ad	$8.72
POLARIS - WASHER, CONE	7555796	102706	8	$5.44	http://www.ad	$43.52
POLARIS - KIT-SERVICE HUB W/BEARING	2204717	548821	2	$76.12	http://www.ad	$152.24
POLARIS - STUD, Front	7518654	164106	8	$2.90	http://www.ad	$23.20
POLARIS - DISC, BRAKE, FRONT	5250068	164107	2	$47.12	http://www.ad	$94.24
POLARIS - RING, RETAINING	7710440	132032	2	$11.20	http://www.ad	$22.40
POLARIS - CARRIER, BEARING, RH	5135443	164110	1	$105.31	http://www.ad	$105.31
POLARIS - CARRIER, BEARING, LH	5135442	164111	1	$157.54	http://www.ad	$157.54
POLARIS - HUB, REAR WHEEL	5135113	130783	2	$75.24	http://www.ad	$150.48
POLARIS - STUD, Back	7518378	133220	8	$1.45	http://www.ad	$11.60
POLARIS - DISC, BRAKE, REAR	5248250	130782	2	$54.38	http://www.ad	$108.76
POLARIS - BOLT, Back	7515522	103326	8	$2.54	http://www.ad	$20.32
POLARIS - BEARING, CARRIER, WHEEL	3514635	132030	2	$42.05	http://www.ad	$84.10
26X8-12 Tires			4	$100.00		$400.00
POLARIS - ASM., FRONT BRAKE CALIPER, LH	1911186	121132	1	$252.29	http://www.ad	$252.29
POLARIS - ASM., FRONT BRAKE CALIPER, RH	1911187	121133	1	$252.29	http://www.ad	$252.29
POLARIS - ASM., REAR BRAKE CALIPER, RH	1911545	162714	1	$243.59	http://www.ad	$243.59
POLARIS - ASM., REAR BRAKE CALIPER, LH	1911544	300260	1	$243.59	http://www.ad	$243.59
FRONT Brake, Caliper Mounting, BOLT	7518760	122057	4	$6.16	http://www.ad	$24.64
REAR Brake, Caliper Mounting, SCREW, CAP	7512365	102879	4	$1.45	http://www.ad	$5.80
REAR Brake, Caliper Mounting, WASHER STEEL	7558402	102877	4	$0.72	http://www.ad	$2.88
REAR Brake, Caliper Mounting, LOCK WASHER	7552901	102878	4	$0.72	http://www.ad	$2.88
POLARIS - WELD-CONTROL ARM UPR FR LH BI	1018203-458	OEM599182	1	$122.66	http://www.ad	$122.66
POLARIS - WELD-CONTROL ARM UPR FR RH BI	1018204-458	OEM599183	1	$122.66	http://www.ad	$122.66
POLARIS - WELD-CONTROL ARM LWR FR LH BI	1018205-458	OEM599184	1	$122.66	http://www.ad	$122.66
POLARIS - WELD-CONTROL ARM LWR FR RH BI	1018206-458	OEM599185	1	$122.66	http://www.ad	$122.66
POLARIS - TUBE, PIVOT	5136324	OEM162986	4	$15.22	http://www.ad	$60.88
POLARIS - BUSHING, A-ARM, LONG, GREY	5436973	OEM162988	8	$6.89	http://www.ad	$55.12
POLARIS - ZERK, FITTING, THREADED	7080433	OEM105184	4	$1.45	http://www.ad	$5.80
POLARIS - BALL-JOINT, 8MM, 5140	7061220	OEM1130933	4	$51.84	http://www.ad	$207.36
POLARIS - RING, RETAINER	7710533	OEM121633	4	$2.54	http://www.ad	$10.16
POLARIS - SCREW, FLANGE	7518458	OEM162999	4	$7.61	http://www.ad	$30.44
POLARIS - NUT, FLANGE	7547313	OEM101353	4	$1.45	http://www.ad	$5.80
POLARIS - NUT, NYLOK	7547405	OEM163000	4	$0.72	http://www.ad	$2.88
POLARIS - SCREW, FLANGE	7516733	OEM163001	4	$6.89	http://www.ad	$27.56
Rear Shocks - ALREADY PURCHASED						
Front Shocks - ALREADY PURCHASED						
Rear Control Arms - ALREADY PURCHASED						
Solid Shaft Collar	1276675		1	$2.15	https://www.su	$2.15
3/4" Pillow Block Bearing	120412P		1	$10.40	https://www.s	$10.40
3/4"x36" Keyed Shaft	12982753		1	$25.35	https://www.s	$25.35
Husqvarna Fuel Tank	581290101		1	$93.99	https://www.a	$93.99
Polaris Prop Shaft	1332904		1	$69.50	https://www.p	$69.50
22HP Predator V-Twin Engine			1	$949.99	https://www.h	$949.99
Polaris RZR 900 Differential	1334309		1	$899.99	https://www.e	$899.99
13 Tooth 3/4" Bore 40 Pitch Roller Chain Sprocket	1212313		1	$5.95	https://www.s	$5.95
3/4" Bolt Flange Bearing	1204122C		1	$10.70	https://www.s	$10.70
#40 Roller Chain	1116340		1	$23.25	https://www.s	$23.25

Figure 31: Bill of Materials

Fabrication and Assembly

Fabrication Methods

- Utilize tools at the Victory Parkway Campus North Lab to manufacture and assemble such as:
    - Mig Welder
    - Plasma cutter
    - Lathe
    - Drill press
    - Hand tools (wrench, ratchet/socket, screwdriver, Allen wrench, mallet, measuring tape)
    - Power tools (drill, jigsaw, chop saw, griding/cutting wheel)

Frame Fabrication

Fabrication for the frame was a top priority at the beginning for our team. Since everything mounts to the frame it was crucial to start on the fabrication as soon as possible. First step was to purchase tube steel to add and modify. Since we were given an existing cage from a go cart shown in *Figure 32* below we had to figure out what parts we needed to remove to make it match our model.

Figure 32: Starting Frame

This first thing we cut of the UTV was the from suspension mounting bars. Shown below in *Figure 33* is the original cage with the red lines drawn on the picture to show exactly sections got cut off. We did this process using an angle grinder with a cutting wheel attached. Then the next picture *Figure 34* shows the frame with those sections cut out.

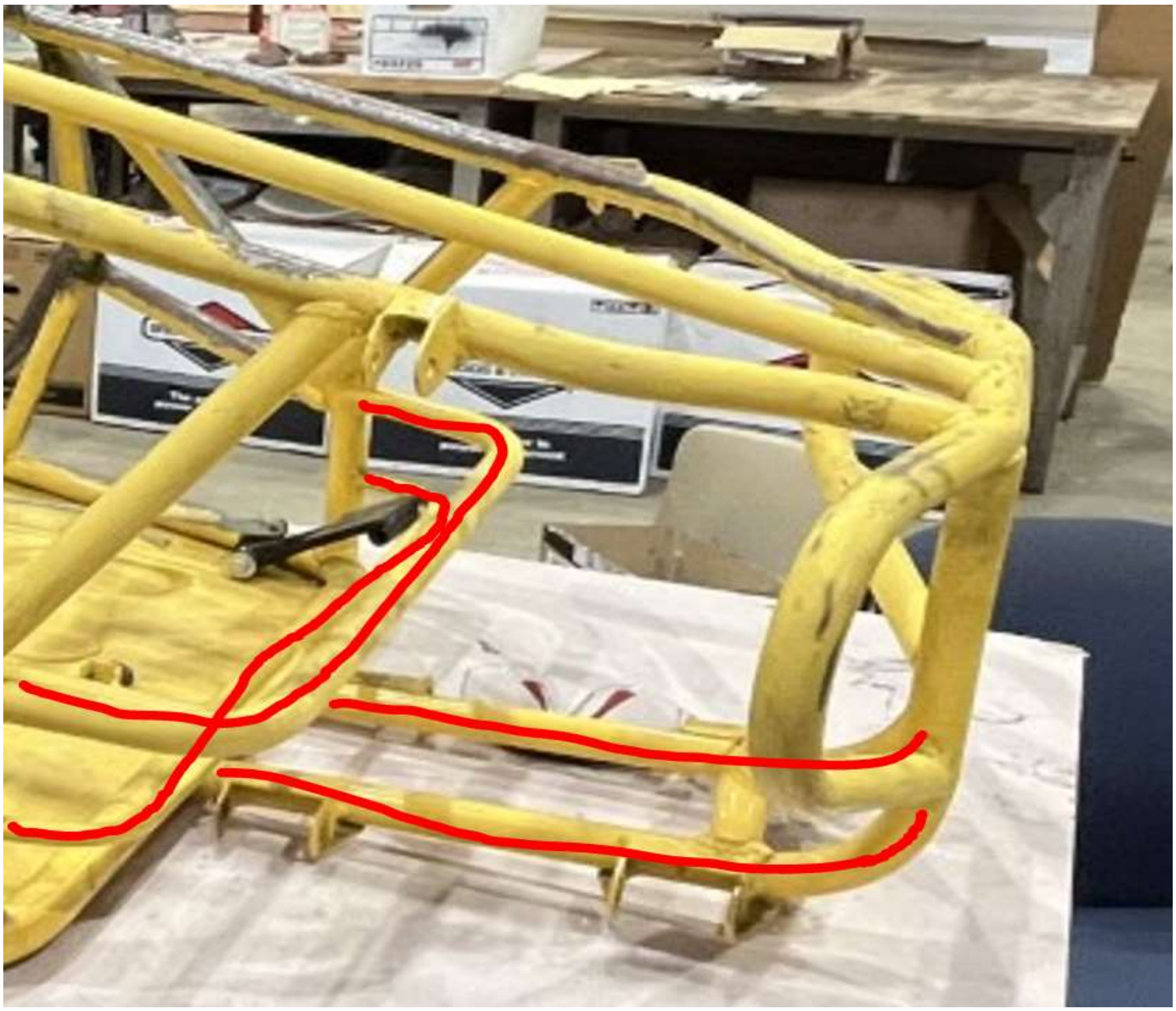


Figure 33: Original Nose

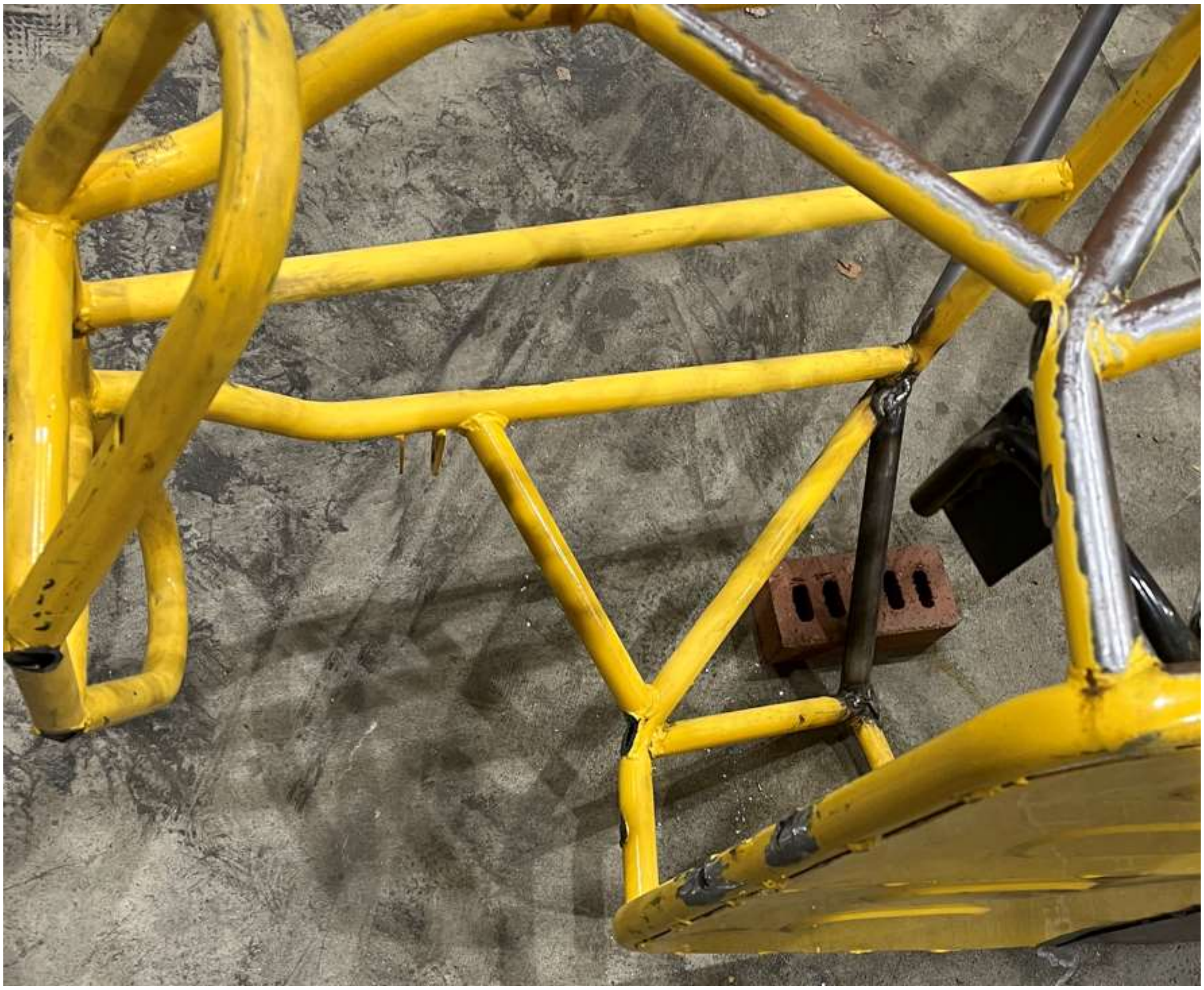


Figure 34: Cut Nose

Next, we had to remove the thin metal under the frame (shown in *Figure 35*). This was not structural to this frame, and it was needed to come off so we could better reinforce the bottom of the frame by putting and "X" shaped cross members shown in *Figure 36* below.

Figure 35: Removal of bottom plate

Figure 36: "X" member

We made a separate sub assembly of the rear bottom and then welded it to the back of the frame shown in *Figure 37&38*. After that was assembled we were able to mount out engine and exactly where to cut the frame to fit the engine (shown in *Figures 39&40*).

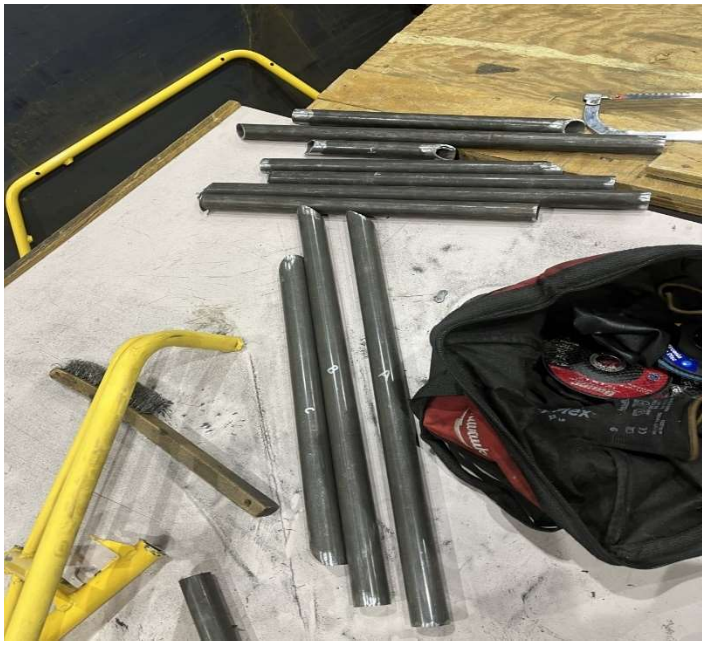


Figure 37: pieces for rear

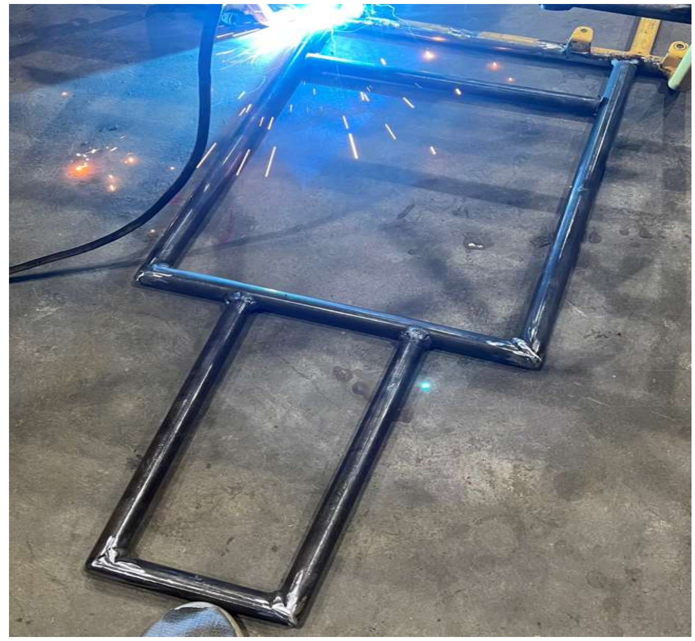


Figure 38: Rear Attachment

Figure 39: Engine interference

Figure 40: Engine Clearance

We manufactured our own mounting brackets for the control arms show in *Figure 41*. Once we had the mounting brackets we started to remount the front control are bars to the correct position we needed as shown in *Figure 42*. Once we got the two bars welded in the correct place and brackets put on we welded another "X" cross member to add rigidity to the suspension (shown in *Figure* 43). Then, after the bottom control arm mounting bars were welded we welded a top control arm bar so when we are ready to weld the pipes for the top control are we have a support bar to weld it to (shown in *Figure 44*).

Figure 41: Manufactured Mounting Brackets

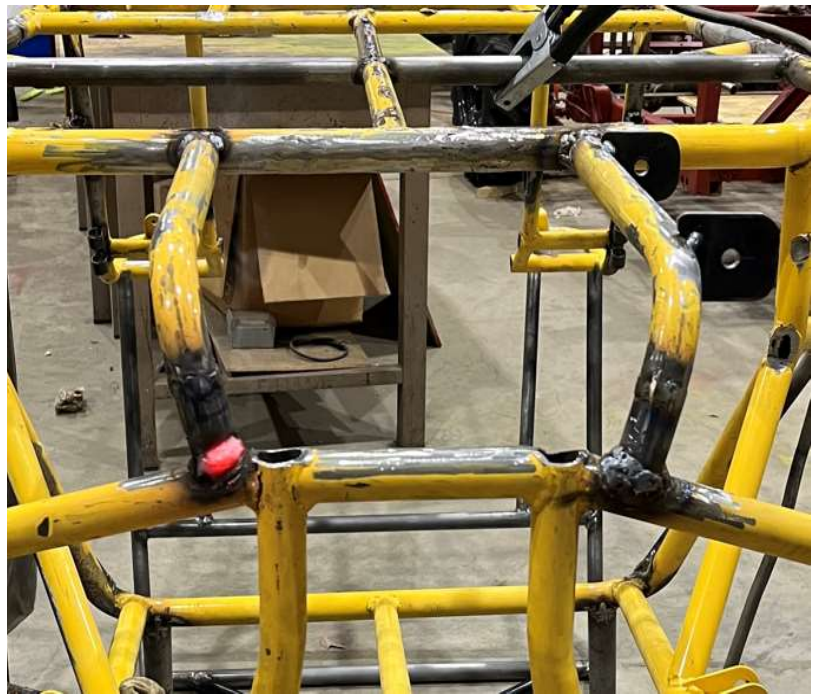


Figure 42: Front control bars

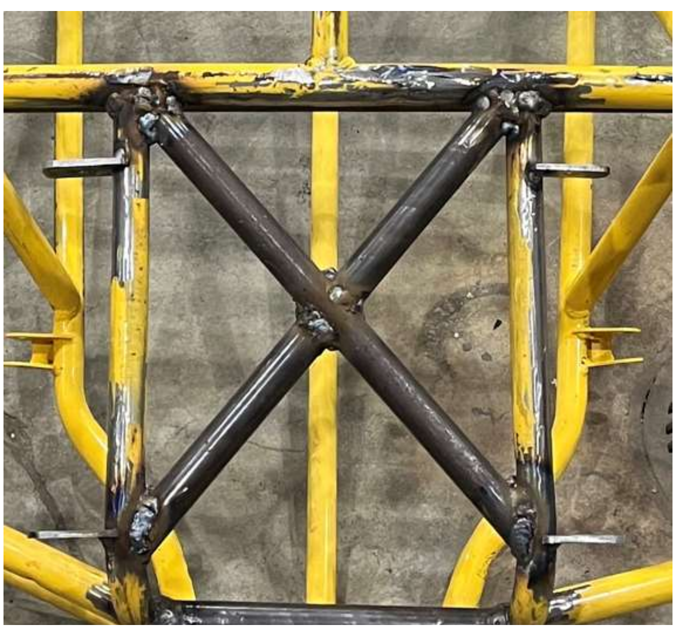


Figure 43: "X" member

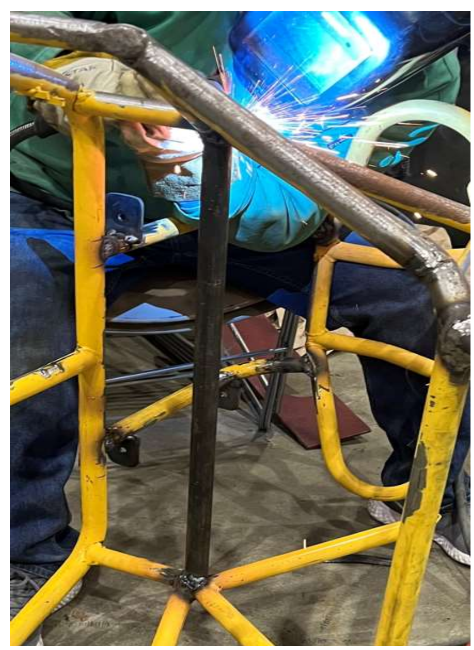


Figure 44: Top Control arm bar

Then we received our order of sheet metal we were going to cut and use for the bottom plates of both the cabin and engine mounting. This was a 12-gauge sheet of hot rolled steel that was plasma cut to required size as shown in *Figure 45*. In *Figure 46* it shows the pieces cut and laid out on the frame before welding to get an idea of where to grind to help the pieces sit flush with the bottom pipes. Once flush we welded the plates to the top and bottom of the frame piping and welded the front and back plates together as well to get more rigidity.

Figure 45: Plasma cut flooring

Figure 46: Bottom plate mounting

We welded a bar going the total height of the cabin and one the length of the cabin for end to end shown in *Figure 47*. In my FEA analysis on the frame when I included these members it drastically increased my factor of safety values across the board. It is a good brace from front to back of the vehicle. After those were welded we welded vertical pipes from the horizonal brace to the floor as shown in *Figure 48*.

Figure 47: Bracing Bars

Figure 48: Vertical Bracing bars

To finish the front upper control arm mounting we had to at a horizontal pipe coming of the pipe we welded in *Figure 44* above. This was moved around, and tack welded where the tire would sit 90° to the floor so there is no camber or toe to worry about (shown in *Figure 48)*.

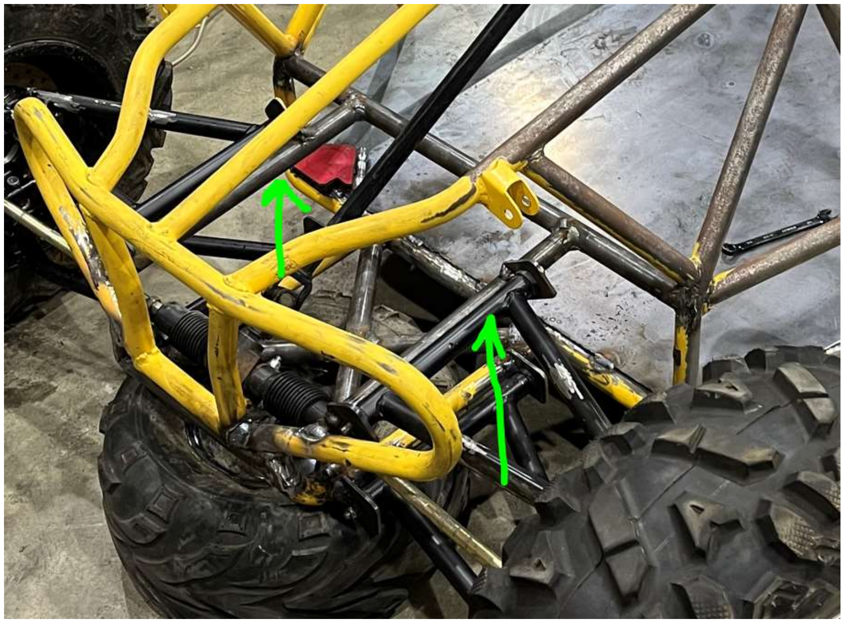


Figure 48: Upper control arm mount

For the rear upper control are we had to make a V-shape design as show in *Figure 49&50*. This was needed because if we put it parallel to the bottom control arm the top of the wheel would be angles towards the vehicle which is not good for our application.

Figure 49: rear suspension

Figure 50: Rear suspension

Once the rear suspension was mounted we were able the subassembly of the cargo bed. This consisted of making three equivalent rectangles out of tubing shown in *Figure 51&52*. Next, we added the vertical pipes shown in *Figure 53*. Then finally welded to the frame in the rear showed in *Figure 54*.

Figure 51: Bed rectangle

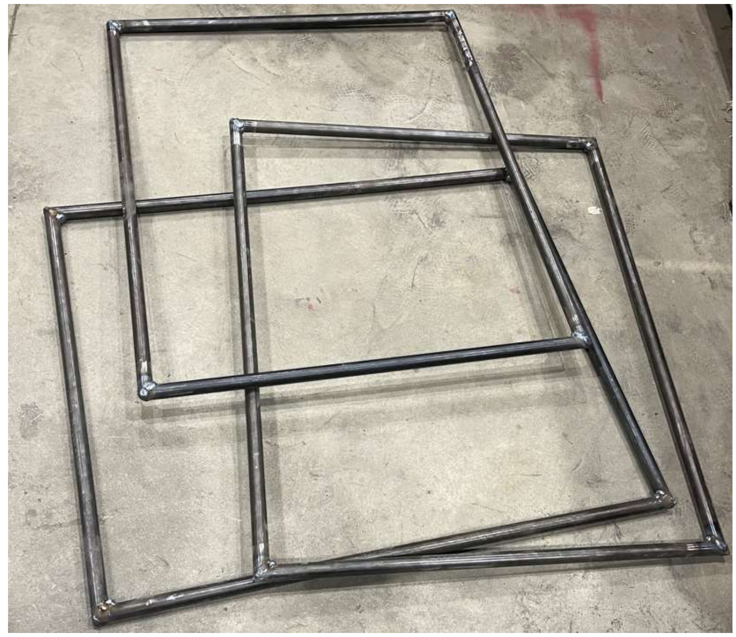


Figure 52: 3 Bed pieces

Figure 53: Bed vertical members

Figure 54: Finished bed mounting

Before and After

After finishing up welding and cutting we were able to paint the UTV we used Sherman Williams Krylon paint. We made our colors black and red in honor of graduating from UC. Below is a comparison of before and after manufacturing of the frame (shown in *Figure 55&56)*.

Figure 55: Starting frame

Figure 56: Finished frame and painting (April 2022)

Test and Proof of Design

Engineering Characteristics Tested

- Top speed
- Braking distance
- Payload capacity
- Turning radius
- Overall dimensions (weights and width)

Testing Methods

Top speed: Position UTV on a straight, level surface and accelerate until engine can no longer produce a higher velocity; note speed on speedometer once max velocity is reached.

Braking distance: Accelerate to top speed and setup wide-angle, slow-motion camera to capture braking process; note where braking begins in the video and correlate the video to physical setting to measure distance necessary to come to a full stop.

Payload capacity: Load three grown men into the bed and observe whether the suspension can support the weight or not; put two grown men in the cab as well. ANSI/OPEI B71.9-2016 requires a UTV to carry at least 350 lbs. of payload (3). As seen in Figure 29, the UTV can comfortably carry 3 grown men (~500 lbs.) in the bed (shown in *Figure 57)*.

Figure 57: Loaded bed

Turning radius: Align the UTV in the parking lot and mark the outward facing, front tire. Turn the wheel all the way to one side and begin to turn. Conclude the test once the UTV has completed a full 180° turn and measure the distance of the same outward facing, front tire from the beginning mark. This measurement is the turning diameter. Therefore, divide the value by two to obtain the turning radius. Desired turning radius for the UTV is set at 25ft because a 2020 Polaris RZR's turning radius is about 22ft.

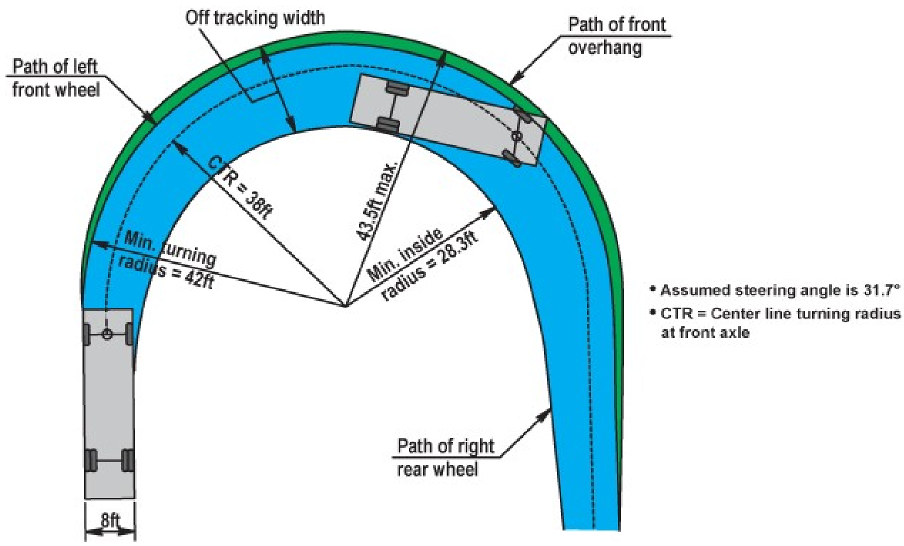


Figure 58: Turning Radius

Weight: A shop crane was utilized to test the overall weight of the UTV. The crane was set to a limit of 1 ton (2000 lbs.) and connected to the UTV. The crane was raised and the UTV lifted off the ground, proving that its weight is less than 2000 lbs. and thus in compliance with the ANSI/OPEI B71.9-2016 standard for a UTV.

Figure 59: Gross Weight

Width: The UTV was placed on level ground and a tape measure was used to measure the UTV at its widest point.

Testing Results

Characteristic Tested	Desired Value	Value Achieved
Top speed	25 mph	25 mph
Braking distance	30 ft	TBD
Payload capacity	>350 lbs.	~900 lbs.
Turning radius	~25 ft	~23 ft
Weight	<4000 lbs.	<2000 lbs.
Width	<80"	54"

Shaft Failure

During the testing phase, the input shaft on the forward/reverse gearbox sheared while trying to drive up a very steep hill near the Victory Parkway Campus (shown in *Figure 60*). The steep hill caused the CVT to shift into its lowest gear/highest torque setting to drive the UTV up the hill. This shaft was not tested using FEA because it was a supplier part purchased by the previous UTV group, and therefore it was not expected to fail. This shaft failure meant some testing for the UTV could not be conducted, as indicated by the "TBD" in the "Value Achieved" section of the table above. However, with the existing drivetrain, the UTV did achieve about 10 mph and the brakes do function properly.

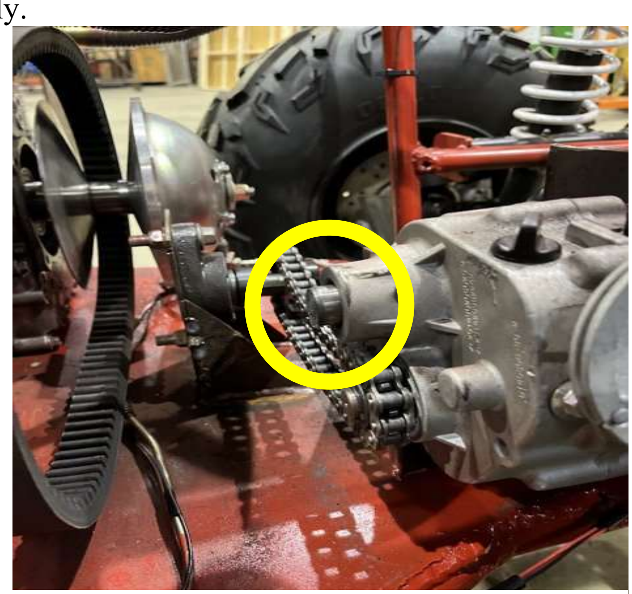


Figure 60: Shaft Failure

Due to the shaft failure, the drivetrain had to be redesigned to make the UTV drivable again. It was decided that a Schafer Driveline forward/neutral/reverse gearbox and differential would be purchased and installed into the UTV (shown in *Figure 61*). The Schafer gearbox will eliminate the need for the old gearbox, as well as the chain and sprocket connected to the driveshaft, U-joint, and existing differential.

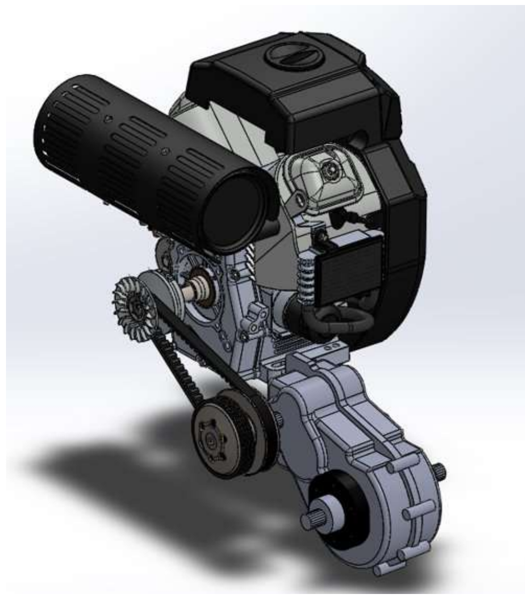


Figure 61: New Drive Train

The new drivetrain setup was completed and produced a more robust driving experience. The UTV was able to achieve the top speed of 25 mph, as well as scale the steep hill that caused the original drivetrain to fail. The UTV can also traverse offroad terrain. When the CVT is in a 1:1 ratio, the new drivetrain should achieve 30 mph and a top speed of 51 mph when the CVT is in its maximum ratio of 0.59:1. Braking distance has still not been tested.

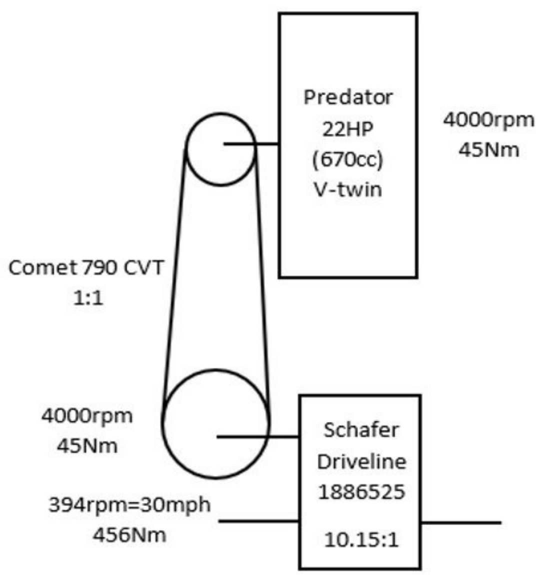


Figure 62: New Drive train schematic

Project Management

Proposed Budget

- Given the purchased components that the group already has, and the frame already having been built, we set a budget limit of $8,000 to complete the project.
- $1,050 remaining for materials, like tube steel, steel plates, sheet metal, etc.)

Component	Cost
Suspension	$1,250
Drivetrain	$2,500
Brakes	$1,100
Wheel Assembly	$2,100
Total	$6,950

Actual Budget

While the proposed budget was $8000, due to the shaft failure and other various purchased parts, the final cost of the UTV was likely more in the range of $10,000.

Proposed Schedule

Remaining Components Put on Order	12/10/21
Components Arrive	01/10/22
Assembly Start	01/10/22
Finish Assembly	04/01/22
Begin Testing	04/04/22
Tech Expo	04/15/22

Actual Schedule

Due to the Covid-19 pandemic, the first two weeks of the spring 2022 semester were conducted virtually, meaning we did not have the opportunity to get into the lab and physically work on the UTV until January 24. As a result of this two-week delay, our schedule had to be adjusted. The shaft failure also caused a setback to the schedule since the drivetrain had to be rebuilt and retested.

Assembly Start	01/24/22
Finish Assembly	04/13/22
Tech Expo	04/14/22
Begin Testing	04/15/22
Final Presentation	04/26/22
Finish Redesigned Drivetrain Assembly and Testing	04/28/22

Plan to Finish

After completing the assembly of the redesigned drivetrain, the UTV is functionally finished. The UTV runs and drives as it was intended.

Conclusion

Overall, this project has exceeded my expectations. We all put in an immense amount of time into this, and it was all worth it. Everything about the project was team oriented. There was not one thing where we didn’t talk about it with the team. This was because everyone’s different part of the UTV had to fit together with each other. I felt very comfortable in the early stages of this project when we were in the design phase using SolidWorks. Once we got into the fabrication and assembly I think all of us were out of their comfort zone. We all have only had one welding class with minimal experience so when we were tasked with fabricating the whole frame at first it was overwhelming. But week after week we kept getting better and more confident in out work. Due to time constraints, we were working up to 20-30 hours a week into our project trying to get it ready by Tech Expo and ultimately the end of the semester. Despite some setbacks such as missing two weeks due to covid and things like gearbox failures our final testing got effected the most. With all the set backs we got a whole new drivetrain and put it together in two weeks and were able to meet all our ANSI standards required to recognize our vehicle as a UTV.

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