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EML 4905 Senior Design Project

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Requirement for the Degree of
Bachelor of Science
In
Mechanical Engineering

Human Powered Lunar 100% Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Juan Manuel Valencia, Bruno Pinillos, and Juan Carlos Herrera, it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Abstract

The objective of this project was to design, analyze and construct a Moon Buggy to compete in the "NASA Great Moon Buggy Race." Following rules provided by NASA, a buggy has been built to transverse the rough terrain of the competition, which simulates the Moon's surface. To achieve this, a study of the construction of a lightweight heavy-duty suspension and a design for the optimum gear ratio has been done in order to achieve maximum performance within the boundaries given. Different studies were done using programs such as SolidWorks and ANSYS to obtain data that would help predict the behavior of the machine before it was created. The data obtained from the CAD software extremely helped in the construction and optimization of the vehicle. Using that data adjustments were made to the design in order to make the vehicle structurally sound.

To effectively achieve the desired results, the rough terrain that would be encountered at the competition was replicated. This replication was made in order to adequately examine the vehicle and assure that it would be able to overcome all the obstacles confronted. The vehicle performed as expected and all necessary adjustments were made that was crucial during testing that may have caused problems during the actual competition.

1. <u>Introduction</u>

1.1. Problem Statement

Between 1963 and 1972, NASA developed the Apollo Program. Out of all the Apollo missions, just six reached and landed on the Moon. Out of these six missions only three of these missions (15, 16, 17) used Lunar Roving Vehicles (LRV) or Moon Buggies. These vehicles were made in order to extend and assist the astronaut's explorations on the Moon.

The challenge presently faced, is that of designing, constructing, and improving the Moon Buggy that was originally designed in 1971. Faced with many of the same hurdles that were encountered in 1971, a Moon Buggy must be designed. The hurdles that are to be overcome are as follows:

- The vehicle must be completely human powered.
- No energy storage device is permitted.
- Must collapse to fit in a 4 ft. x 4 ft. x 4 ft. box
- Assembled Vehicle with passengers on board must be 15" from the ground.
- Not permitted to be wider than 4 ft. measured at the outer surface of the wheels.
- The turning radius must be less than 15 ft..
- Must contain fenders and simulated parts such as an antenna, batteries, camera, and screen.

Furthermore, the vehicle will carry only two passengers. These passengers are to be one male and one female. These two passengers must carry the preassembled vehicle a total of 20 ft. without the help of wheels or any other form of assistance that is not physically carrying the vehicle. This also includes dragging the vehicle or any ground contact during the traveling of the set distance. Once they reach the desired distance, the next task is to fully assemble the vehicle.

For obvious safety reasons, the passengers must wear helmets, gloves, snug clothing to avoid any snag and safety goggles. Seat restraints must be designed in order to protect the passengers during motion.

1.2. Motivation

The motivation is to win the competition with the best and most innovative design possible. Research and calculations will go in to the design of the vehicle, as it will be built from scratch. Many conceptual designs will be developed along the way until the achievement of the most efficient design.

Not only is winning the competition a motivation, but also the challenge of the making the design, within itself is a challenge. Another great motivation is the challenge of working with a team and combining ideas from different backgrounds in order to achieve a common result in its own right is a huge motivation.

1.3. Literature Survey

The obstacles currently presented with are similar to those that the original rover team was faced with. It had 17 months from contract approval in October 1969 until delivery at the Kennedy Space Center on April 1, 1971. No other spaceflight hardware or equipment was developed in a time period equaling less than three years.

The team, which included contractors Boeing and General Motors, worked together in new ways to complete and deliver the Moon Buggy to the next phase, which was already under construction. There was no time for errors as the deadline was quickly approaching.

The mobility system of the lunar vehicle, which General Motors had the opportunity to build and design, had the capabilities to overcome obstacles that could be up to 12 in. tall and to cross craters. The tires were made of a woven mesh of zinc-coated piano wire covered by titanium threads.

The power system that was used was two 36-volt silver zinc batteries and four quarter-horsepower electric motors that powered each of the wheels.

The LRV was an early electric vehicle designed to operate on the Moon. With the production of the LRV, the astronauts could drastically extend the distances they traveled on the Moon. Three LRVs were constructed during the Apollo missions. In Apollo missions 15, 16, and 17, the three LRVs that were developed were used. These vehicles were used once a day for each of the three days that the Apollo missions were to last. David Scott and Jim Irwin first piloted the lunar vehicle for Apollo 15, then John Young and Charles Duke for Apollo 16 and finally Gene Cernan and Harrison Schmitt for the Apollo 17 mission.

The original weight and payload capacities of the Lunar Roving Vehicle were that of a mass of 462.9 lbs. and a payload of 1080.3 lbs. The frame was 122.05 in. long with a wheelbase of 90.55 in.. The maximum height was 44.88 in.. The frame was made of aluminum alloy 2219 tubing welded assemblies and consisted of a three part chassis which was hinged in the center so it could be folded up and hung in the Lunar Module quad 1 bay. It had two side-by-side fold-able seats made of tubular aluminum with nylon webbing and aluminum flooring. The suspension consisted of a double horizontal wishbone with upper and lower torsion bars and a damper unit between the chassis and upper wishbone. Fully loaded, the LRV had a ground clearance of 14.17 in., the wheels consisted of a spun aluminum hub and a 32.20 in. diameter and 9.055 in. wide tire made of zinc coated woven 0.0327 in. diameter steel strands attached to the rim and discs of formed aluminum. (1)

When the LRV was to be deployed by the astronauts, it was done so by a series of pulleys, braked reels, which used ropes and cloth tape. When the rover was in the shuttle, it was to be stored in a folded manner and places in such a way that the chassis would be facing out to allow ease of release. As the rover was let down from the bay, most of its deployment would be automatic. The rover components locked into place upon opening. Once the rover was released form the bay the rear wheels would fold out and lock into place allowing for the Lunar Rover to be unfolded. Pulleys again would be used to lower the rover to the lunar surface where the pins, cables, and tripods would be removed allowing for the seats and footrests to be adjusted in order to prepare it for the upcoming expedition.

With this in mind, it is easy to see why the competition revolves around speed and space, as both are major factors in space travel. The longer the deployment time, the higher the oxygen consumption would be by the astronauts. The same can be said for space occupancy on the vessel. The greater the Lunar Rover foot print, the less room that can be used for supplies that are desperately needed by the astronauts.

For this competition, what has been observed is that many groups have not taken into account the correct placement of the center of gravity which would lead to the Moon Buggy either flipping from front to back or from side to side. Other observations are that of the buggy not being structurally sound caused the failure at certain points along the structure, predominately at the center of the vehicle or at the point where the wheels attach to the frame. Within the rules, these issues will be addressed and accounted for in the final design.

1.4. Construction Requirements

See Appendix.

1.5. Passenger Rules

See Appendix.

2. Project Formulation

2.1. Project Objectives

The primary objective of this project is to develop from the ground up a Moon Buggy which is a simplified version of that used by astronauts. Using some of the same methodologies that would be used by NASA, a Moon Buggy will be constructed to overcome terrain similar to that of the Moon's. A course will be laid out with many different obstacles that the Moon Buggy must withstand. Careful consideration to this rough terrain will be given in the design leading up to the competition. Along with the conditions set forth in the previous paragraphs, the Moon Buggy will use the power supplied from the two passengers to take on the course that shall be presented. Although surviving the course is a feat in its own right, the obstacle of time must also be tackled. Being able to find a balance between handling the rugged course while still being able to achieve a low time will be a desired outcome.

3. Conceptual Design

3.1. Concept Design

The design below is a proposed design without a suspension, which would not withstand the extensive beating that the vehicle would take on the lunar surface.

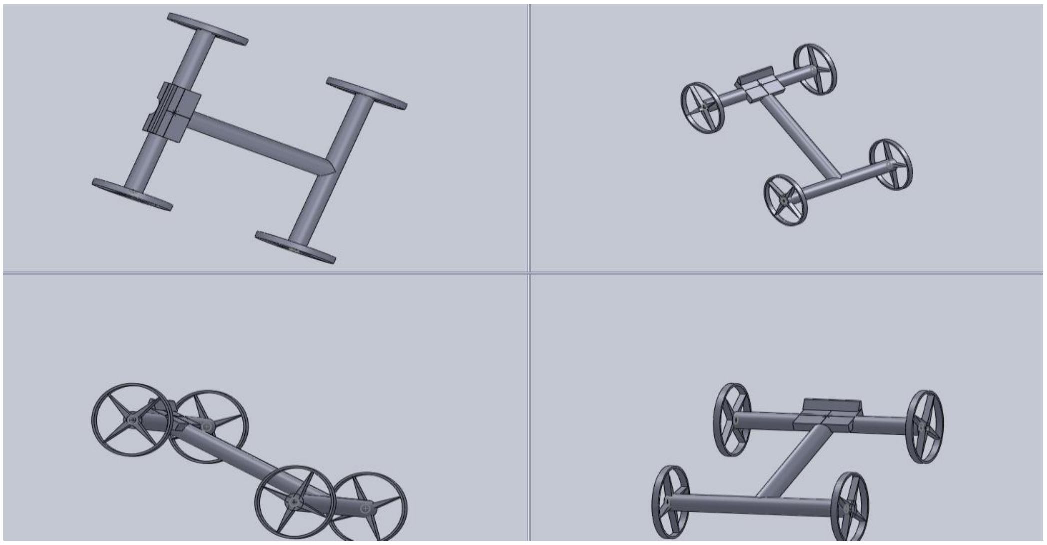


Figure 1 Failed Concept

Below is the conceptual design of the suspension that is to be used. Modifications might need to be made as further testing is being performed to verify that the suspension will withstand the rough terrain that the course will contain.

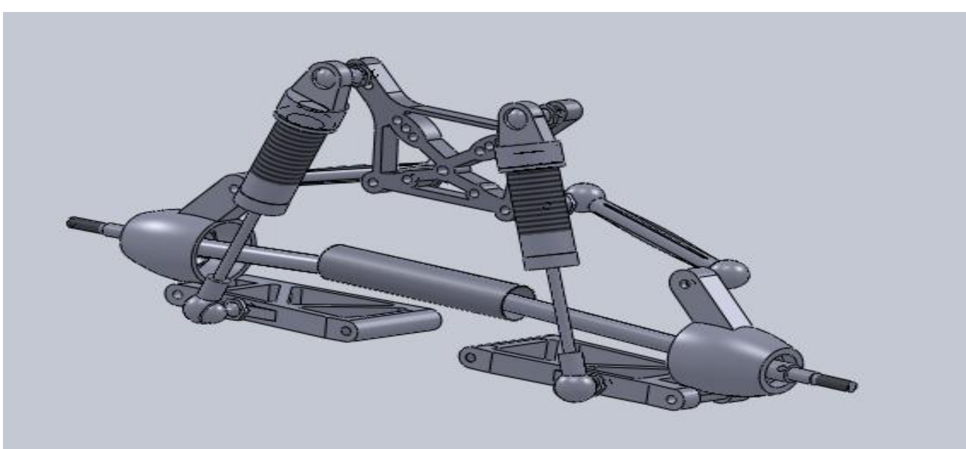


Figure 2 Proposed Suspensions

In the image that can be viewed below is a proposed wheel and rim design that will be used in the design of the Moon Buggy.

Figure 3 Wheel Rim Concepts

3.2. Proposed Design

Figure 4 and Figure 5 contain the design of the chassis along with the front and back suspension. With the constraints set forth by N.A.S.A. the design seen below is the best option at the moment of all concepts being currently explored. These figures also contain the suspension that is needed to overcome the rough terrain the vehicle will be presented with. The evolution of the design can be seen in Figures 6 and 7. These figures demonstrate the seating, pedal placement and steering mechanism locations. What can also be seen is the placement of the hinge that will allow the vehicle to bend in order to meet the criteria set forth by the competition. As can be seen below, in figures 4 and 5 the hinge is placed on the topside of the beam. While on figures 6 and 7 it is placed at the bottom of the beam. This adjustment was done in order for the hinge to be in a position where it is working against the weight of the rider in order for it not to bend at that point. While the setup in figures 4 and 5 would allow the hinge to bend easily as this would be the natural movement of the hinge, which would allow the hinge to bend with the weight. As can easily be seen, this adjustment makes perfect sense.

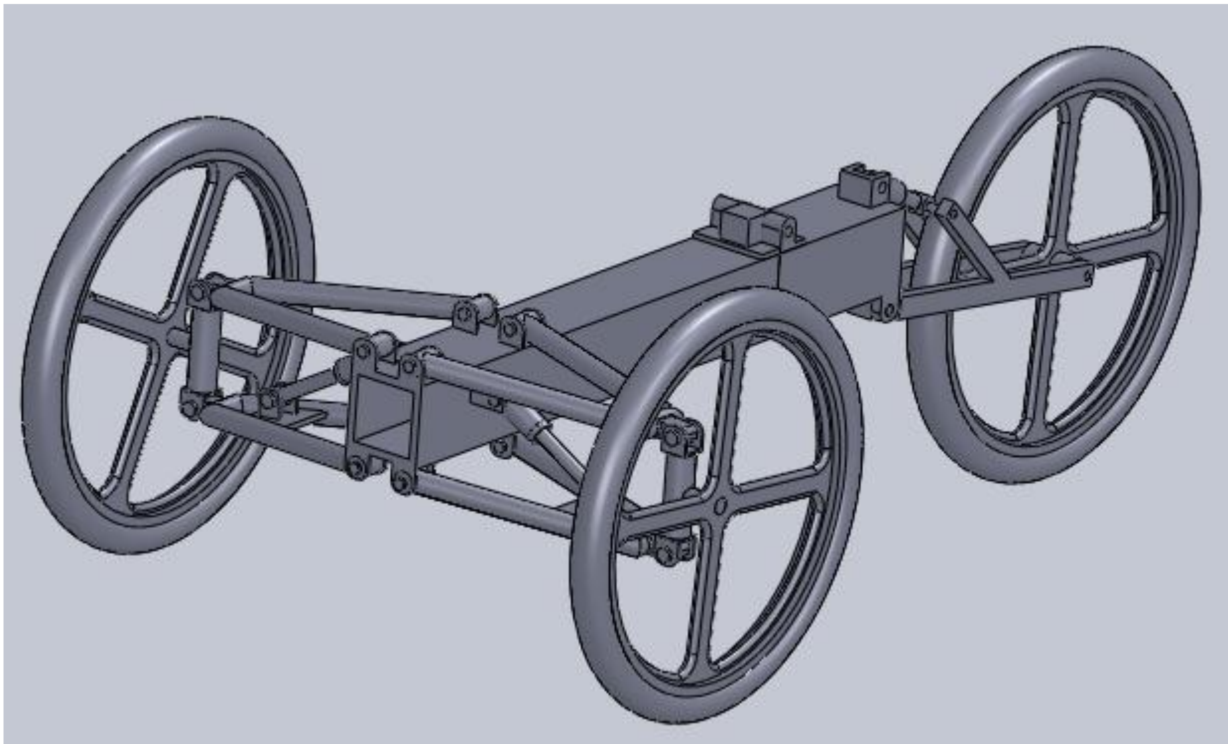


Figure 4 Chassis and Suspension Design

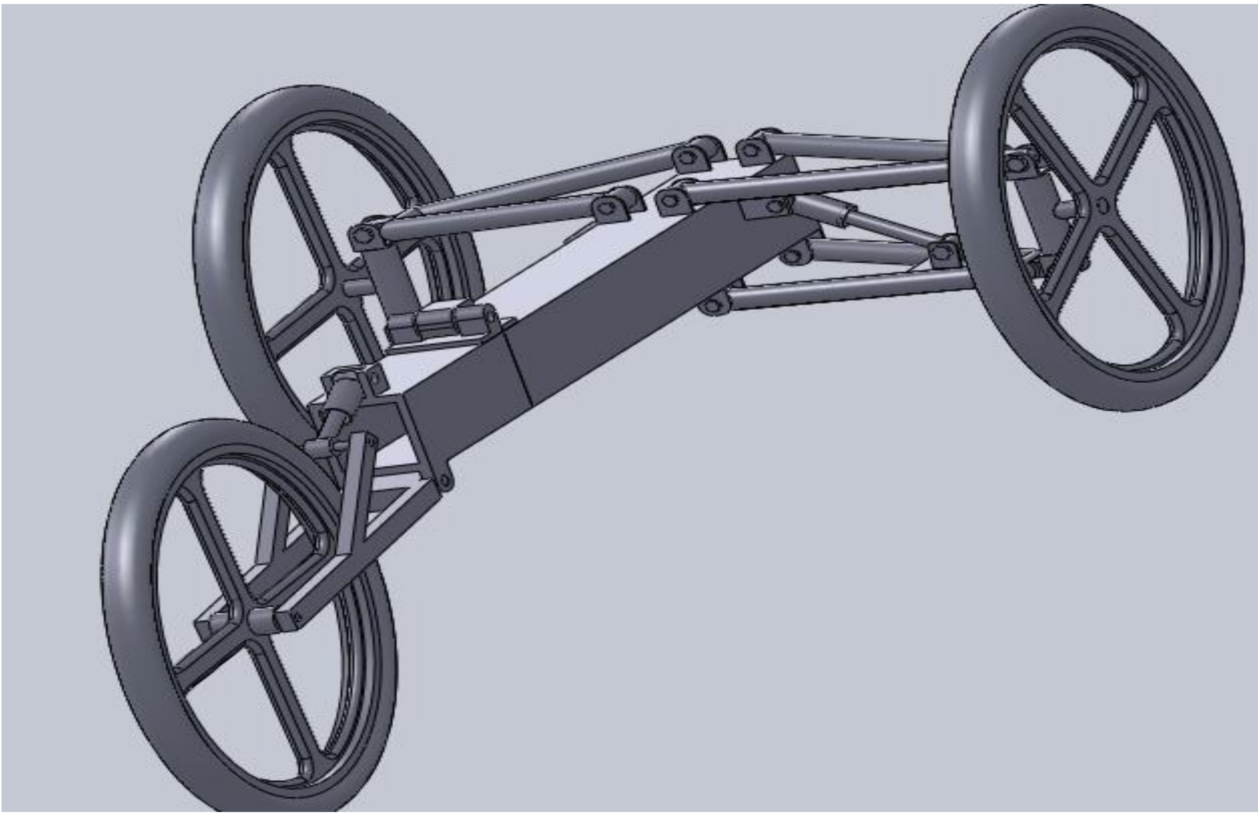


Figure 5 Chassis and Rear Suspension Design

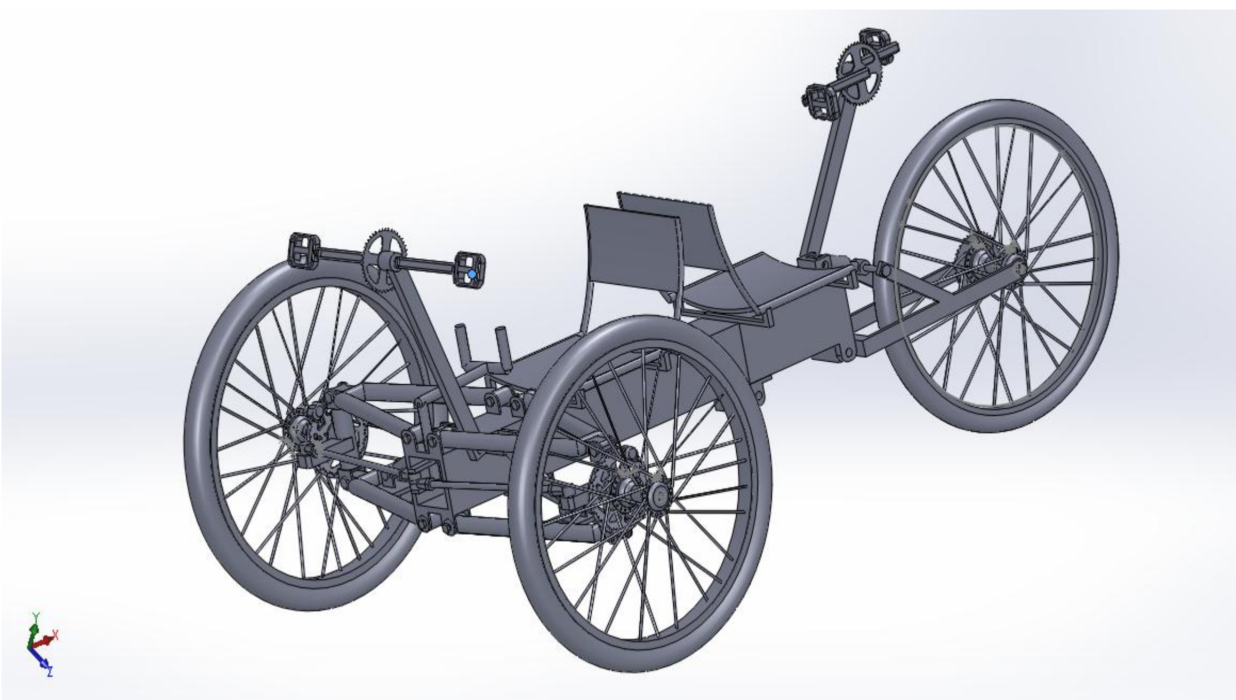


Figure 6 Updated Proposed Design

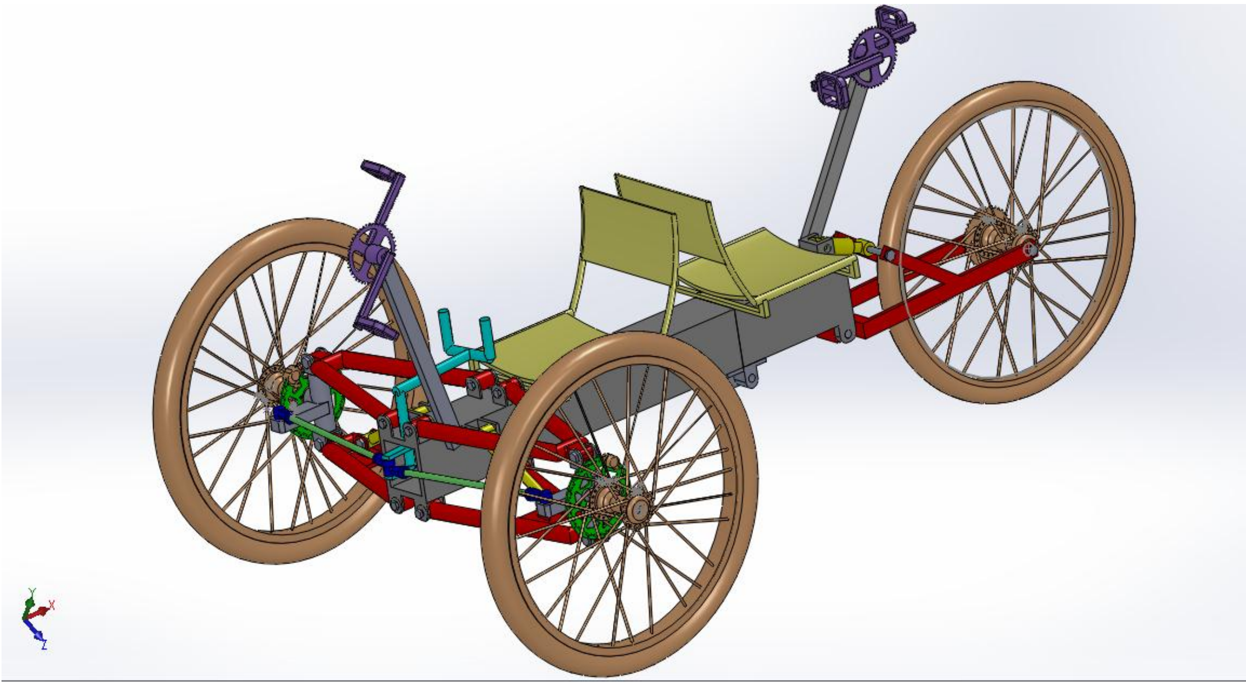


Figure 7 Proposed Design

4. Analytical Analysis

One of the principal concerns of this project is the speed that will be needed for the two passengers to reach the finish line. From previous competitions a good time to run the whole track is more or less five minutes, starting from here the value of the torque needed to be applied, by the passengers could be calculated. From the next equation the average velocity needed to complete the race is found from

$$V = \frac{x}{d}$$

Knowing the velocity at which the Moon Buggy has to travel, the wheels will have the same angular velocity as the second sprocket because a solid shaft connects both of them. For this calculation the angular velocity formula will be used.

$$w = \frac{V}{r}$$

Knowing the number of teeth or the diameter of each sprocket, for the front part of the powertrain, the next formula will relate the angular velocity of each one of the sprockets with its diameter.

$$\frac{w1}{d1} = \frac{w2}{d2}$$

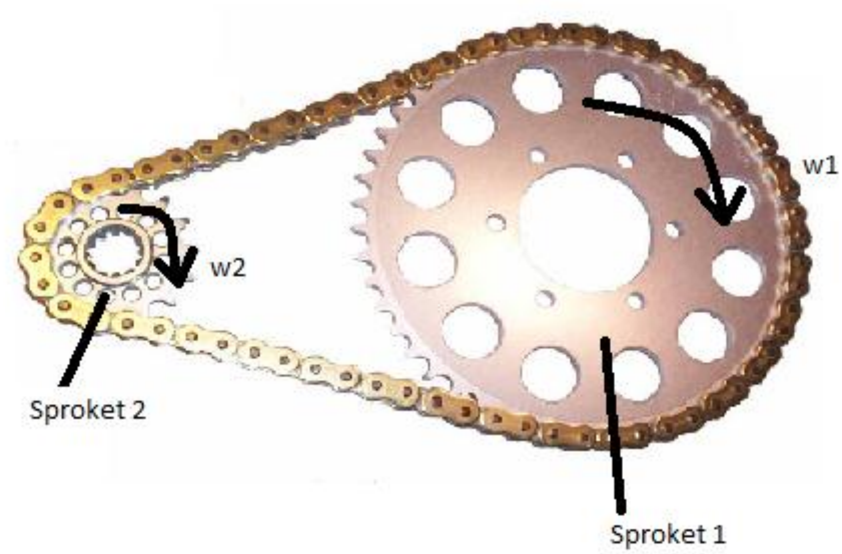
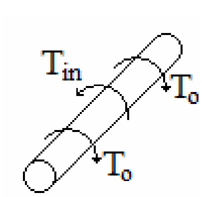


Figure 8 Chain and Sprocket

Now knowing one of the angular velocities of the sprocket connected to the pedals, it is easy to calculate the revolutions per minute (rpm) needed to achieve the average velocity.

It is of primary importance to ensure that the shaft that is going to transmit the torque to the wheels resist the stress to which it is going to be exposed, a safe diameter for the shaft could be calculated from the next formula

$$= \left[\frac{32n}{\pi}\left(\frac{KfMa}{Se} + \frac{\sqrt{3}Tm}{2Sut}\right)\right]^{1/3}$$



Where n is the factor of safety that is wanted, M_a is the midrange bending moment, T_m is the midrange torque, S_{ut} is the tensile strength, this last values depends on the material and can be found from tables of the mechanical design book, finally k_f is the stress concentration factor that could be found using the next formula

$$Kf = 1 + q(Kt - 1)$$

Where q is the notch factor and k_t is the stress concentration factors, these two values are found on tables of the mechanical engineering design book.

The value of S_e is the endurance limit of the shaft and has to be calculated using the following equation

$$Se = KaKbKcKdKeSe'$$

k_a **Surface Factor**

$$Ka = aSut^b$$

Surface Factor k_a		
Surface finish	a (MPa)	b
Ground	1,58	-0,085
Machined or Cold Drawn	4,51	-0265
Hot rolled	57,7	-0,718
As Forged	272	-0,995

Table 1 Surface Factor

k_b **Size Factor**

$$1, \quad d \leq 7.6mm$$

$$0.85, \quad 7.6 \leq d \leq 50mm$$

$$0.75, \quad d \geq 50mm$$

k_c **Loading Factor**

1, Bending

0.85, Axial

0.75, Torsion

k_d **Temperature Factor**

$$k_d = 0.975 + 0.432(10^{-3})T_F - 0.115(10^{-5})T_F^{2} + 0.104(10^{-8})T_F^{3} - 0.595(10^{-12})T_F^{4}$$

k_e **Reliability Factor**

Reliability	K_r
0,5	1
0,9	0,897
0,95	0,868
0,99	0,814
0,999	0,753
0,9999	0,702
0,99999	0,659
0,99999	0,620

Table 2 Reliability Factor

On the other hand, it is necessary to make sure that the main structure of the buggy will support all the loads to which it will be exposed to, therefore it is necessary to calculate what will be the factor of safety of the hallow square beam that will be the body frame, an approximation of the free body diagram of the beam will be:

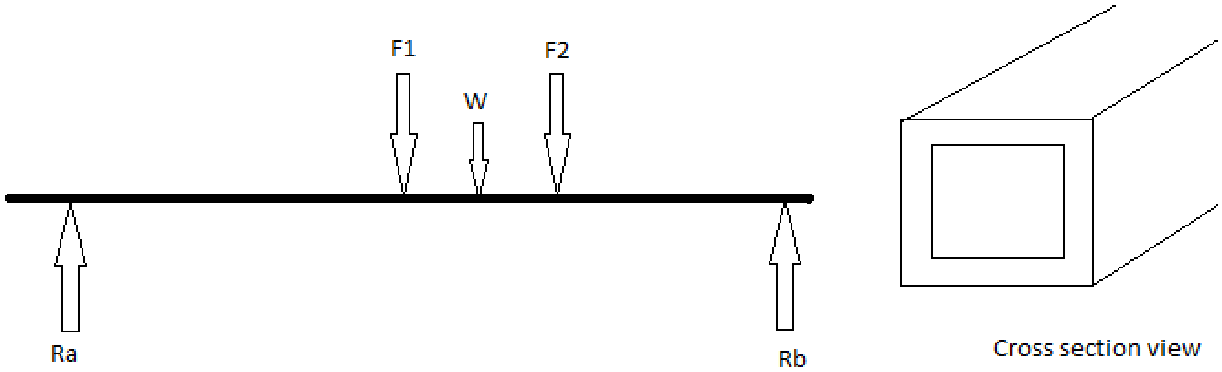


Figure 9 Force Diagram

From this configuration it is easy to find the shear and moment diagram. From these two diagrams the maximum values could be easily obtained, as well as each resultant force. Also it is necessary to find the moment of inertia of the cross section of the beam with the following formula.

$$I = \frac{b\square^{3}}{12}$$

With the moment of inertia of the beam, and for the design that is being developed, the best method to find the factor of safety is the distortion energy method because this will include the shear stress and shear strain that the beam will develop.

$$\sigma = \frac{Mc}{I} \; \tau = \frac{VQ}{Ic}$$

$$\sigma_1 = \sigma_{\max} = \tfrac{1}{2}(\sigma_x + \sigma_y) + \sqrt{\left[\tfrac{1}{2}(\sigma_x - \sigma_y)\right]^2 + \tau_{xy}^2}$$

$$\sigma_2 = \sigma_{\min} = \tfrac{1}{2}(\sigma_x + \sigma_y) - \sqrt{\left[\tfrac{1}{2}(\sigma_x - \sigma_y)\right]^2 + \tau_{xy}^2}$$

$$\sigma' = \sqrt{\sigma 1^2 - \sigma 1 \sigma 2 + \sigma 2^2 + 3\tau xy}$$

Taking in to account all of these formulas, the factor of safety of the beam can be calculated knowing the material of the beam as is expressed in the following formula.

$$n = \frac{Sy}{\sigma'}$$

The group developed a program using C# software to check different cross sections and position of forces to find the maximum shear stress as well as the maximum values of momentum and shear force. Using this program, it is easy to compare final results and take a decision on what material is better to use, and what cross section will be used.

The full extent of the program can be seen in the appendix.

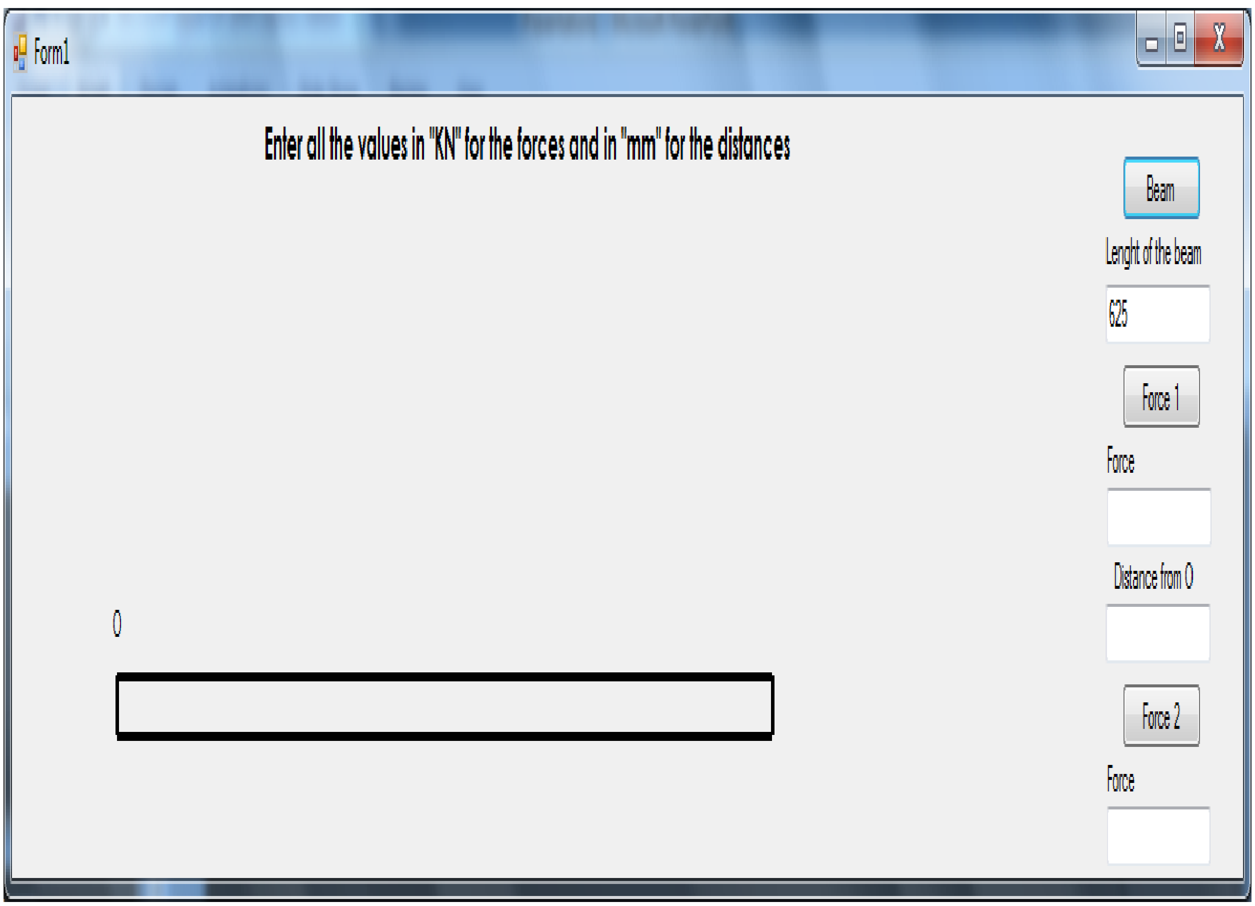


Figure 10 Stresses, Strain and Moment Program

5. **Major Components**

- Frame
    - Square hollow aluminum pipe.
    - Steering system.
        - Steering column
        - Tie rods
        - Tie rods ends
    - Folding hinge
- Suspension
    - A-arms
    - Rear arm suspension
    - Shock absorbers
    - Wheel hubs
    - Bushings
- Powertrain
    - Pedals Arrangement
    - Gears ratio
    - Front differential
    - Front wheels axels
    - Chain
- Additional Components
    - Disk brakes and calipers
    - Passenger seats
    - 26 in. wheels

6. Structural Design

The structural design on the prototype will be composed mainly of a hollow square pipe with a hinge, which will allow the entire body to fold onto itself. All the other components including the suspension system on the back, front wheels, the power train and the steering configuration will be attached to the square frame by the means of the welded mounts.

From the picture below, it is clear that the main goal on the structural portion of the whole project is to reduce the weight of the entire configuration, as well as maximize the suspension and power train performance. On the other hand, the welding portions of the Moon Buggy is where the failure of the system or the cracks will start to appear therefore it is of primary importance to ensure a factor of safety greater than at least one on these areas.

All the weight of the passengers, as well as the resultant forces due to the rough terrain where the Moon Buggy will compete, has to be resisted by the suspension system and the square frame. on these two major components of the structural design a force distribution will develop which has to be supported by the entire assembly.

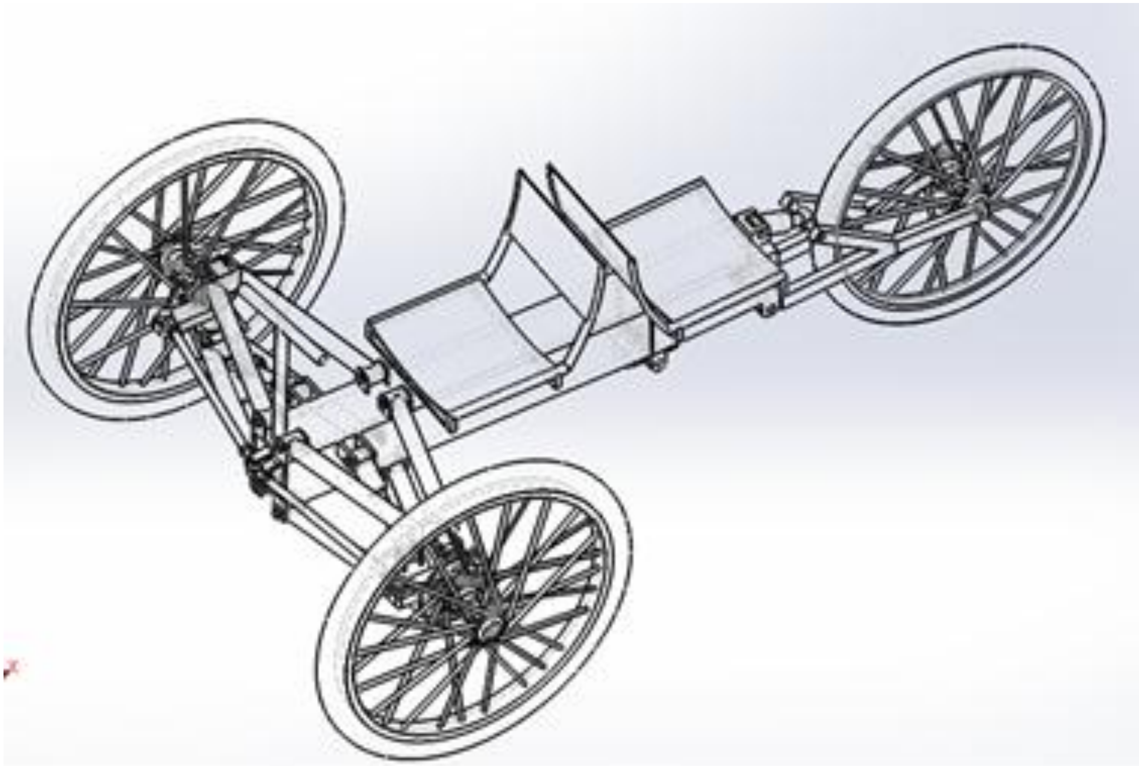


Figure 11 Structural Designs

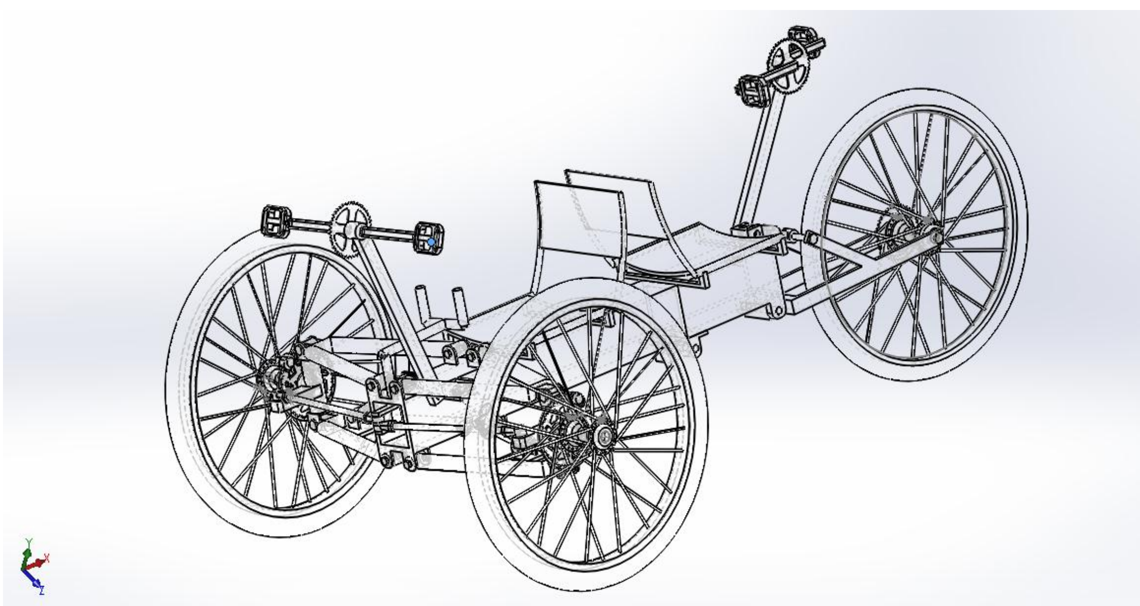


Figure 12 Updated Structural Design

7. Cost Analysis

The cost analysis for this design was broken up into three portions in order to ease the tracking of man-hours that will be consumed in the completion of this project.

The first portion is the "Computer Portion". This consists of any time that is physically spent on the computer in order to complete a task that cannot be completed in any other form. Whether it is time spent researching, emailing or any type of computer interaction it must be logged and cataloged under the correct heading. If a heading does not exist for the task, then it must be created. Using Excel all the hours will be tabulated and the cost per hour will be reported.

As can be seen below the table shows the tasks needed to be performed. Any task not listed will be added through the completion of this project. This table is simple, easy to follow in order to correctly tabulate project hours

Computer Portion			
Task	**Hrs**	**Cost**	**Total $**
Component Analysis	45	0.5	22.5
SolidWorks	205	0.5	102.5
Research	40	0.5	20
Project Formulation	30	0.5	15
Power Point Formulation	10	0.5	5
Design Fromulation	30	0.5	15
Report	60	0.5	30
Product Ordering	10	0.5	5
Assistant Interview	2	0.5	1
Project Organization	20	0.5	10

Table 3 Computer Portion

Next is the portion, which pertains to the fabrication and assembly of the design. This portion is referred to as the "Building Portion". Here, anything that consists of building, welding and machining, among plenty of other tasks, will be tabulated. Once again the man hours spent will be tabulated and the cost per hour will be reported for accurate cost analysis. As mentioned before any task not listed can and will be added in.

Building Portion			
Task	**Hours**	**Cost**	**Total $**
Welding	17	20	340
Assembly	3	20	60
Pre-Fabrication	4	20	80
Locating Product	4	20	80
Frame Assembly	0.5	20	10
Brake Assembly	0.5	20	10
Suspension Assembly	3	20	60
Overall Assembly	20	20	400
Problem Identification	5	20	100
Tuning	1	20	20

Table 4 Building Portion

Finally is the "Testing Portion" of the design. Here a course is developed and the prototype is tested to ensure that it will perform as expected once entered into the competition. This is where any major modifications take place and where possible repairs might need to occur, if any portion of the vehicle does not perform as expected.

Testing Portion			
Task	**Hours**	**Cost**	**Total $**
Course Assembly	1	5	5
Course Testing	2	5	10
Problem Circumventing	1	5	5
Repair	2	5	10
Modification	1	5	5
Replacement Parts	2	5	10

Table 5 Testing Portion

When these portions are fully completed the overall man-hours along with the cost of the materials will be formulated and combined. Now the total cost of the project, which includes man-hours and parts, will be known and analyzed. This next table shows how the overall cost will be determined and how much each component affects the final price of the design. This table will also help for future projects. The table benefits future projects as it can be seen which task the team has spent the most time and what can be done, if anything can be done to reduce the time spent on that specific task in order to be more efficient.

Overall Man Hours		
	Hours	**Cost**
Computer Portion	452	$226.00
Building Portion	58	$1,160.00
Testing Portion	9	$45.00
Overall Hours and Cost	519	$1,431.00
Overall Cost		
Prototype		0
Materials Cost		744.21
Overall Cost		**$2,175.21**

Table 6 Total Costs

8. Prototype System Description

The prototype consists of an aluminum hollow square pipe from which aluminum ears are welded in order to hold the pair of double a-arms that form the front suspension. Also from this frame a single arm is attached to the back for the suspension of the rear wheel. The frame is cut, and joined back again using a heavy-duty hinge in order for it to be able to comply with the rules and fit in a 4 ft. cube.

The steering of the vehicle is composed of a steering column, which goes through the frame and linking the front wheels using 2 individual tie rods, each with its respective tie rod ends.

The suspension of this prototype, as mentioned before, consists of 2 sets of double a-arm systems in the front of the buggy, while using a single arm for the rear suspension. The shocks absorbers being used are small and lightweight similar to the ones found of on the front and rear suspension of most bicycles.

The buggy uses 3 bicycle wheels 26 in. in diameter, 2 of these wheels are slightly modified in order to be able to receive an axle which powers the front wheels, and the rear wheel is adjusted to work with a pair of specially calculated sprockets which are later explained. The front wheels are mounted as fabricated with heavy-duty hubs, which allow joining the wheels to the double a-arms suspension, the tie rod ends, brake calipers, and the axle.

The vehicle braking system is similar to the one found in most cars on the road, it consists of a brake disk in each wheel, and single piston calipers, which are controlled, mechanically with the use of cables.

The powertrain for the buggy consists of a propulsion system where the rear passenger powers the vehicle. The rear passenger pedaling moves a set of 2 specially calculated sprockets, which gives power to the rear wheel. These sprockets are optimized for speed and torque, which are needed for the changing terrain that will be encountered.

9. Prototype Cost Analysis

When designing the Moon Buggy, the rules must be referenced. As the buggy is to be carried by the passengers for a total of 20 ft.. It is imperative to make the buggy as light as possible. Choosing a material like steel will definitely sustain the terrain, which the course will present, but it will be at the sacrifice of weight and mobility.

Using aluminum, presents a great opportunity to have strength and a huge weight reduction compared to steel. Although steel has more strength it also weighs much more than aluminum. In an effort to reduce weight the following portions of the vehicle will be constructed out of aluminum. These parts are, the frame, drive train, A-arms and tie rods. As can be seen in the table below, close to **$300.00** will be spent in the purchase of aluminum.

Aluminum/Steel							
Material	**Type**	**Thickness (in)**	**Length (ft.)**	**Quantity**	**Price**	**Use of Material**	**Speedy Metals**
Aluminum	Square Tube	0.125	6	1	$186.24	Frame	**Speedy Metals**
Aluminum	Square Tube	1	9	1	$42.00	Frame	**Speedy Metals**
Aluminum	Round Tube	0.75	0.5833	4	$2.87	Drive Train	**Speedy Metals**
Steel	Round Tube	0.75	4	1	$19.68	Drive Train	**Speedy Metals**
Aluminum	Round Tube	0.25	1.5	2	$1.24	Tie Rods/Front Suspension	**Speedy Metals**
Aluminum	Round Tube	0.25	5.333	1	$2.56	A Arms	**Speedy Metals**
Steel	Ball Bearings			3	$40.62	Steering	**McMaster**
		Preliminary	Price	13	$295.21		

Figure 13 Aluminum and Steel Cost

The grade of aluminum currently being quoted is 6061-T6511. This selection may change as more simulations and calculations are performed. Different grades of aluminum will be examined in order to determine the best possible grade for the current design that will sustain the rough impact to be delivered by the terrain. Different grades of a material can slightly alter the dimensions to be used due to the different hardness, stress and strain of the materials properties.

When analyzing a material that may need a grade change, one may find that the material does not come standard in the size that is needed. Causing for either a change in grade or change in design. These factors are key in the cost of the design. Minor and major set backs can be caused by changes of this nature. Not to mention the overall monetary significance. It is key to completely analyze all components and correctly pick the materials that are going to be used.

Front and Rear Suspension				
Component	**Quantity**	**Price**	**Max Price**	**Purpose**
Bicycle Wheels	3	$35.00	$100.00	Front/Rear Drive
Pedals	4	$25.00	$100.00	Front/Rear Drive
Shocks	3	$120.00	$200.00	Front/ Rear Suspension
Tie Rod Ends	2	$24.00	$50.00	Front Suspension
Disc Brakes	3	$75.00	$150.00	Front/Rear Drive
Brake Lever	2	$10.00	$30.00	Front/Rear Drive
Brake Cables	3	$10.00	$30.00	Front/Rear Drive
Bike Chain	1	$10.00	$50.00	Drive Train
Chain ring	2	$50.00	$100.00	Drive Train
Seats	2	$30.00	$60.00	Front/Back Passenger
Bolts	16	$5.00	$10.00	General Use
Nuts	16	$5.00	$10.00	General Use
Hinge	1	$20.00	$30.00	Collapse Point
Welding Material	1	$30.00	$60.00	Welding Material
Pieces	58	$449.00	$980.00	Preliminary
Grand Total	Price	$744.21	$980.00	Preliminary

Figure 14 Front and Rear Suspension

Above are the components that were used in the vehicle design. These components come in wide ranges of cost, design and quality. Due to the fact that this design is self-funded, many of the more flashy materials might need to be either manufactured or bought as used products, for example; pedals, tie rods, tie rod tips and brakes.

Some of the material costs are unavoidable. For instance, the aluminum is a definite staple to the design if the overall goal of weight reduction is to be achieved. In order to obtain a good power to weight ratio, the weight of every single material must be accounted for. If lighter options are available, they will definitely be explored and analyzed in order to justify the cost increase that it might incur. The cost change will be discussed and compared in order to assess if it is worth the cost.

10.**Plan for Test of Prototype**

The prototype was tested initially using SolidWorks and Ansys, where each part was analyzed independently. These parts were simulated as if they were used in a real life scenario obtaining their factor of safety and their deflections to the loads applied to them.

Once the individual parts were simulated and tested, the full buggy as an assembly was studied using ANSYS in order to find weak points in the structure where possible failures could occur

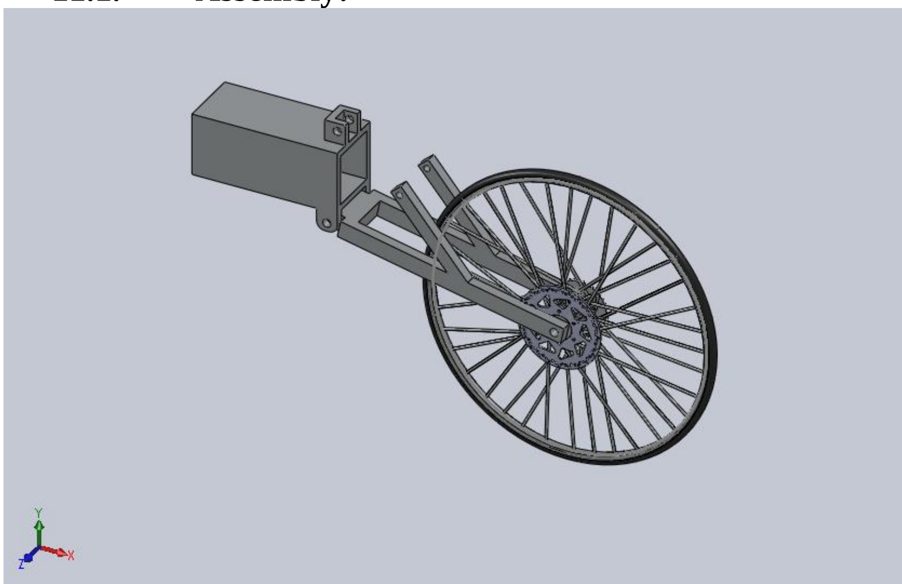
Having obtained video footage of the real course of “The Great Moon Buggy” competition, a replica course was made using materials similar to that seen on the video. The course contains terrain similar to that of the competition and might not be equal in distance but several laps will be performed in order to get an accurate feel for the terrain. Furthermore, tests involving the full on weight of the riders were performed to ensure the vehicle can endure the loads the passengers placed on the structure. Also in South Florida there are numerous off-road terrain parks that allow for easy testing of the vehicle in adverse conditions.

The prototype was analyzed and checked after testing, for any signs of wear, fatigue or possible failure. If any signs of before mentioned are prevalent, then immediate action will be taken in order to properly repair the vehicle and or develop an effective adjustment to prevent the occurrence from happening again in the future.

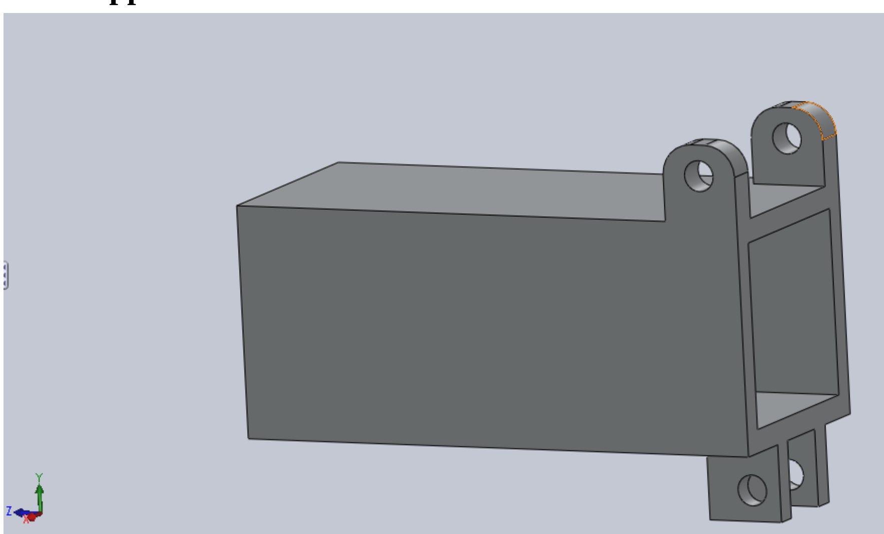
11.Rear Suspension Design:

For our final conceptual design the testing of the rear suspension of the Moon Buggy was performed. The assembly we tested has the following parts:

11.1. Assembly:

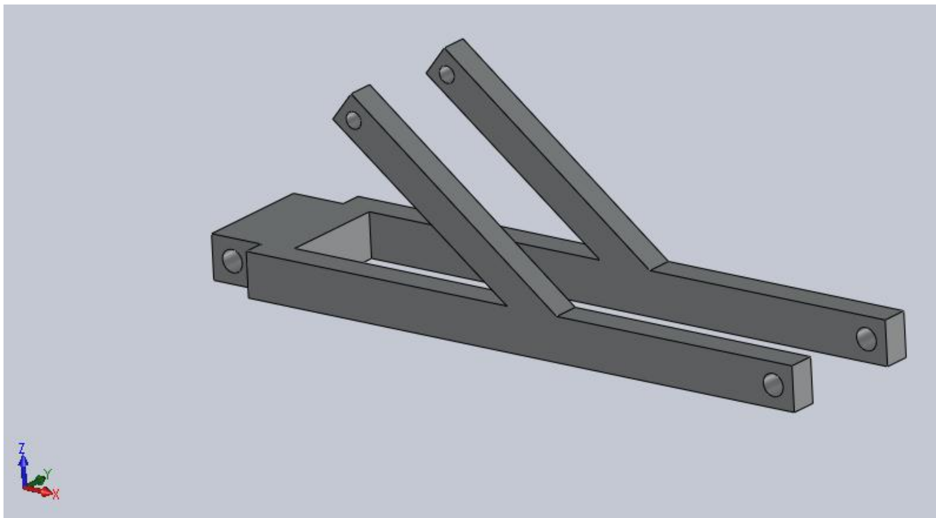


Rear support:



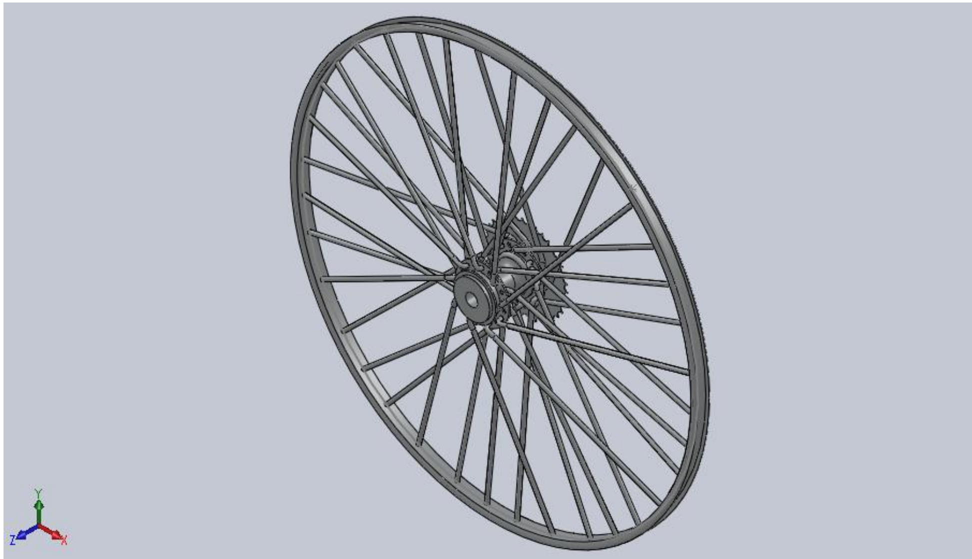
This part was designed to withstand the forces experienced by the axle of the system. The rear support has to be able to perform under the most strenuous conditions of the system in order to provide strength and a long lasting life for the rover.

Rear arm:



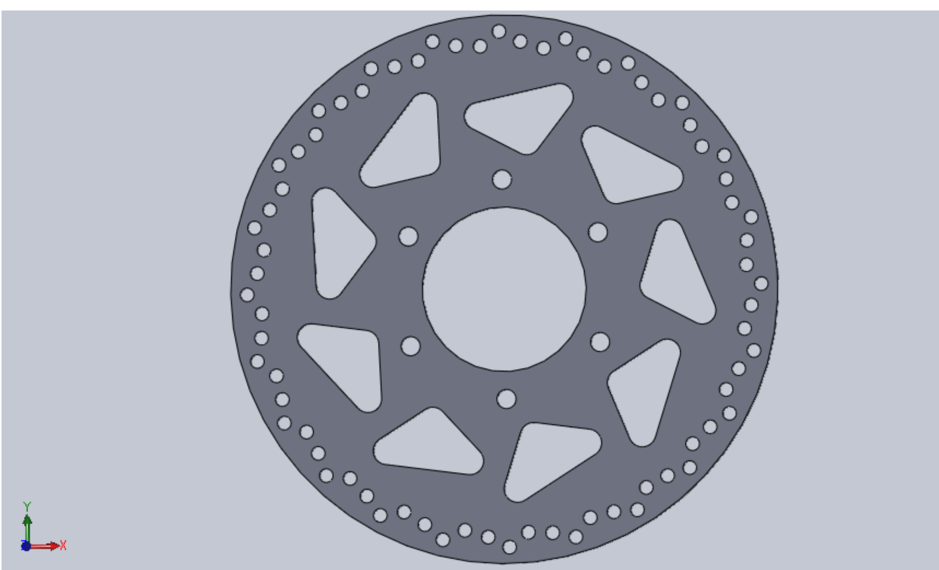
The rear arm connects the moving parts of the tire and translates the forces experienced from its rotation and from the irregularity of the lunar terrain to the rear support. The connection from this part to the rear support is through pins at the bottom and through a suspension system through the top in order to absorb the impact forces due to motion.

Tire axle and rim:



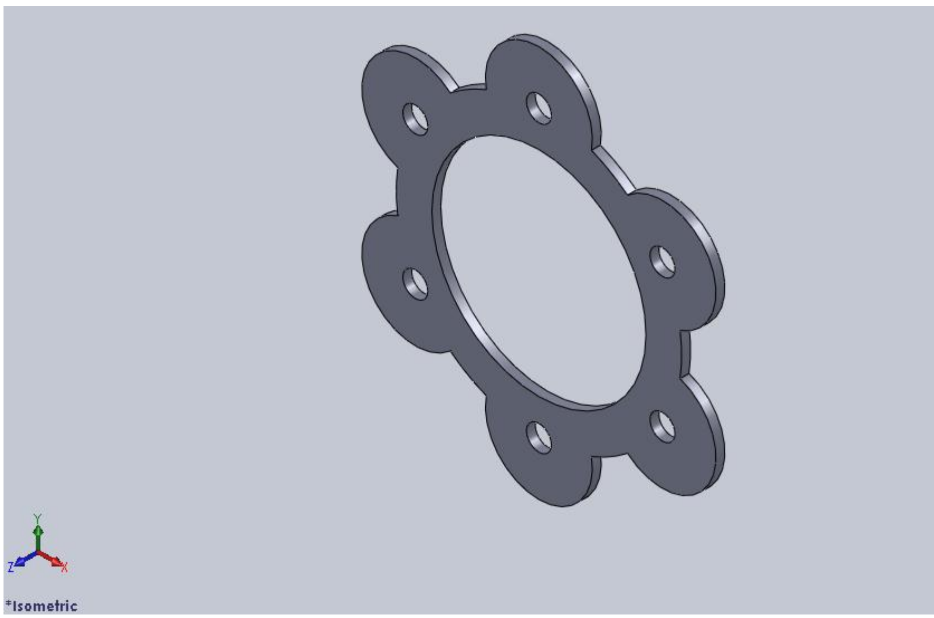
The tire, axle and rim were designed as a whole in order to reduce the number of connections needed and to guarantee a sturdy, longer lasting tire frame. It was also designed for the rigorous weight requirements due to the cost of transportation of objects out of Earth. This part of the system will directly experience the impact forces due to the irregularity of the lunar terrain.

Brake disk:



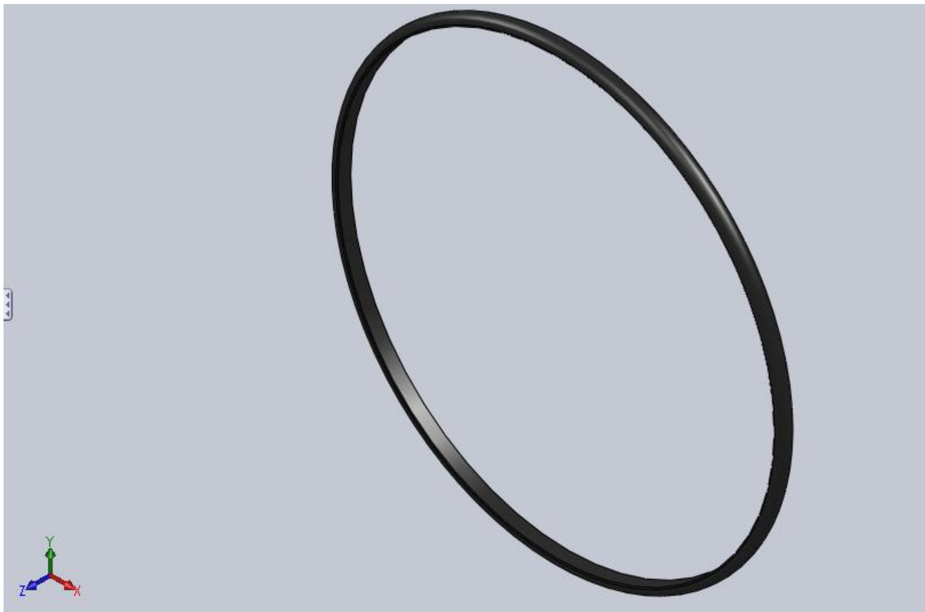
This part serves to slow down the system when stopping. This was included in the assembly because even though it does not directly experience the impact forces, a part of the forces from the tire frame will be moved to the brake disk as well. This brake disk follows the normal convection of high heat transfer rate to protect it from the friction generated from braking, and also it meets the lightweight requirements of space transportation.

Disk mount:



This part was designed in order to be able to connect the brake disk to the tire frame. It will also endure a component of the impact forces that the tire frame experiences. The brake disk and disk mount will experience forces due to the pin connections used.

Tire:



It was decided to include the tire because since it is made out of rubber, it absorbs some of the impact forces experienced by the tire frame.

Note: The material used for all the metallic parts are Aluminum 1060 alloy. Aluminum was used due to its high strength and lightweight.

12. Introduction of Study Cases and Settings:

For this design the following studies were performed using Solidworks and Ansys:

12.1. Static Load Non-adaptive:

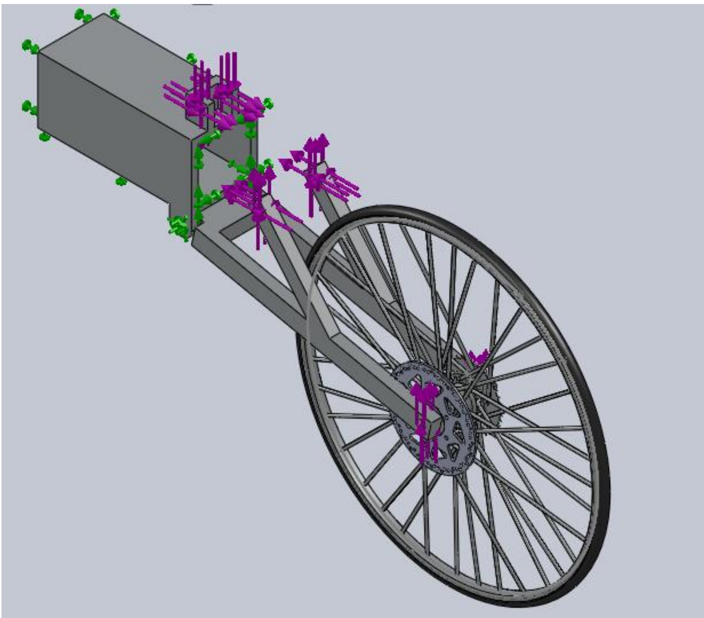
I. We will apply the forces experienced by the tire frame on its main axle since the application of the forces on the tire itself is not possible to achieve. This approximation is very close to reality since tire frame can be taken as a point mass due to symmetry conditions and static loading.

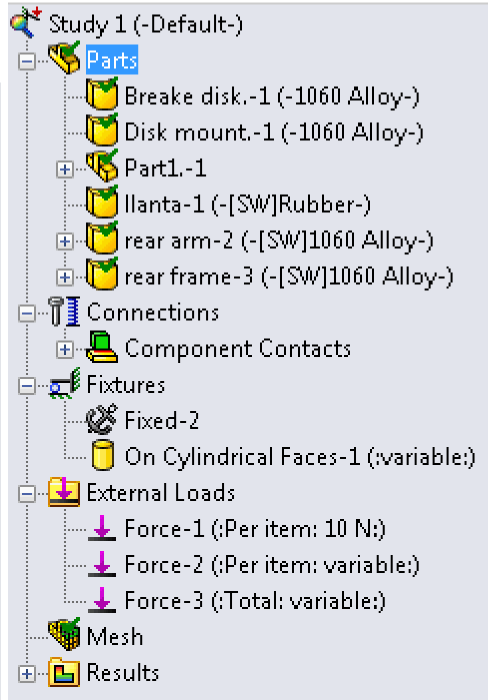
II. We will also apply the forces from the tire frame to the rear support and rear arm due to the spring connection between them.

III. The constraints of the system include a fixed geometry of the inside surface area of the rear support as well as cylindrical constraints of the pinholes for the connections of the multiple parts.

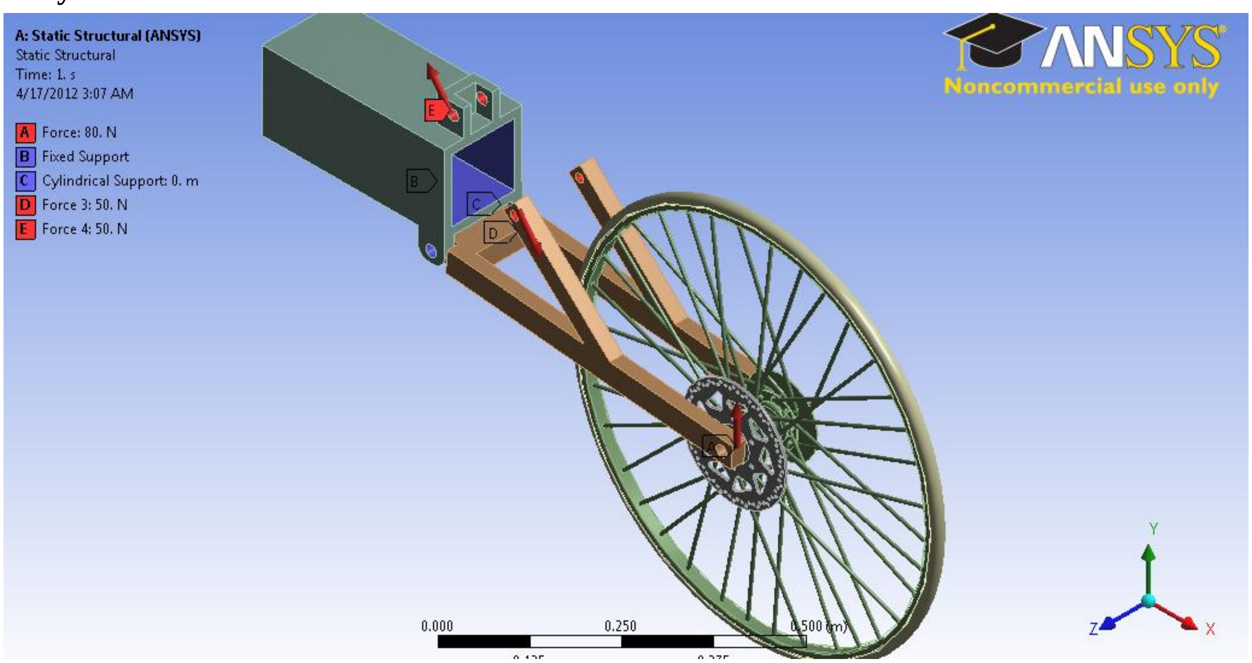
IV. We used standard mesh with a mesh size of 0.7 cm due to the multiple geometries of the parts.

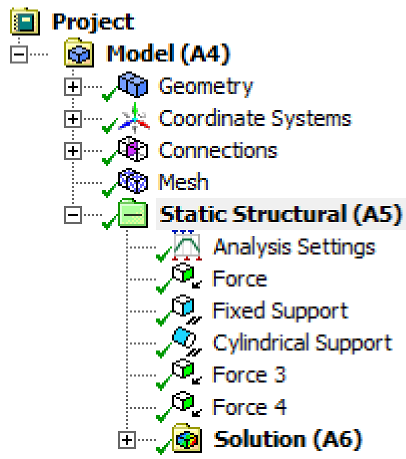
Solidworks:





Ansys:





Note: It was decided to use static load even though the forces experienced by the system will be in fact greatest when the system is in movement.

12.2. Adaptive Static Load Study.

I. The application of forces and constraints is the same as before.

II. Adaptive method used is h-adaptive with 95% accuracy and max number of loops is 3.

12.3. Frequency Study:

I. Applied in order to analyze the deformation of the tire frame due to rotational motion when movement of the rover takes place. We will observe the various natural frequencies to conclude if the system will withstand the proposed speed of 20 miles per hour.

13. Graphs and Results:

13.1. Solidworks: Static Load Non-adaptive:

Von Mises:

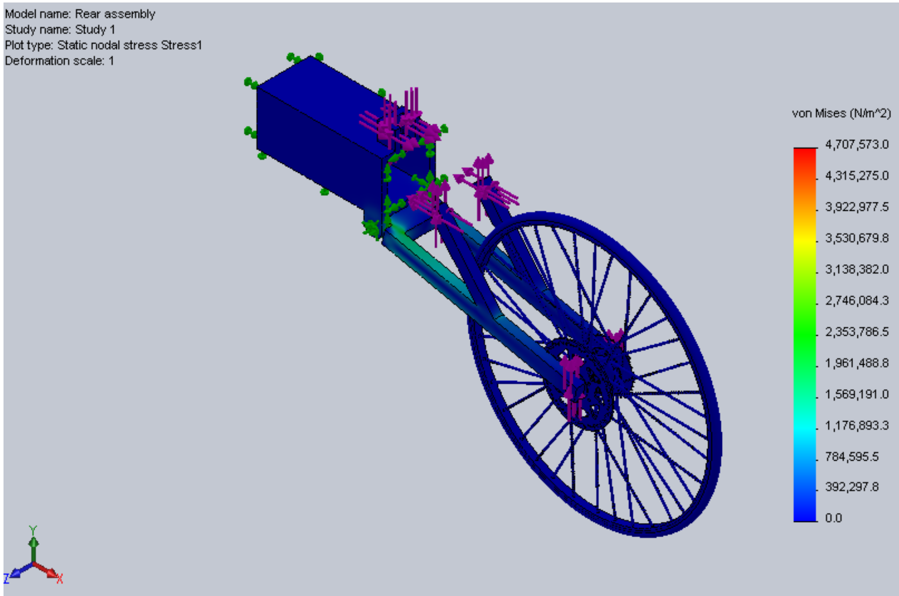


Figure 15 Von Mises

Total displacement:

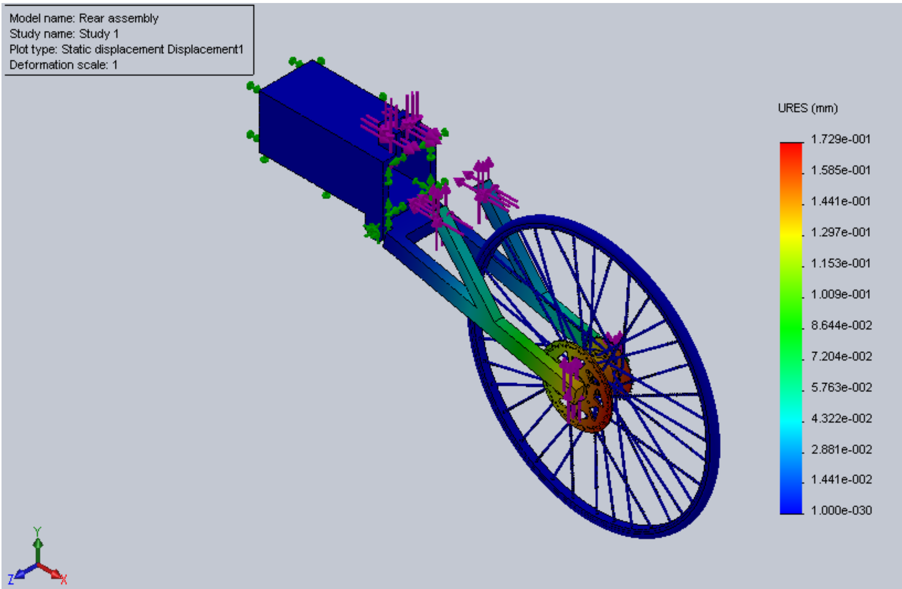


Figure 16 Total Displacement

Displacement Y-component:

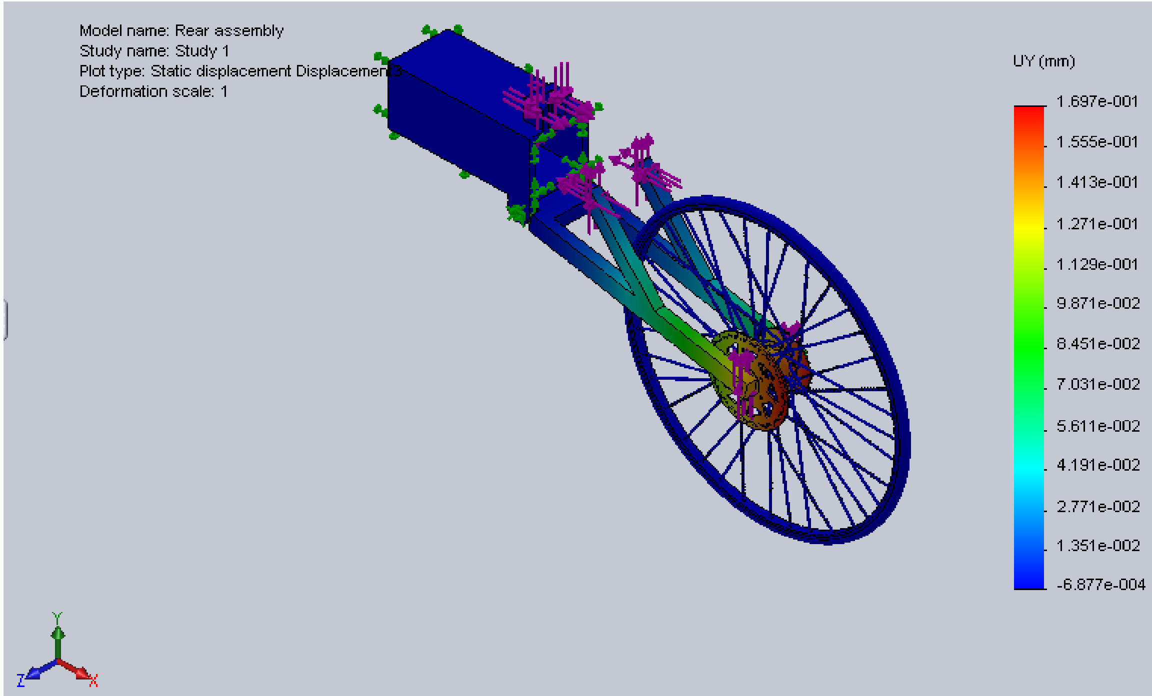


Figure 17 Displacement Y- Component

Factor of Safety:

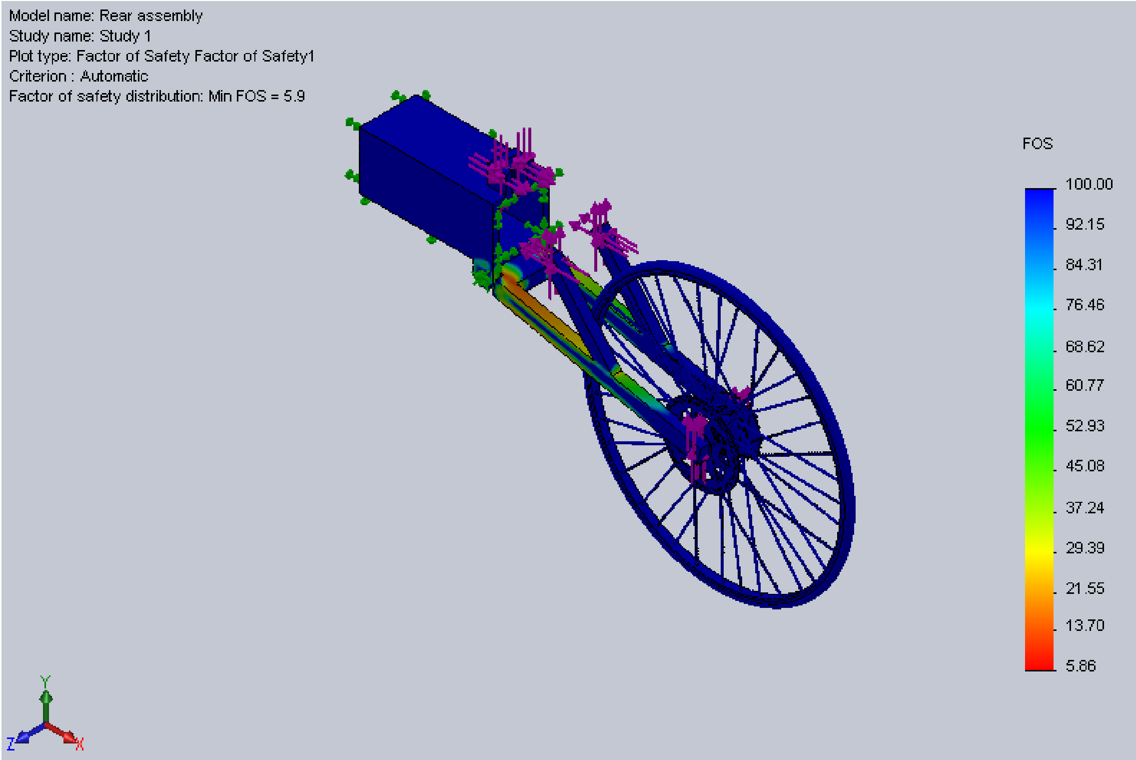


Figure 18 Factor of Safety

Strain:

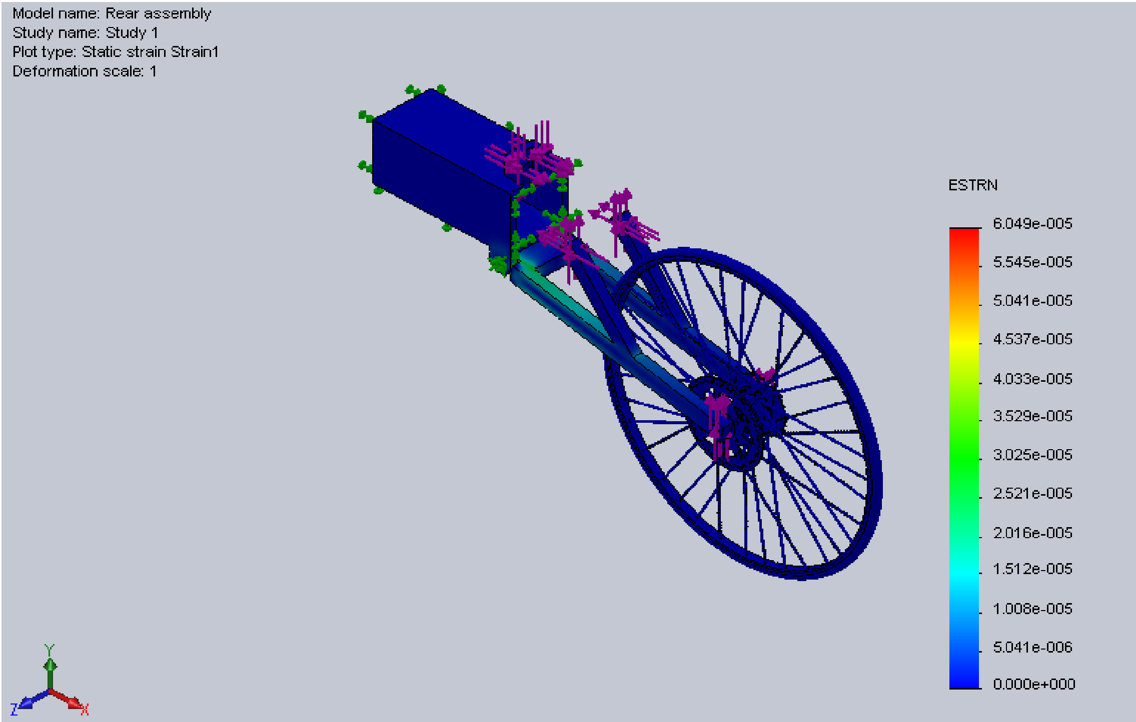


Figure 19 Strain

13.2. Static Load Adaptive:

Von Mises:

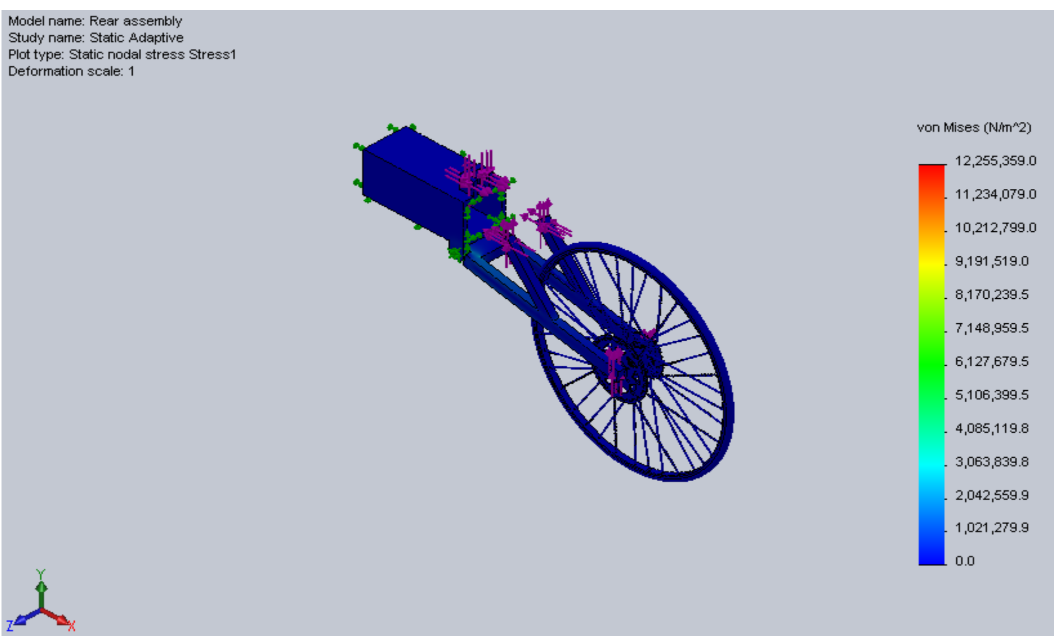


Figure 20 Von Mises

Total Displacement:

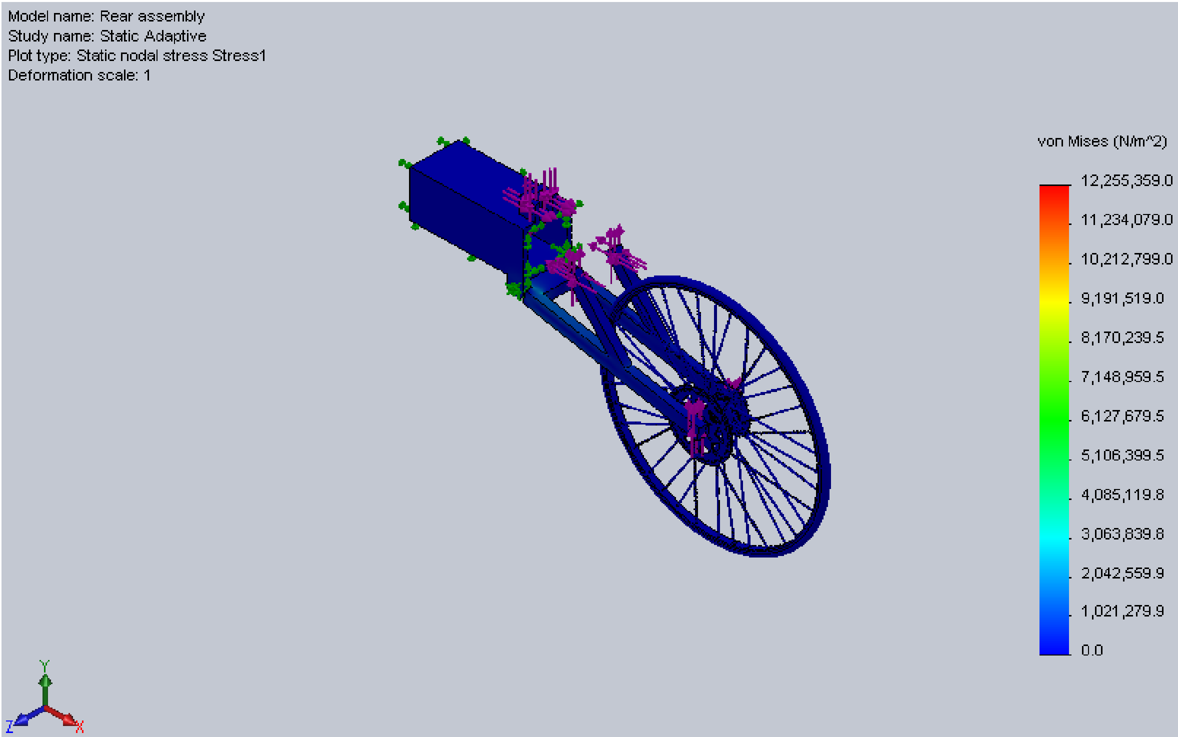


Figure 21 Total Displacement

Displacement Y-component:

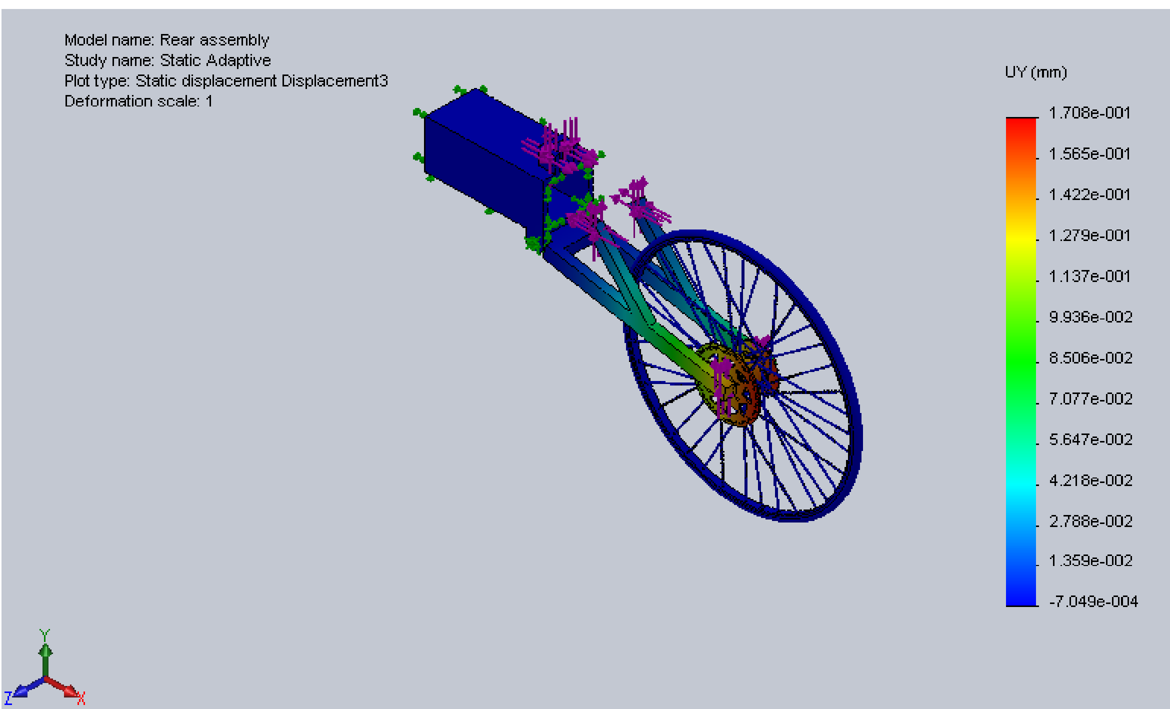


Figure 22 Displacement Y-Component

Factor of Safety:

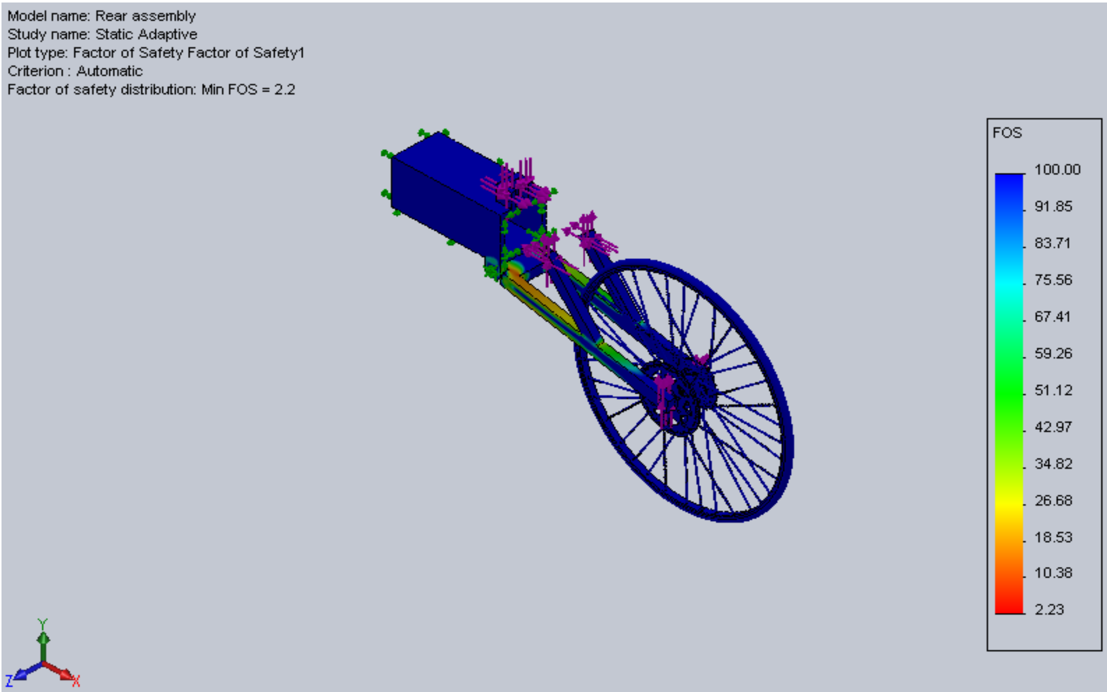


Figure 23 Factor of Safety

Strain:

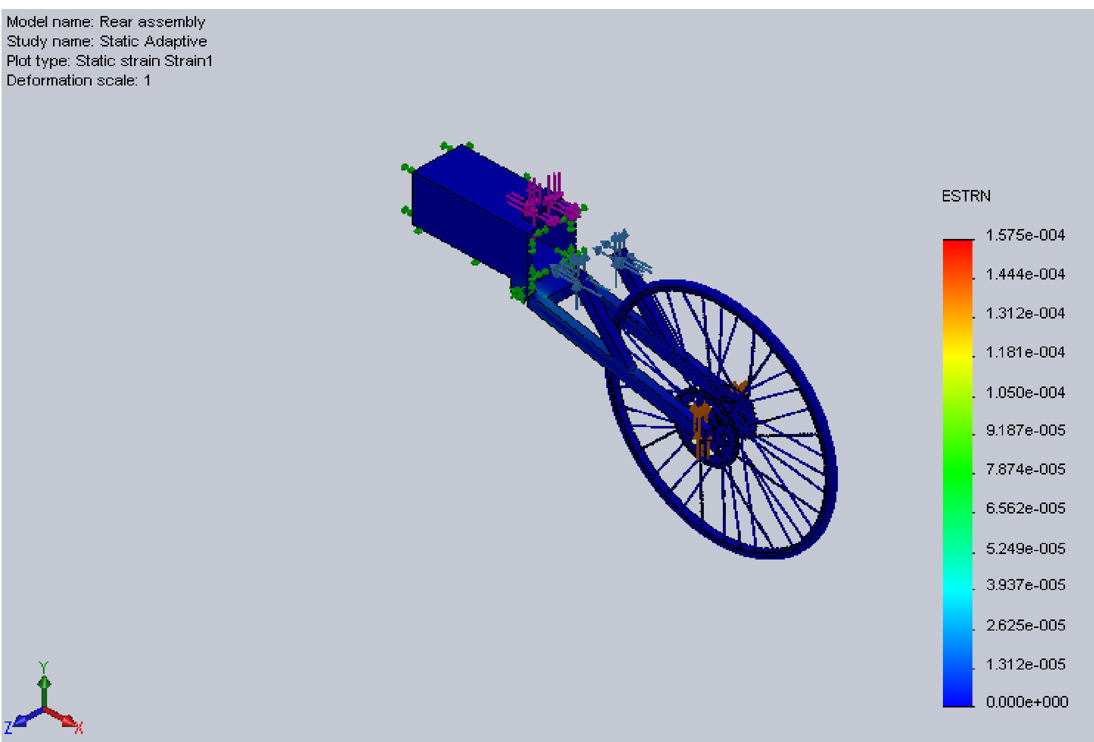


Figure 24 Strain

13.3. Ansys: <u>Static Load Non-adaptive:</u>

Von Mises:

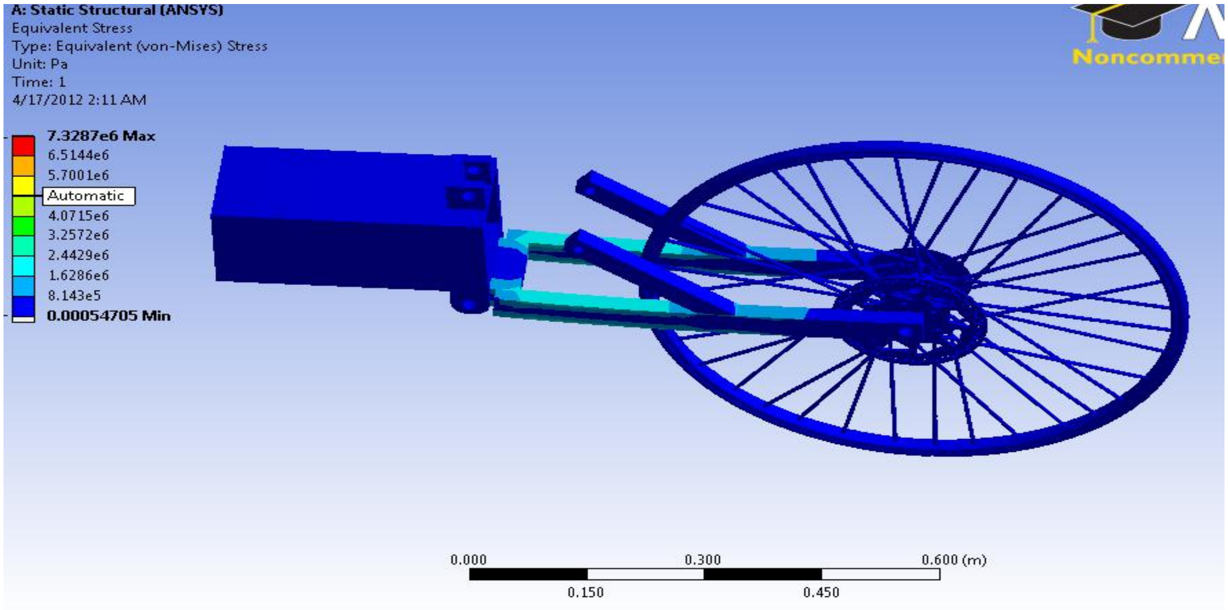


Figure 25 Von Mises

Total Displacement:

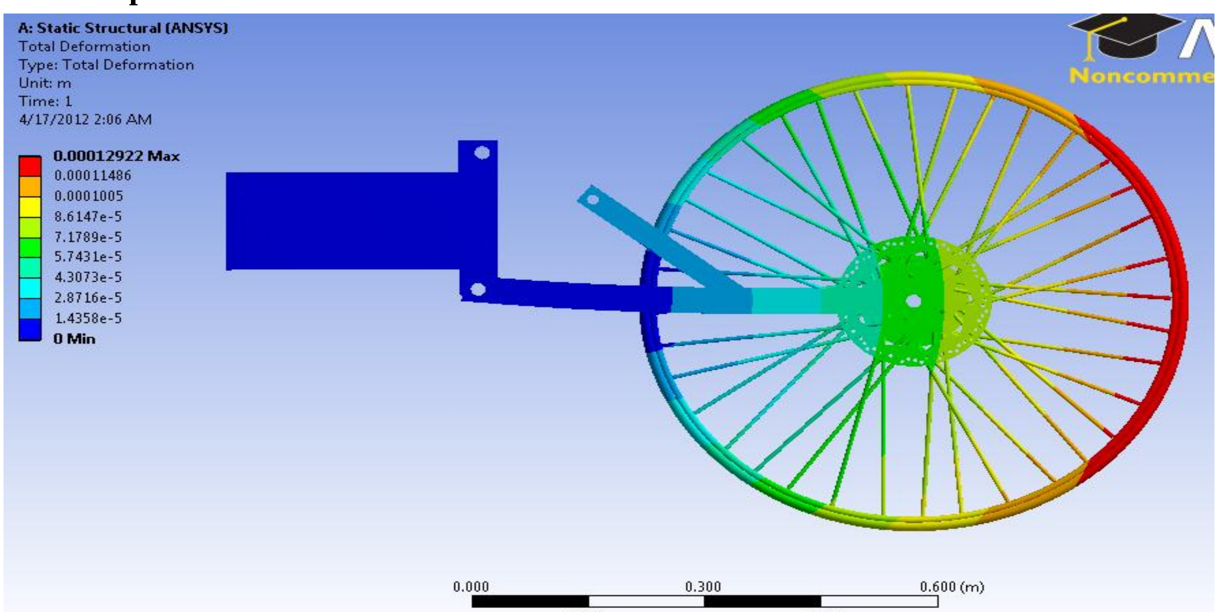


Figure 26 Total Displacement

Displacement Y- component:

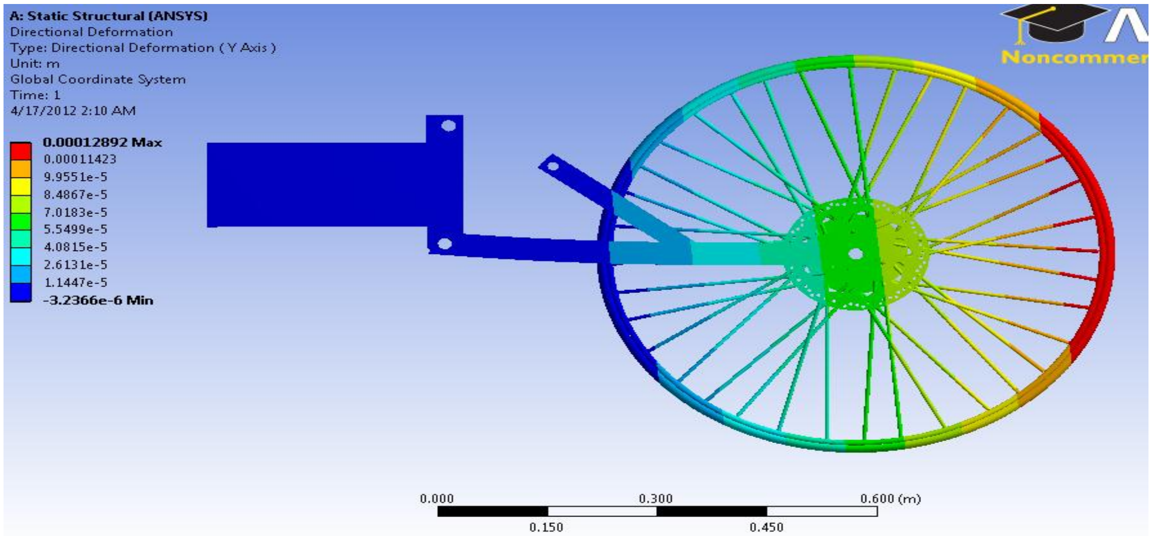


Figure 27 Displacement Y-Component

Factor of Safety:

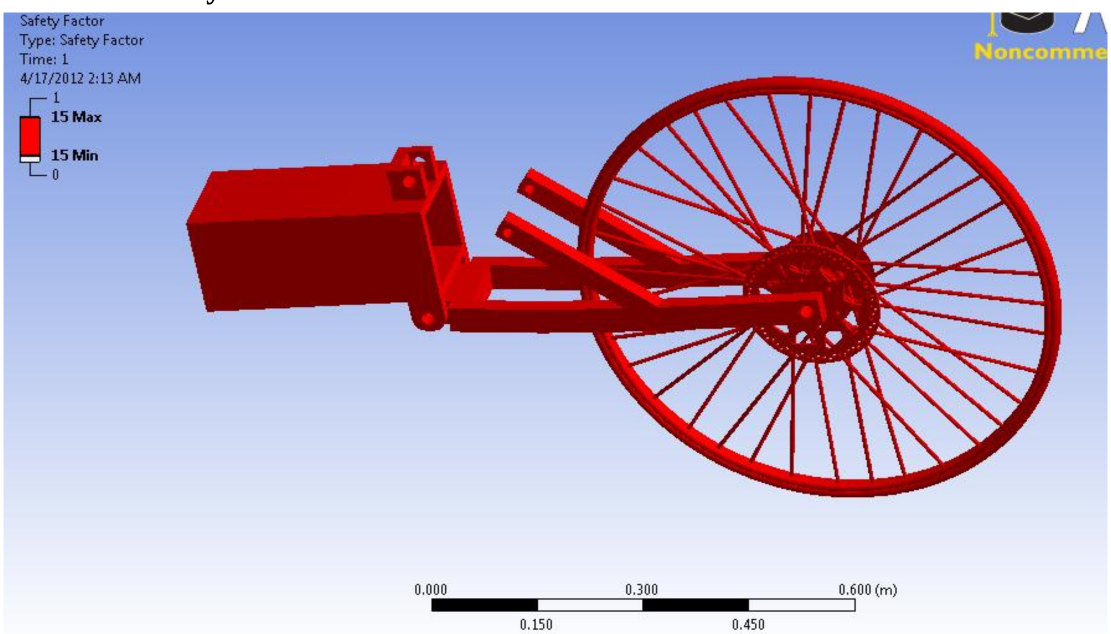


Figure 28 Factor of Safety

Strain:

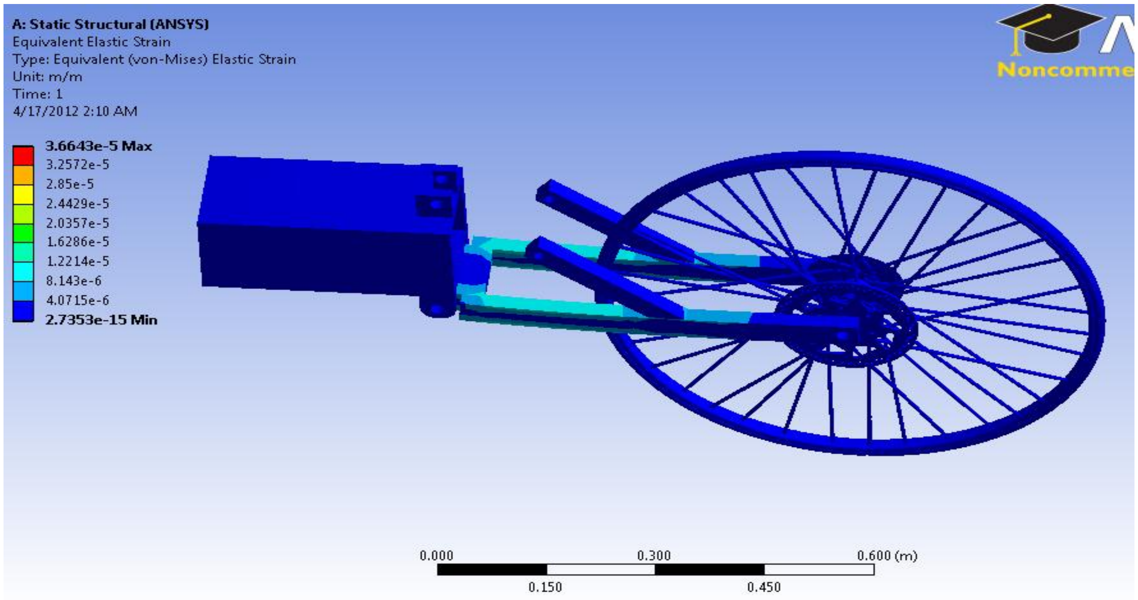


Figure 29 Strain

Displacement X- component:

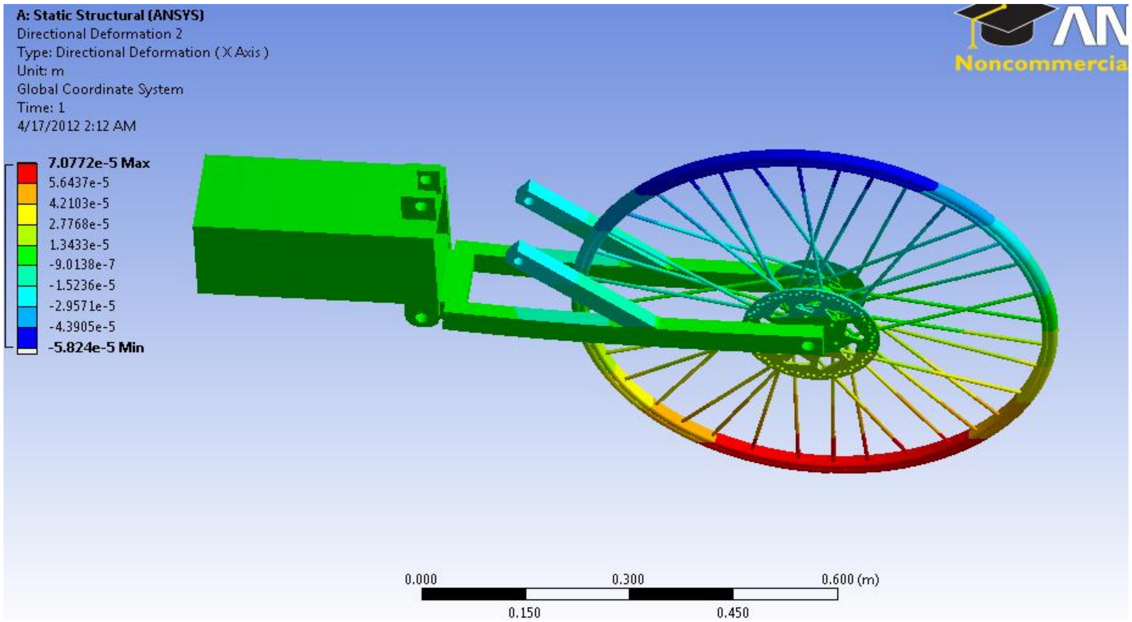


Figure 30 Displacement X-Component

14. Analysis and Discussion:

14.1. Von Mises:

The graphs obtained from Solidworks and Ansys approach the same values, therefore, we can say that the results obtained are a good approximation to the physical reality of the idealized system. We also have to take in account that since we performed static load studies, the results obtained do not represent the condition in which the system is in motion, therefore, further studies of transitional loads, impact, and frequency should be performed in order to guarantee proper performance life of the system. The maximum Von Mises stress was located at the connection between the rear support and rear arm as expected. Therefore, the results do fulfill the physical representation of stress throughout the parts. We must note also that since the application of the forces experienced by the tire is at the main pin connection of the tire frame and rear arm, the tire itself does not experience any kind of stress. Physically this is erroneous; therefore, the idealized system has a large inherited error margin.

14.2. Displacement:

After applying the static adaptive load study using Solidworks, we were able to ensure that the results obtained from the static load studies were converging and therefore were correct approximations for the system. We also noticed that in both programs, the displacement distribution tends to be the same for the different regions of the system. The tire mount and frame experienced the largest displacement as expected. The system behaves as planned from the force application.

14.3. Factor of Safety:

It is importance for us to determine if the system will be able to withstand the forces applied to it. Consequently, we need to find out the minimum factor of safety for the system. From the results, the Solidworks simulations show results that ensure the safety of the system under the applied loading conditions. Therefore, we do not need to consider using stronger materials for the system, or improving the geometry of the parts. From the Ansys simulations, the results show an overall max and min factor of safety, which is not supported by the stress distribution and displacement graphs. This had led us to believe that we cannot use the factor of safety plot from such software since there is big probability of significant error implications.

15.Front Suspension Design:

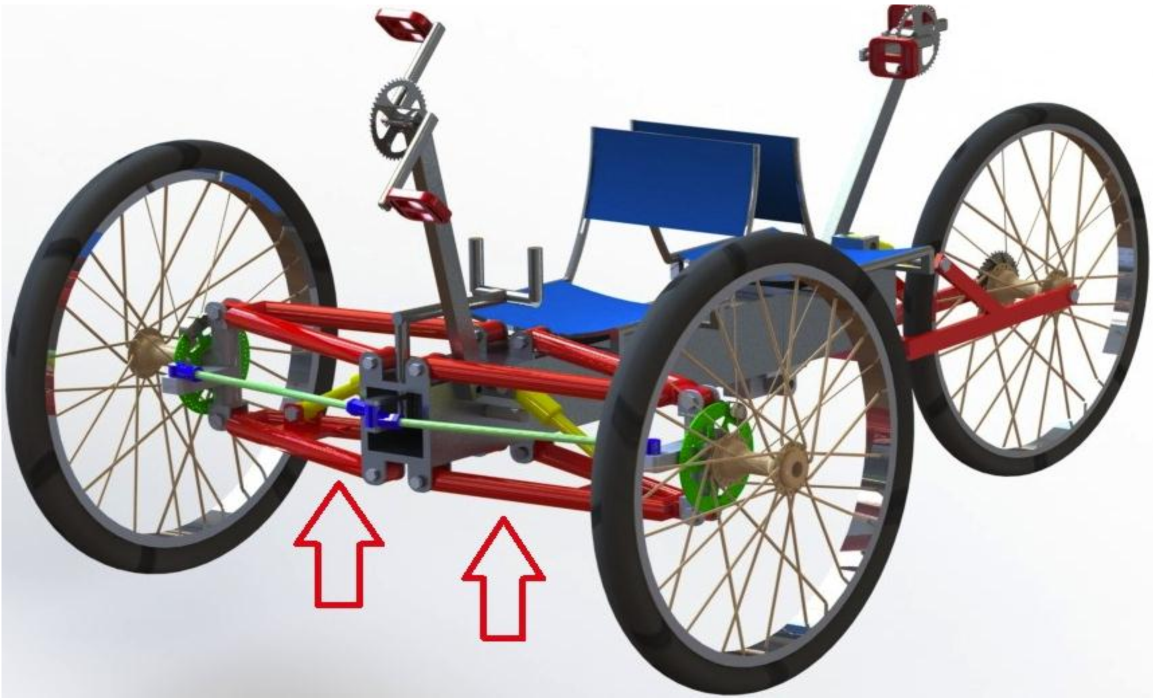


Figure 31 Front Suspension

This is a Buggy that will be racing in the NASA Great Moon Buggy competition. We are analyzing this Buggy's front double–a arm suspension. We are ignoring details involving it's steering, tight–rod ends and its braking system. We are focusing on the suspension geometry consisting of the Aluminum1060–Alloy arms, which undergo specific forces during their intended function. The bolts and screws are made of Cold–Rolled Steel. The wheel hubs are made of Aluminum1060–Alloy and the wheels are assumed to be Nylon.

- ❖ Please note that this Nylon material does not impact the results of our study because we are focusing on the arms of the suspension and the wheel hubs and not every component of the suspension.

The double–A arm suspension is a tough suspension that will sustain the terrain on the Moon and allow good handling, braking, and steering of the vehicle while providing a comfortable ride. The arms contain two points at which the arm connects to the frame of the chassis. Each arm has a joint at the knuckle where the arm can move about its pivot to allow movement of the wheel. The arms are 40 cm long and made in a circular pipe structure. The wheels were built with a basic design in mind, simply to allow the simulations to run smoothly and quickly. Again, this did not have a significant impact on our study as we are focusing strictly on the arms and wheel hubs. The shock supports of the suspension experienced the forces to simulate the Buggy while it travels on the ground. In other words, the forces are acting on the suspension to simulate the Buggy at the instant it goes over a bump on the road.

15.1. An Introduction of the Study Cases and Settings

For each of the following studies, we analyzed the factor of safety and the displacement in the x, y, and z–directions. Please note that the majority of our focus was on the y–direction displacement because it correlates with the direction of the applied forces and it is the only direction in which the suspension allows movement of the Buggy.

Each of the following studies incorporated the following forces:

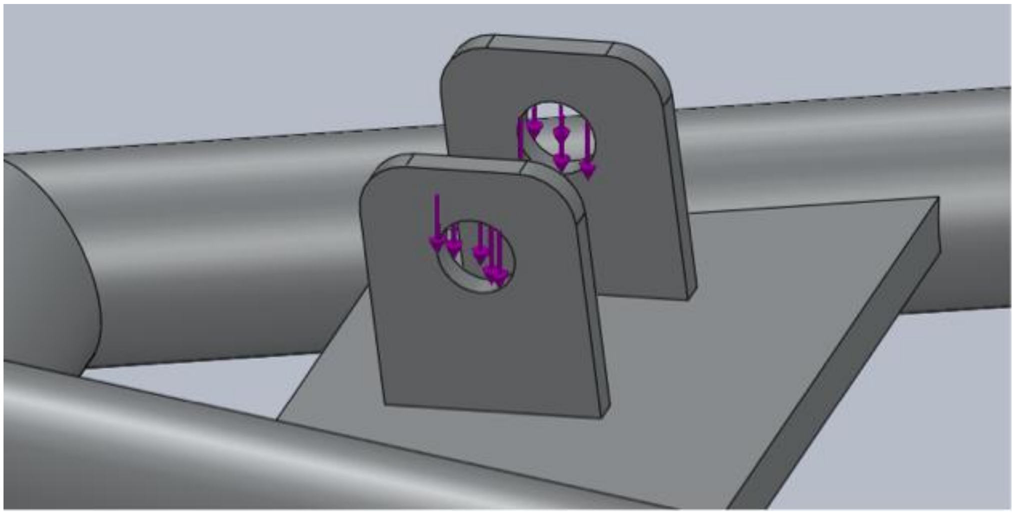


Figure 32 Shock Support

- One force is applied on each of the shock supports of the suspension. The force is applied on the inner surface of the ring where the pin screw will be placed once the Buggy is assembled completely. This simulates the shock that the Buggy sustains at the instant it goes over a bump. The applied force is 25 N in the –y–direction.

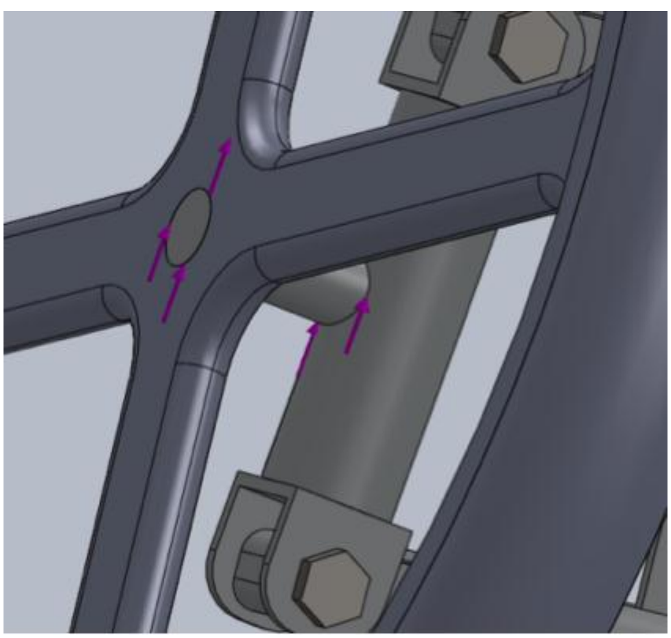


Figure 33 Wheel Hub of Suspension

- One force is applied on each of the wheel hubs of the suspension. The force is applied specifically in the region of the wheel hub where it joins with the wheel. This simulates the shock that the Buggy sustains at the instant it is rising from impact with a bump in the road. The applied force is 75 N in the +y–direction.

16. Simulation Results

16.1. Double A–Arm SolidWorks Analysis Study 1 Mesh Size: 1.48566 cm

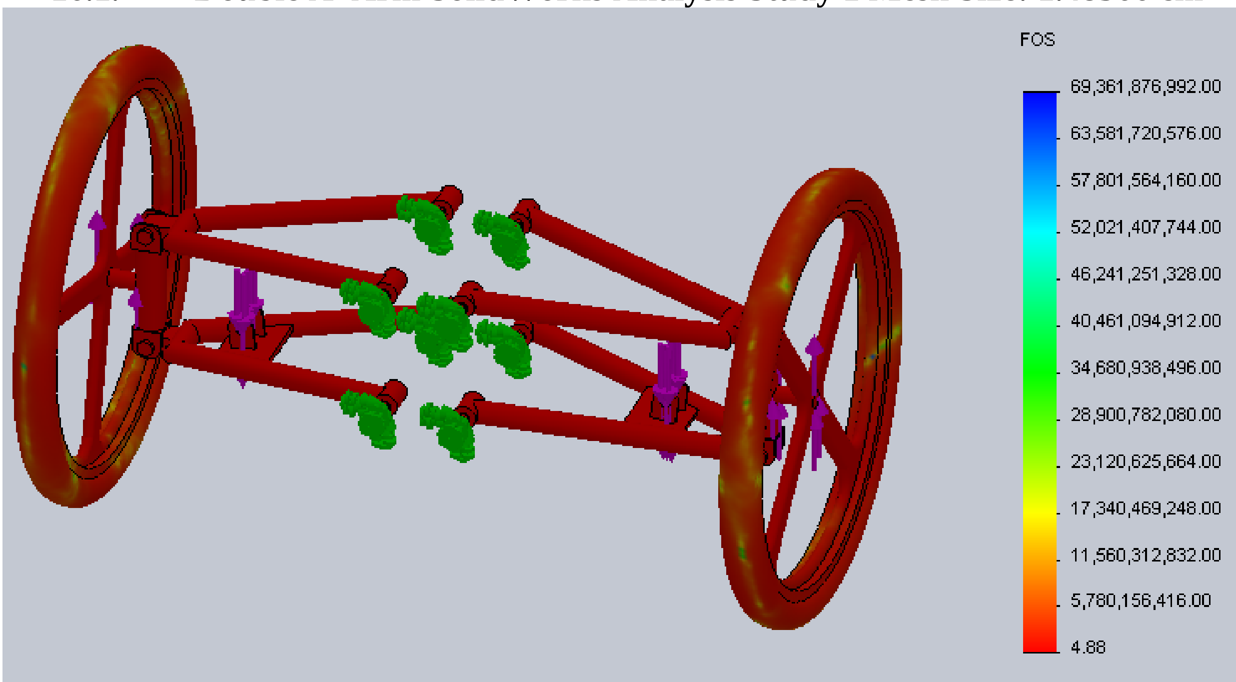


Figure 34 Factor of Safety

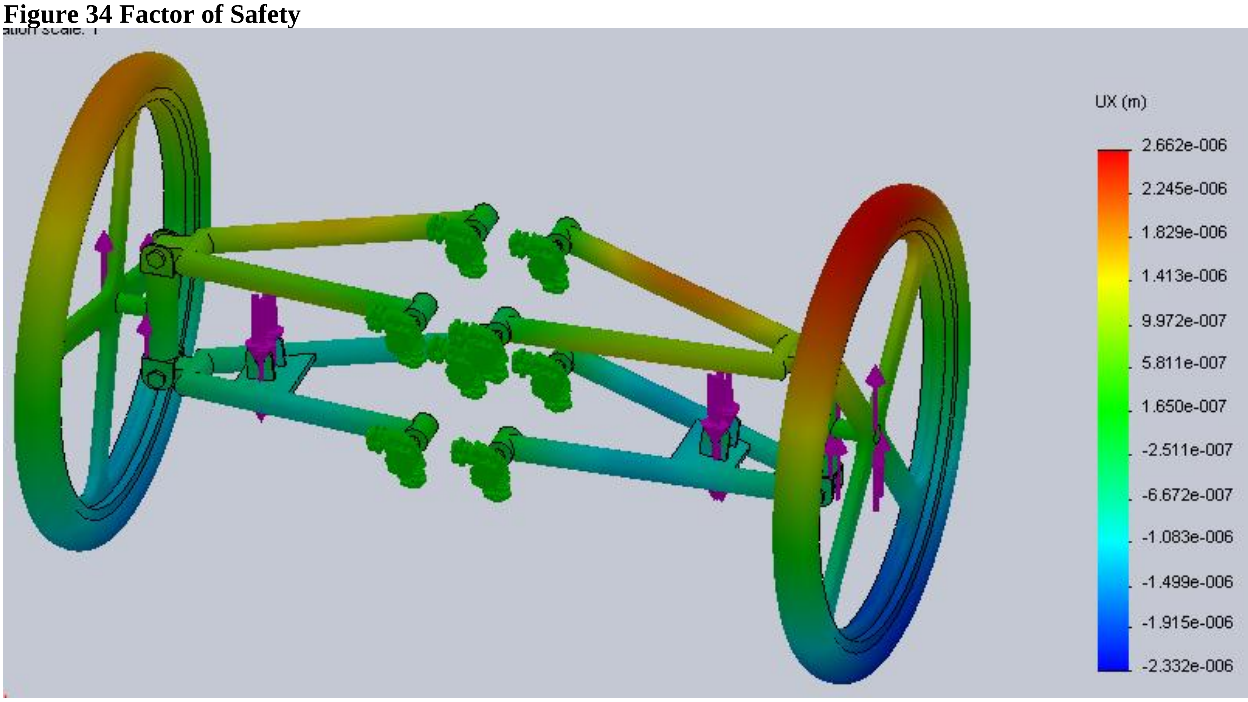


Figure 35 X- Displacement

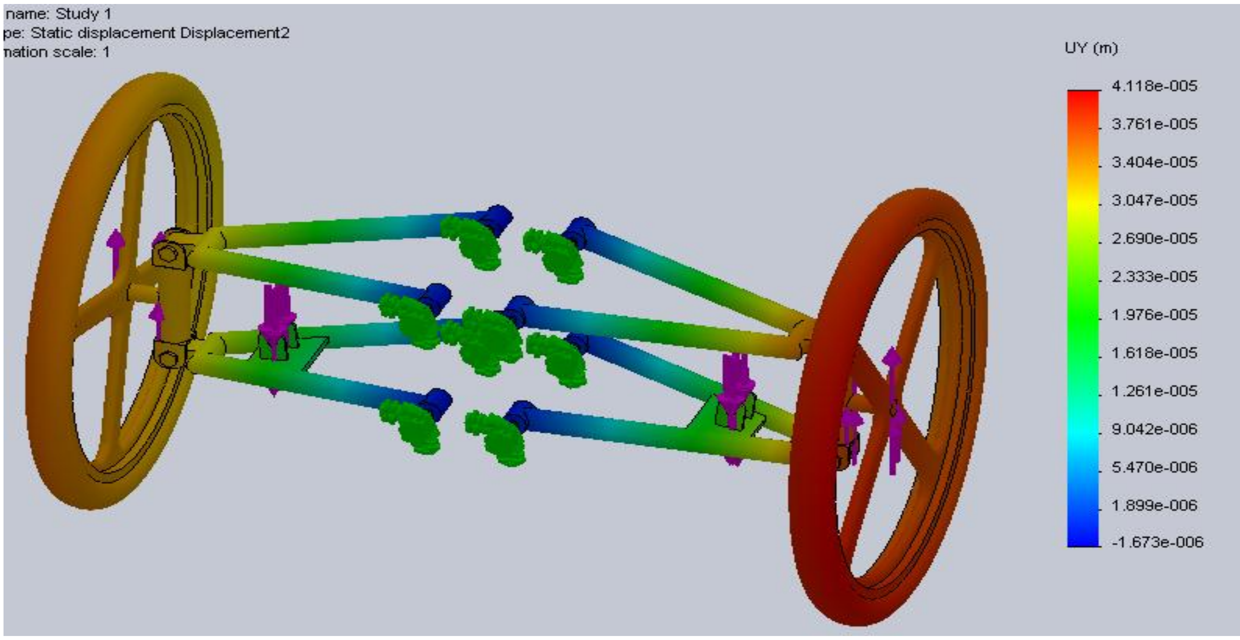


Figure 36 Y-Displacement

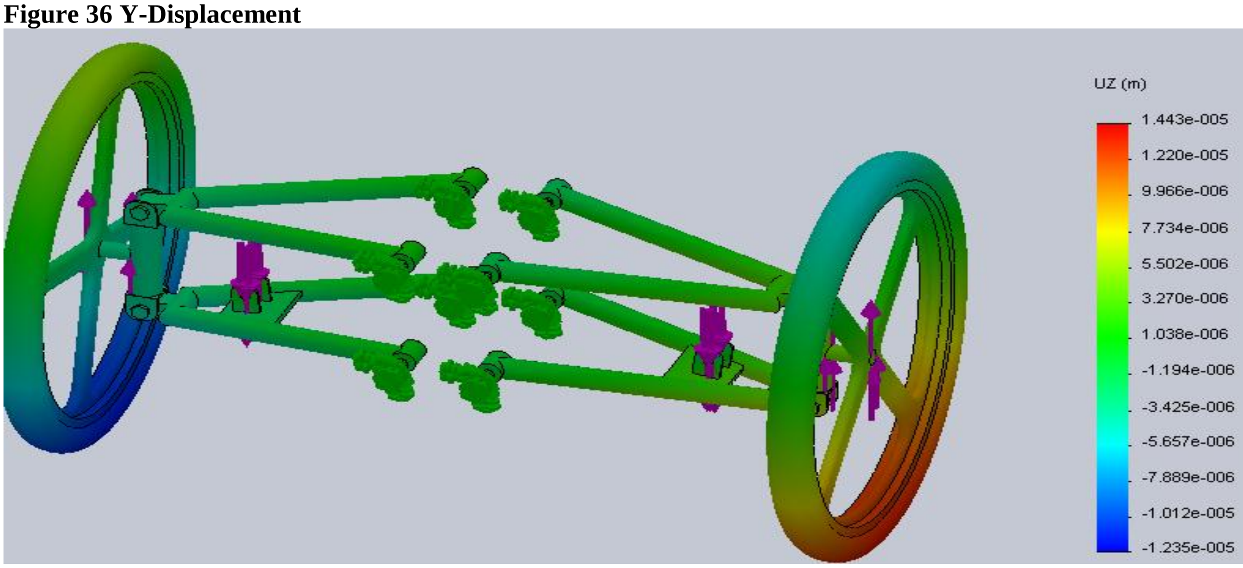


Figure 37 Z-Displacement

Study 2 Mesh Size: 2.3 cm

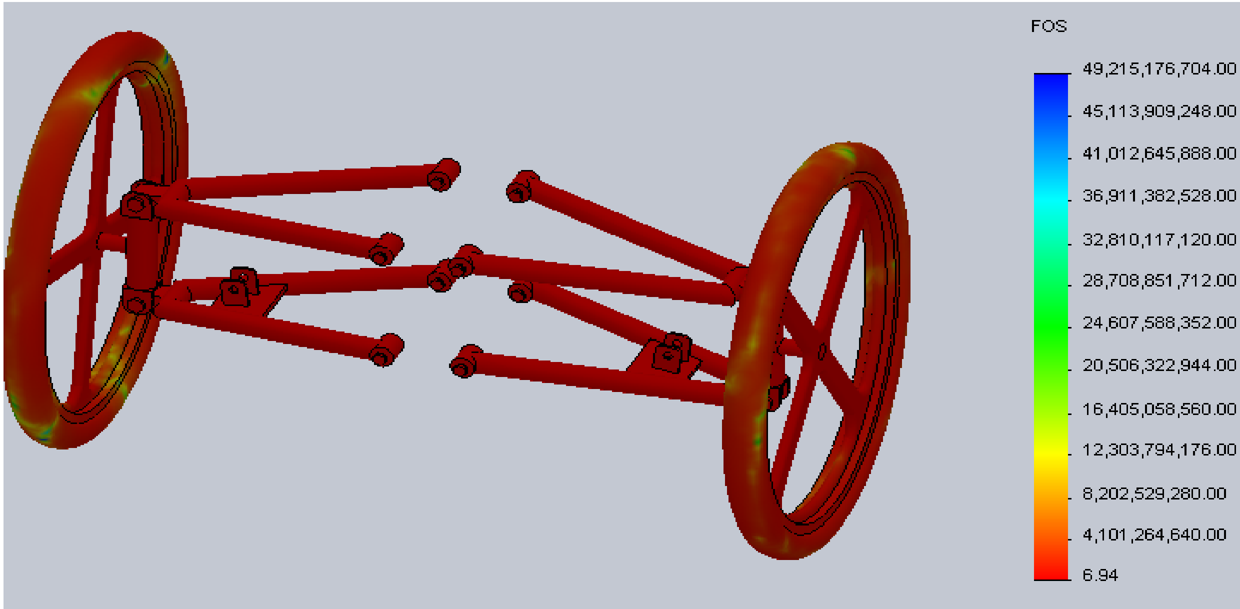


Figure 38 Factor of Safety

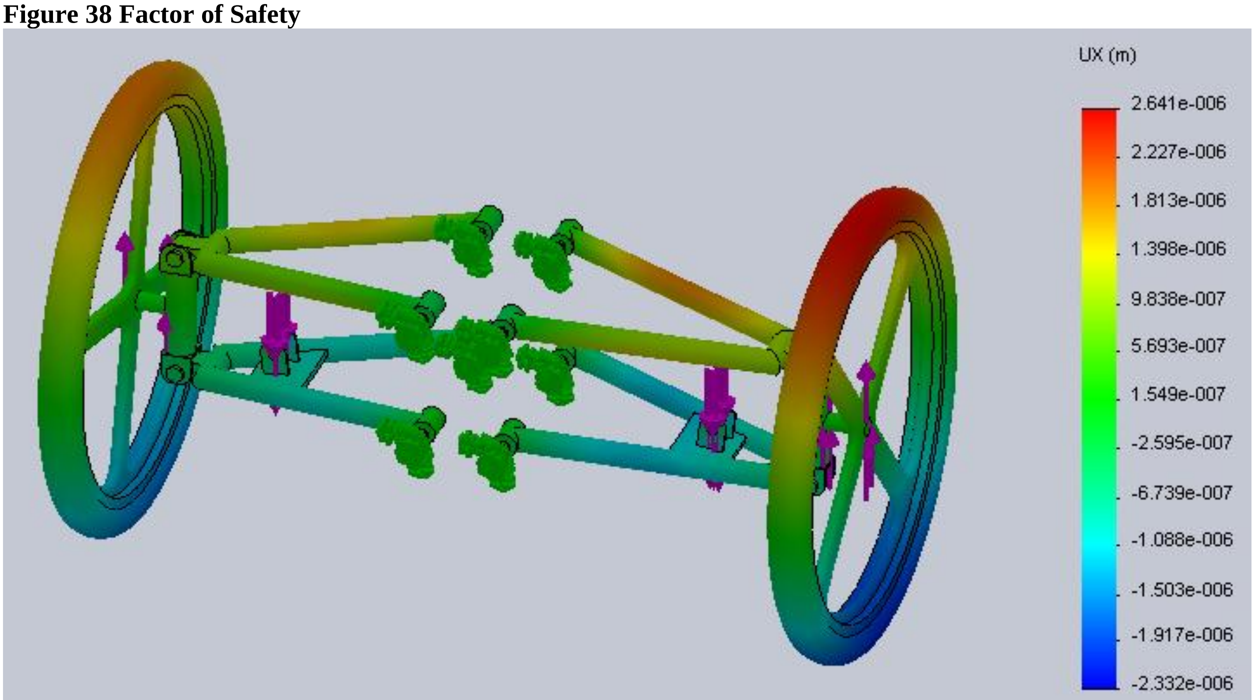


Figure 39 X-Displacement

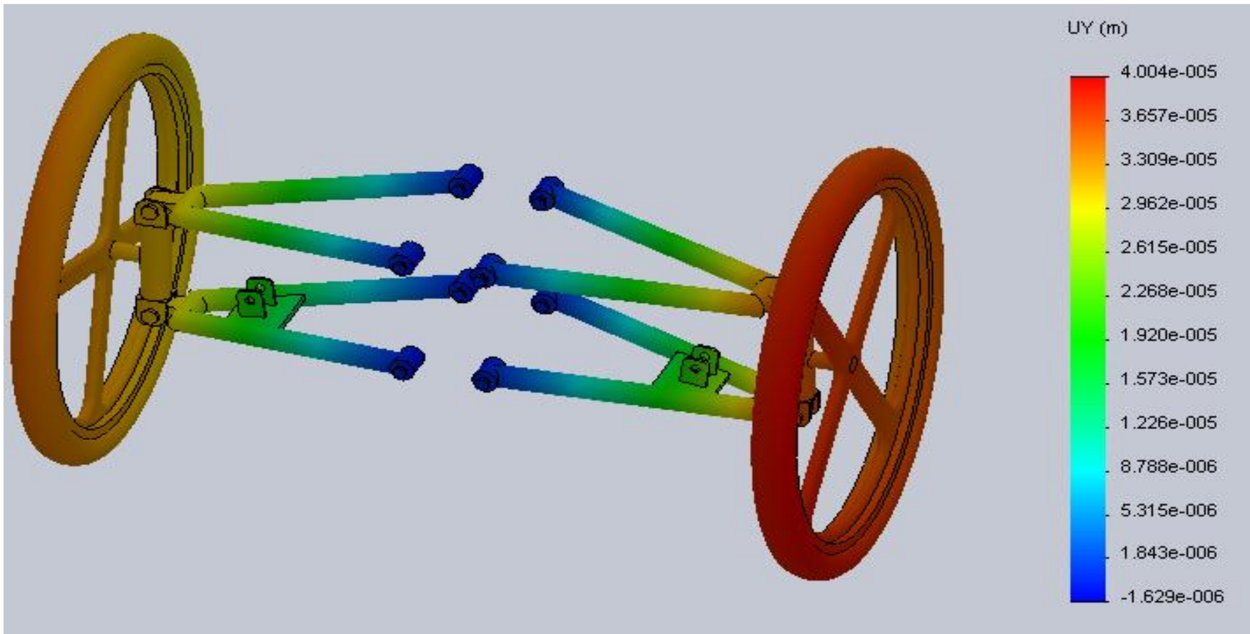


Figure 40 Y-Displacement

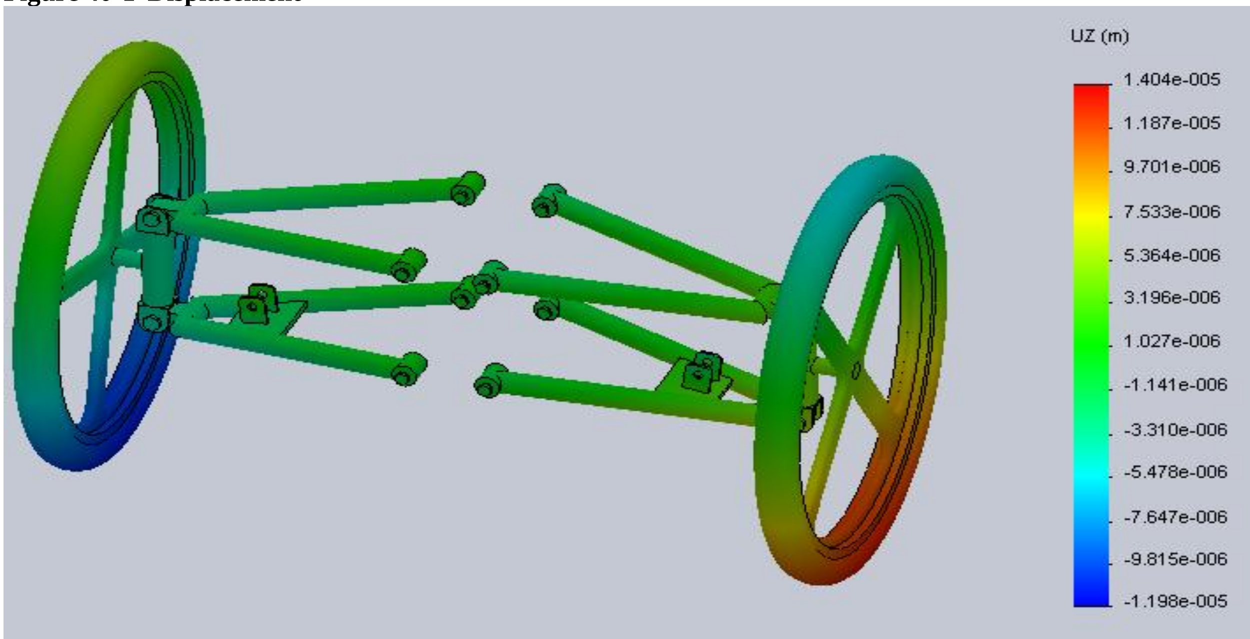


Figure 41 Z-Displacement

Study 3 Mesh Size: 3 cm

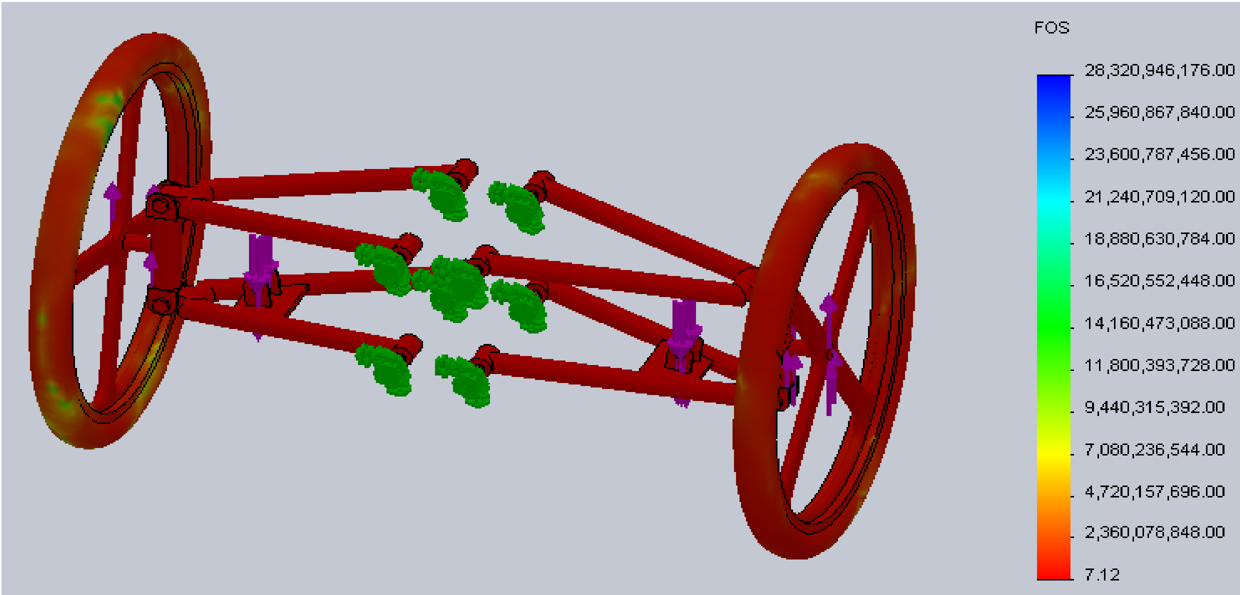


Figure 42 Factor of Safety

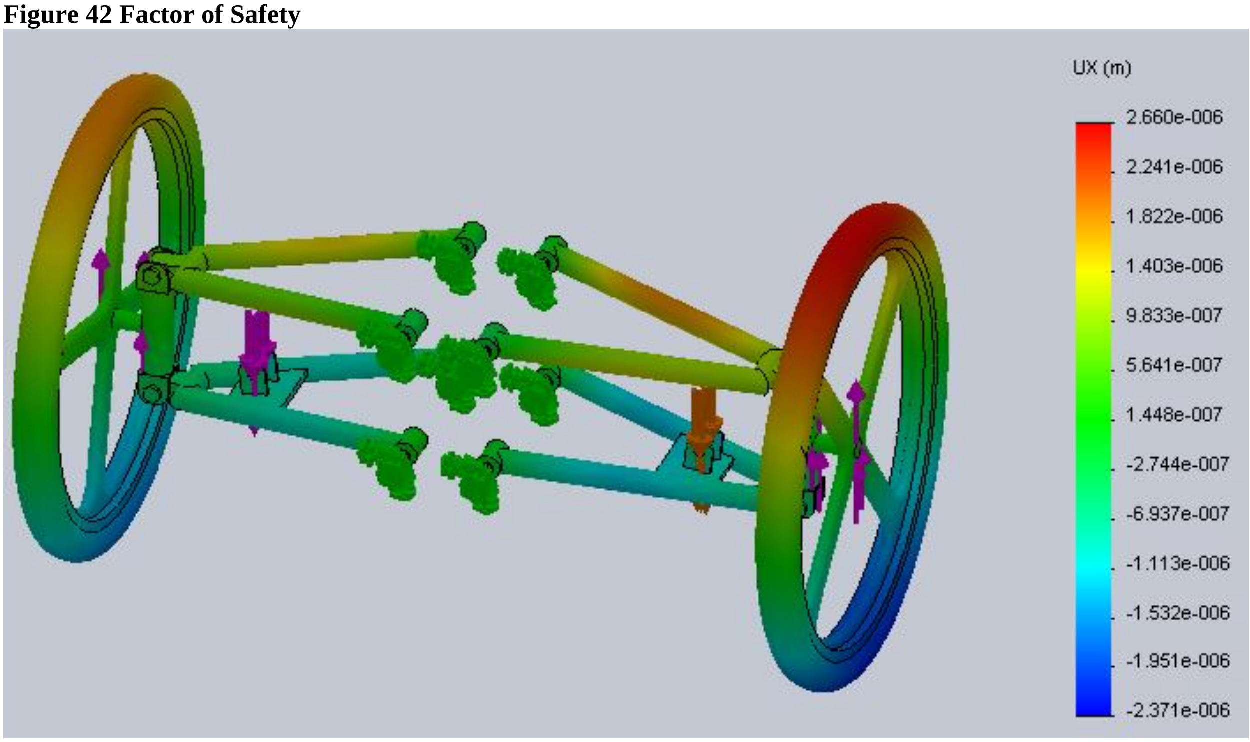


Figure 43 X-Displacement

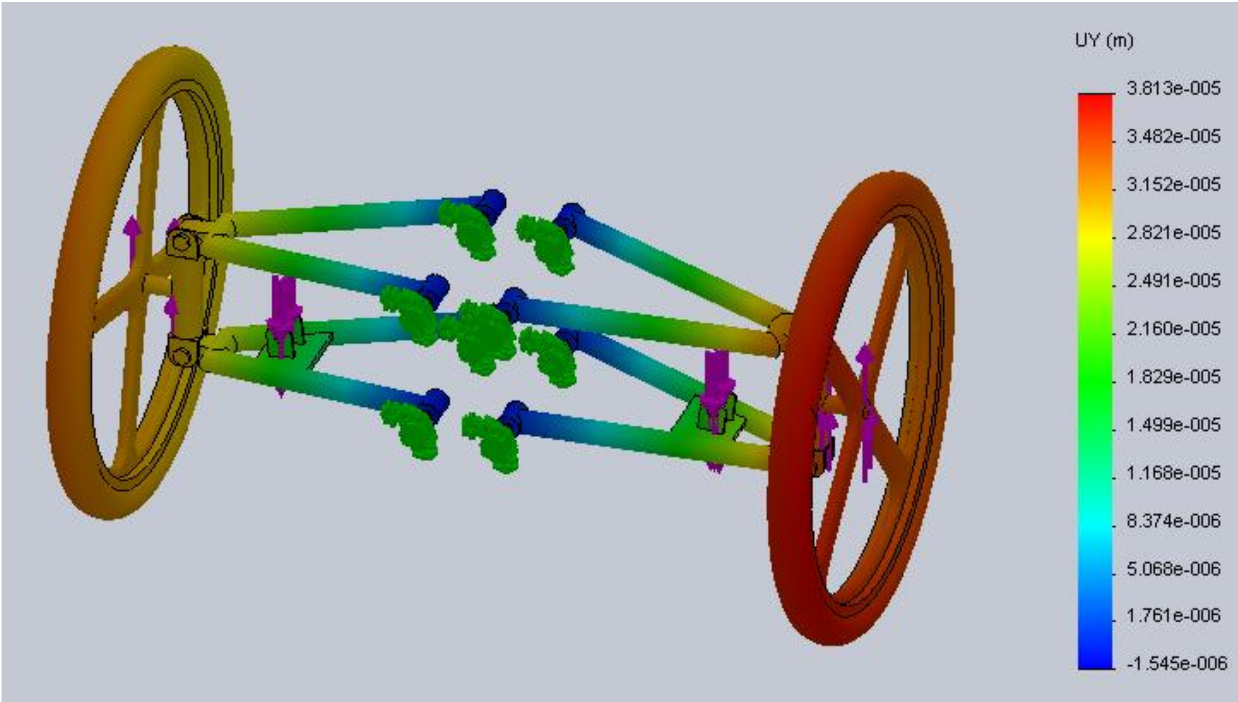


Figure 44 Y-Displacement

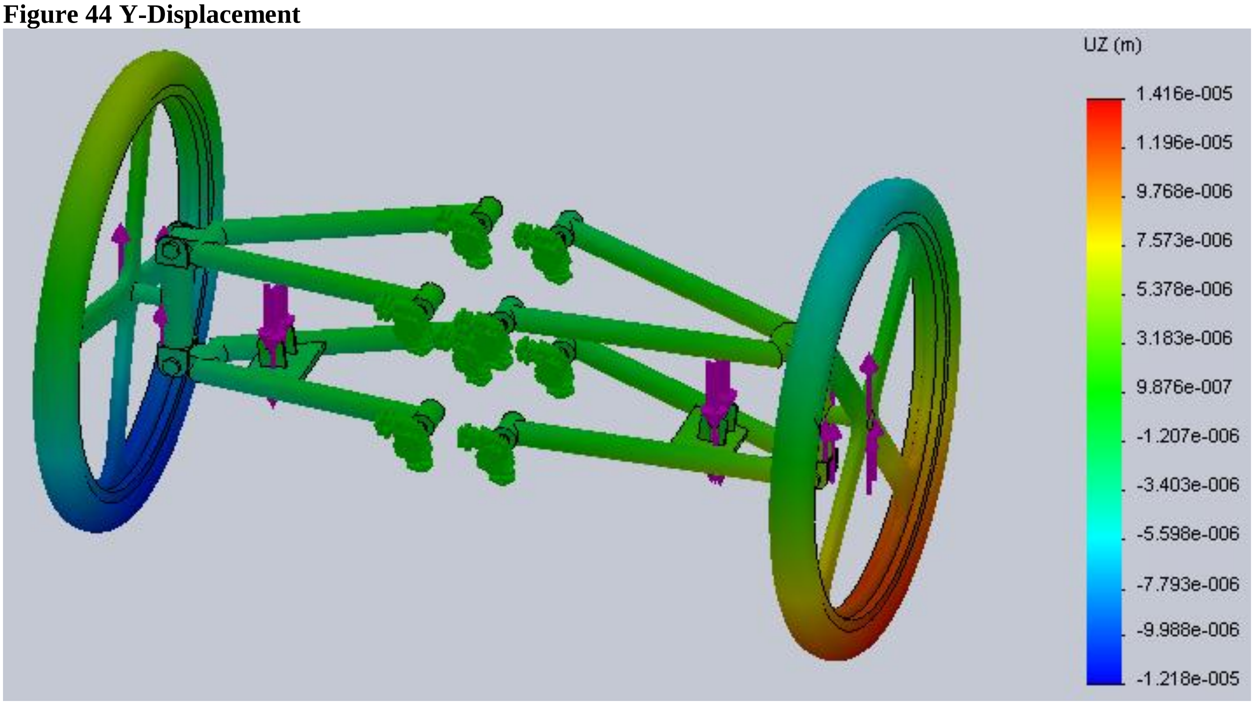


Figure 45 Z-Displacement

SolidWorks Study Analysis Results			
Study	Mesh Size (cm)	Maximum Y–Displacement $\times 10^{-5}$ (m)	Factor of Safety
1	1.48566	4.11	4.88
2	2.3	4	6.94
3	3	3.81	7.12

Table 7 SolidWorks Study Analysis Results

16.2. Double A–Arm ANSYS Analysis

Study 1 Mesh Size: 1.48566 cm

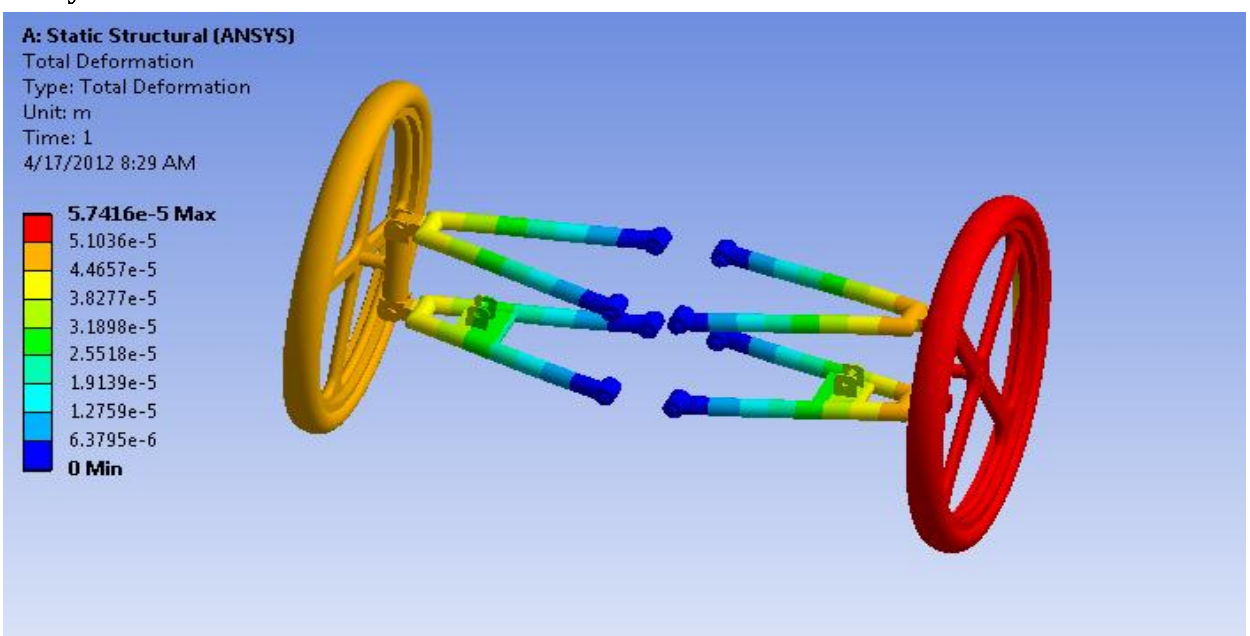


Figure 46 Total Deformation

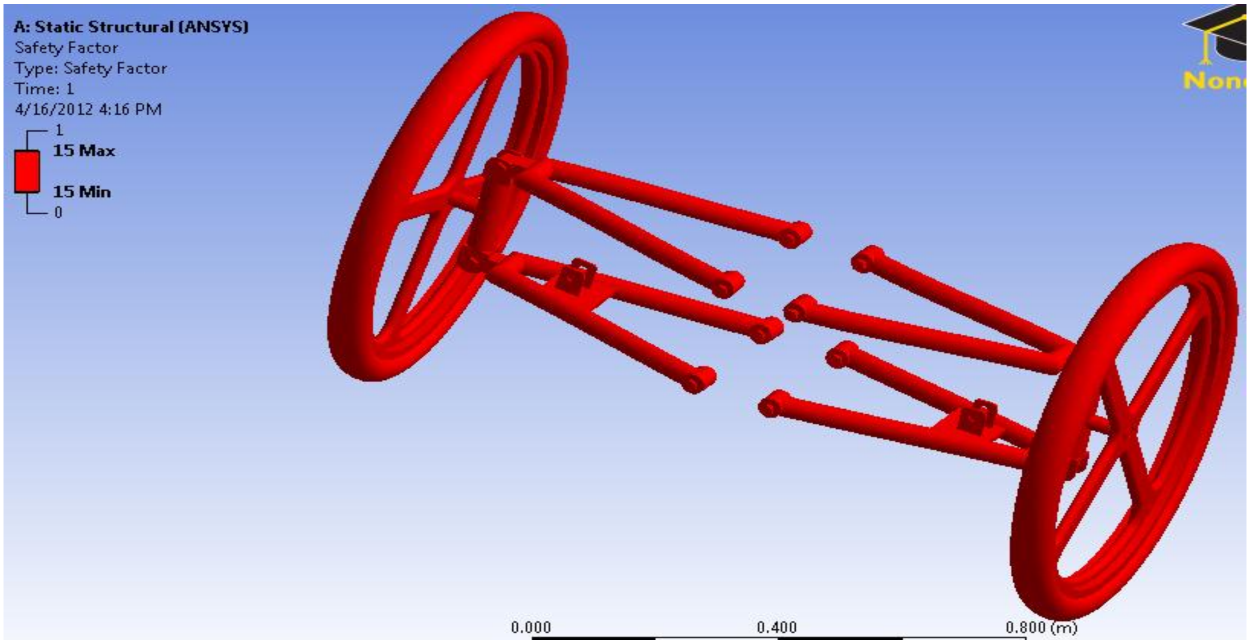


Figure 47 Factor of Safety

Study 2 Mesh Size: 2.3 cm

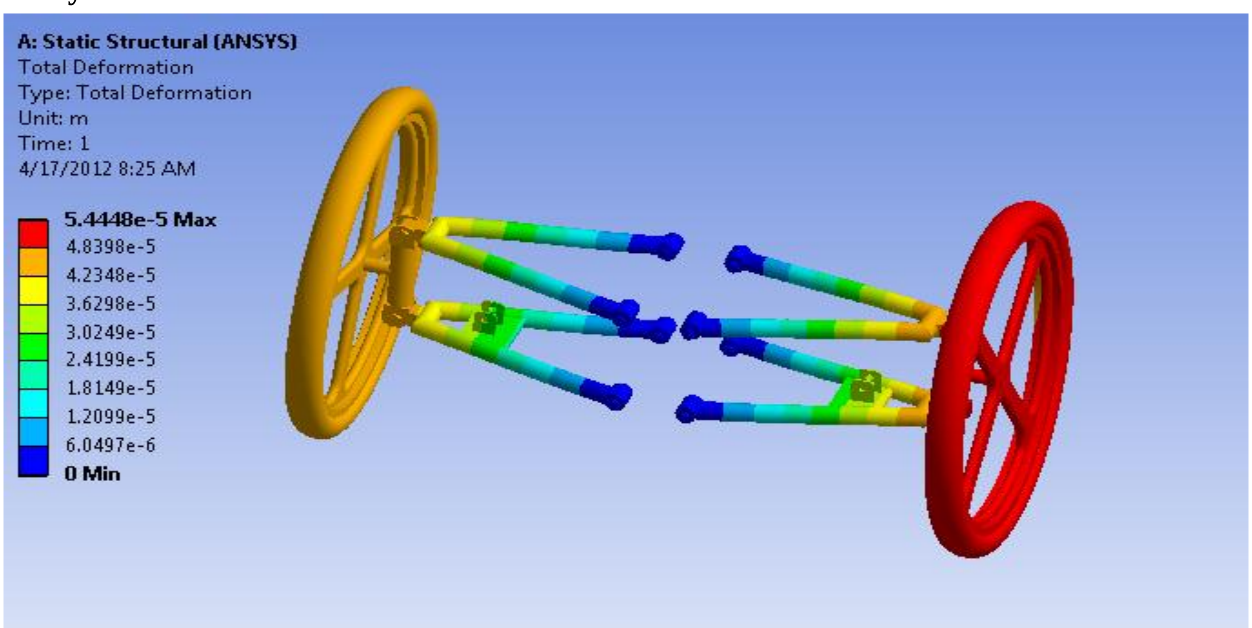


Figure 48 Total Deformation

Factor of Safety is the same as the above Study 1

Study 3 Mesh Size: 3 cm

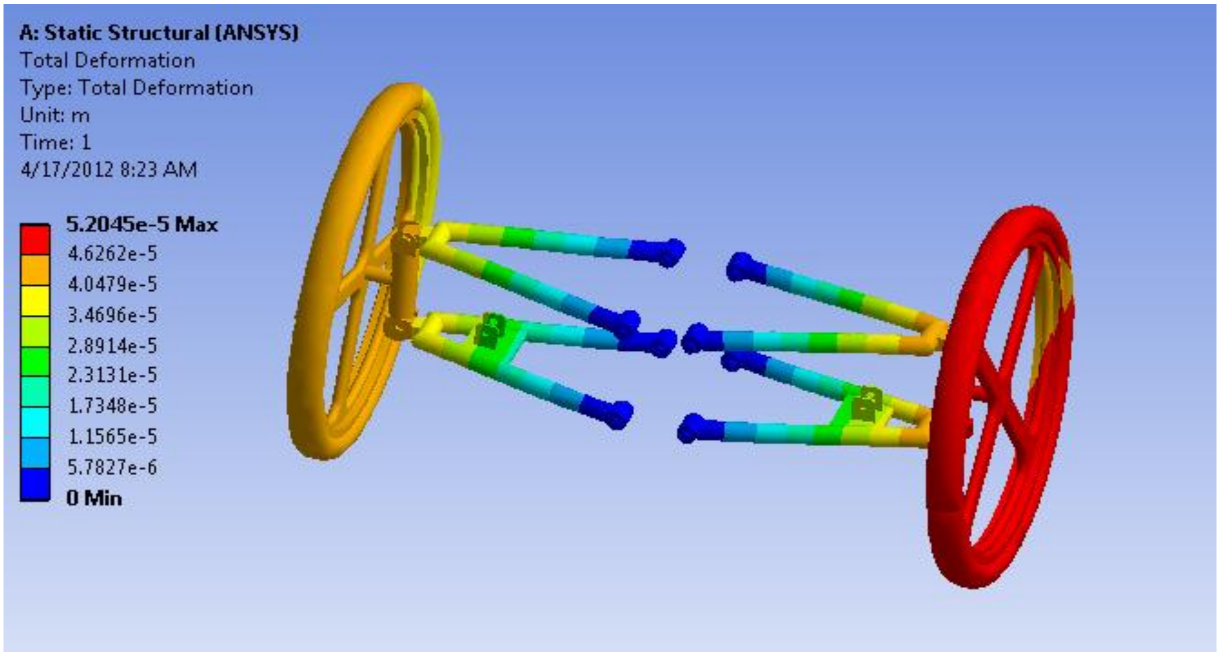


Figure 49 Total Deformation

Factor of Safety is the same as the above Study 1

ANSYS Study Analysis Results			
Study	Mesh Size (cm)	Total Deformation $\times 10^{-5}$ (m)	Factor of Safety
1	1.48566	5.7416	15
2	2.3	5.4448	15
3	3	5.2045	15

Table 8 ANSYS Study Analysis Results

16.3. Fatigue Test

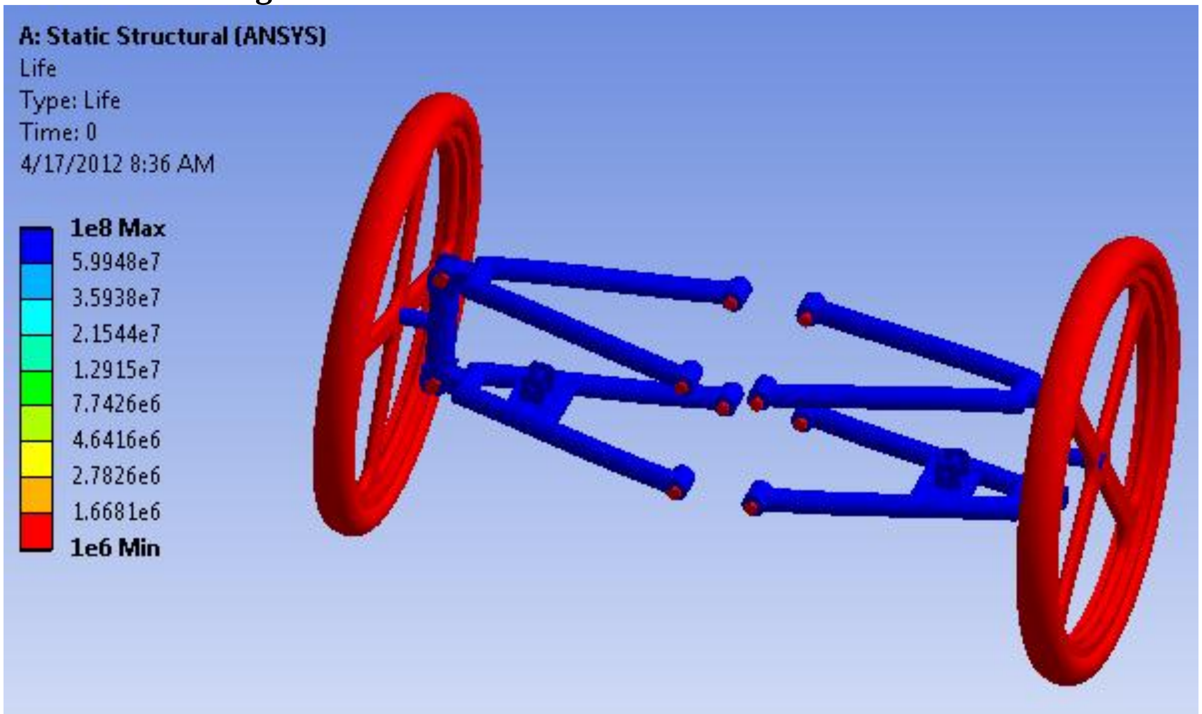


Figure 50 Fatigue Life

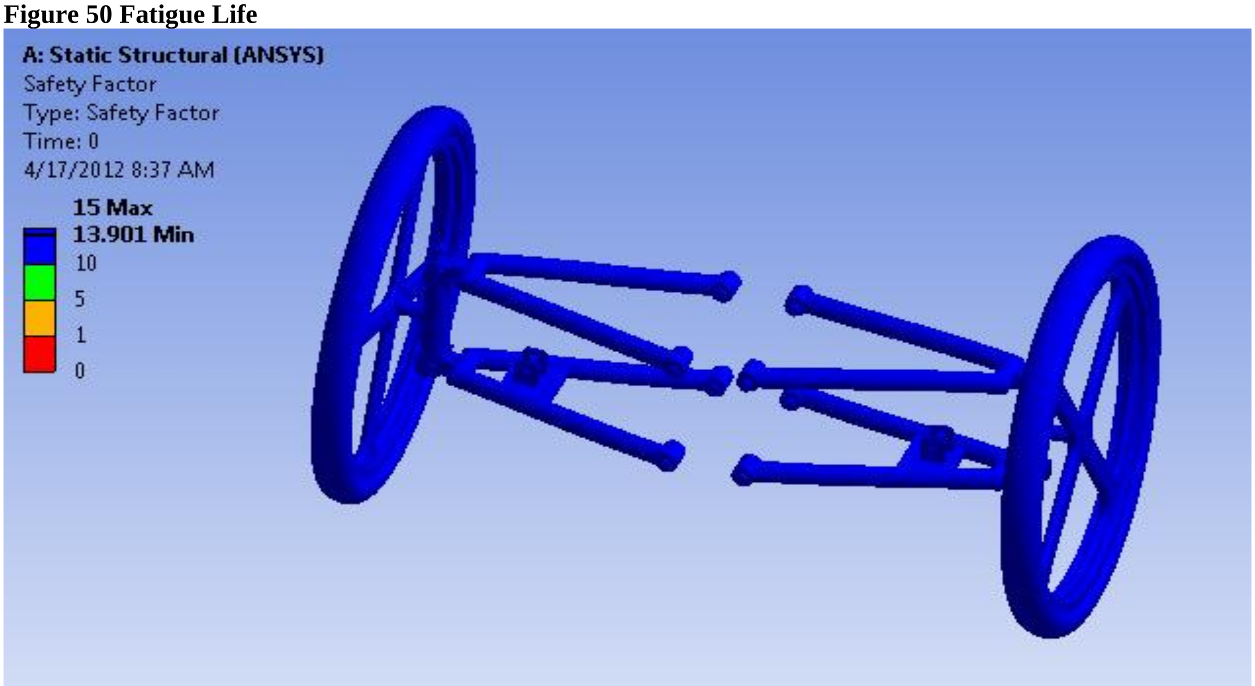


Figure 51 Safety Factor

16.4. SolidWorks Single–Arm Simulation Analysis

Study 1 Mesh Size: 1.5 cm

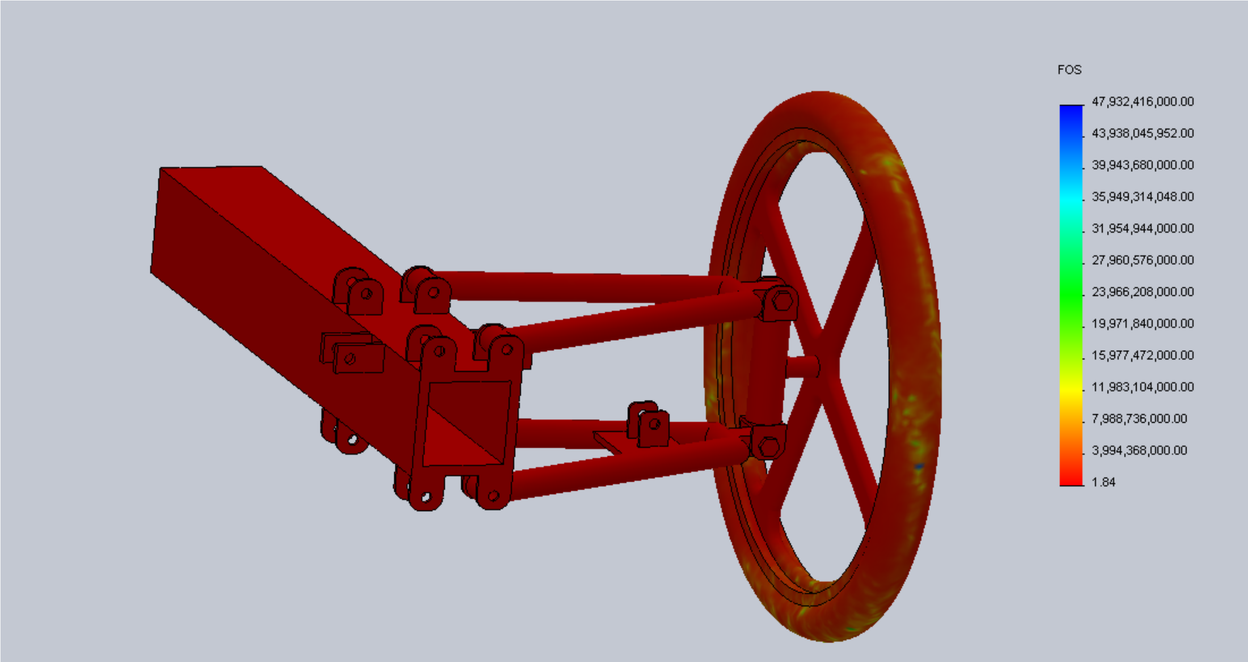


Figure 52 Factor of Safety

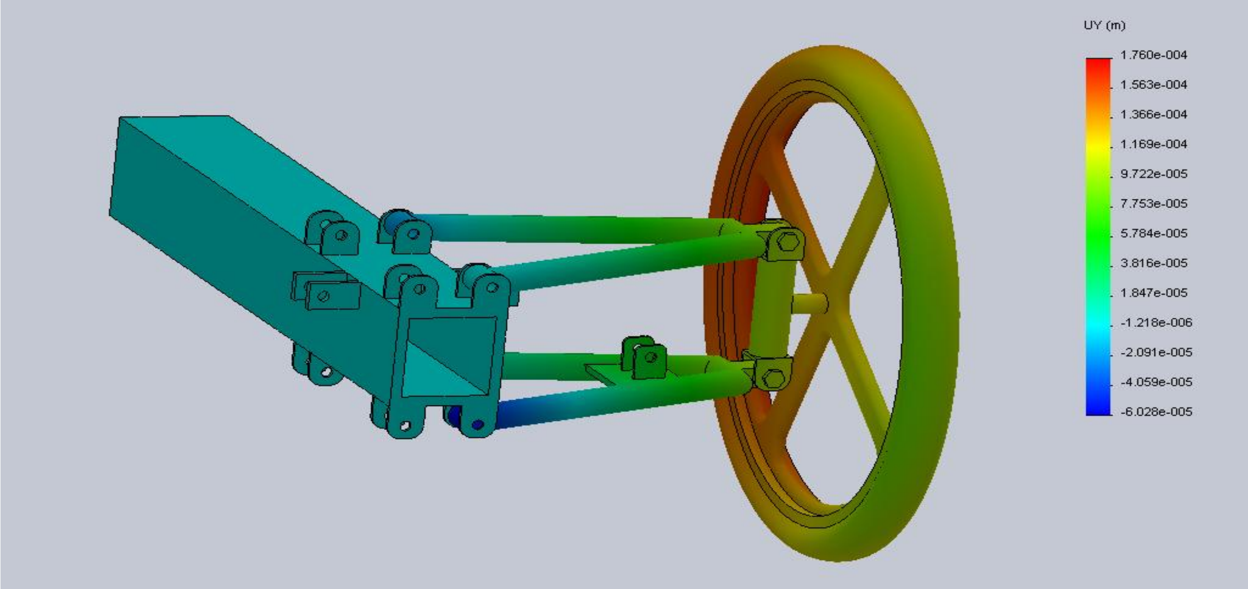


Figure 53 Y-Displacement

Study 2 Mesh Size: 2.3 cm

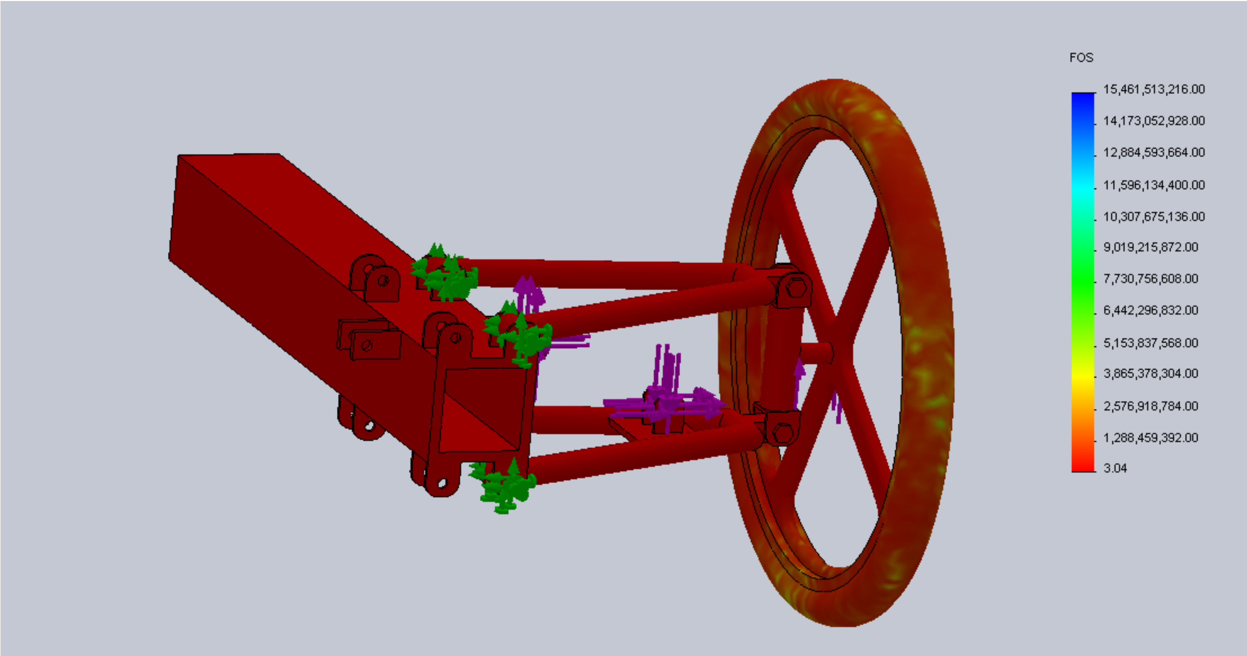


Figure 54 Factor of Safety

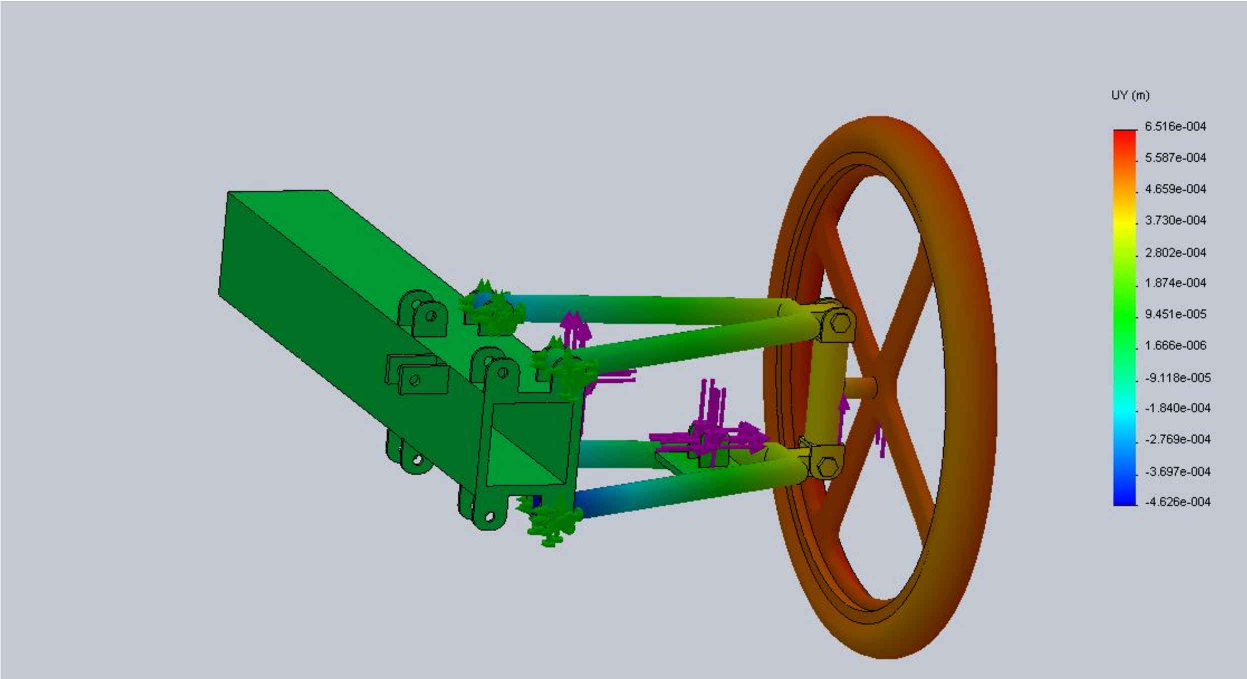


Figure 55 Y-Displacement

Study 3 Mesh Size: 3 cm

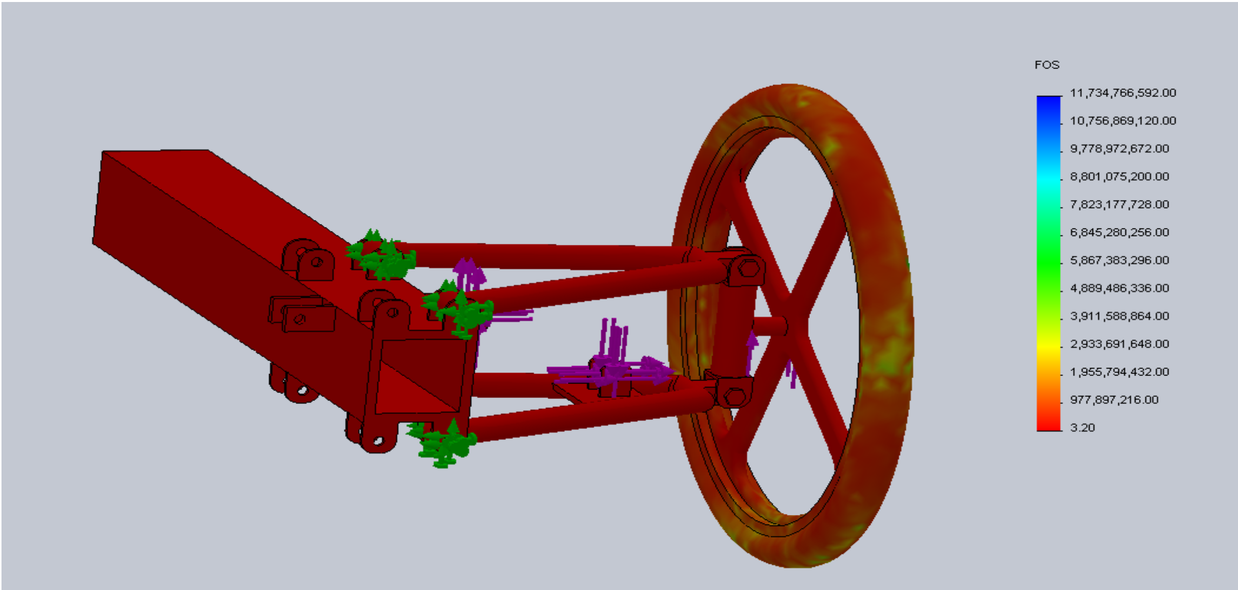


Figure 56 Factor of Safety

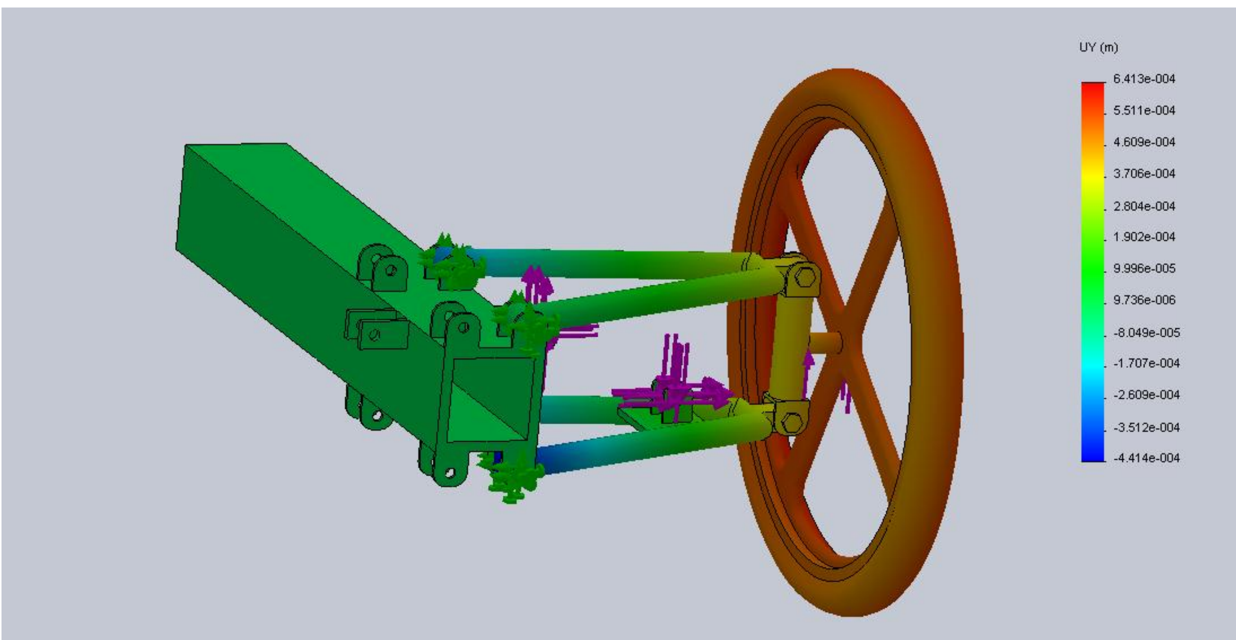


Figure 57 Y-Displacement

SolidWorks Study Analysis Results			
Study	Mesh Size (cm)	Maximum Y–Displacement $\times 10^{-4}$ (m)	Factor of Safety
1	1.5	1.760	1.84
2	2.3	6.516	3.04
3	3	6.413	3.20

Table 3

16.5. ANSYS Single–Arm Simulation Analysis

Study 1 Mesh Size: 1.5 cm

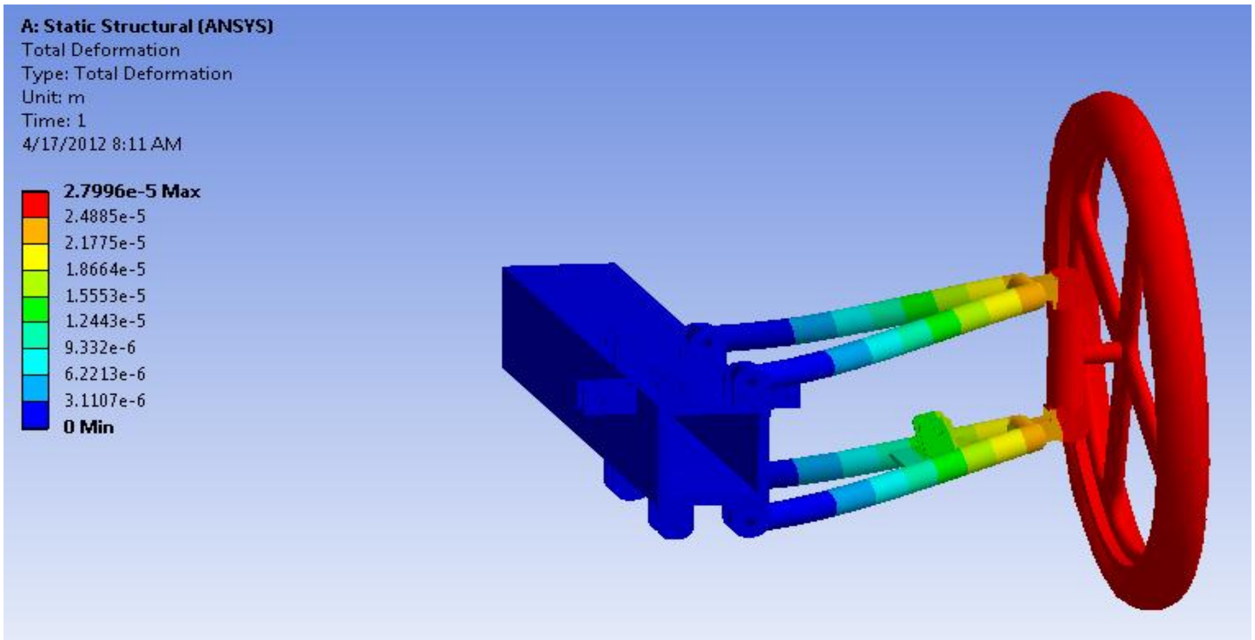


Figure 58 Total Deformation

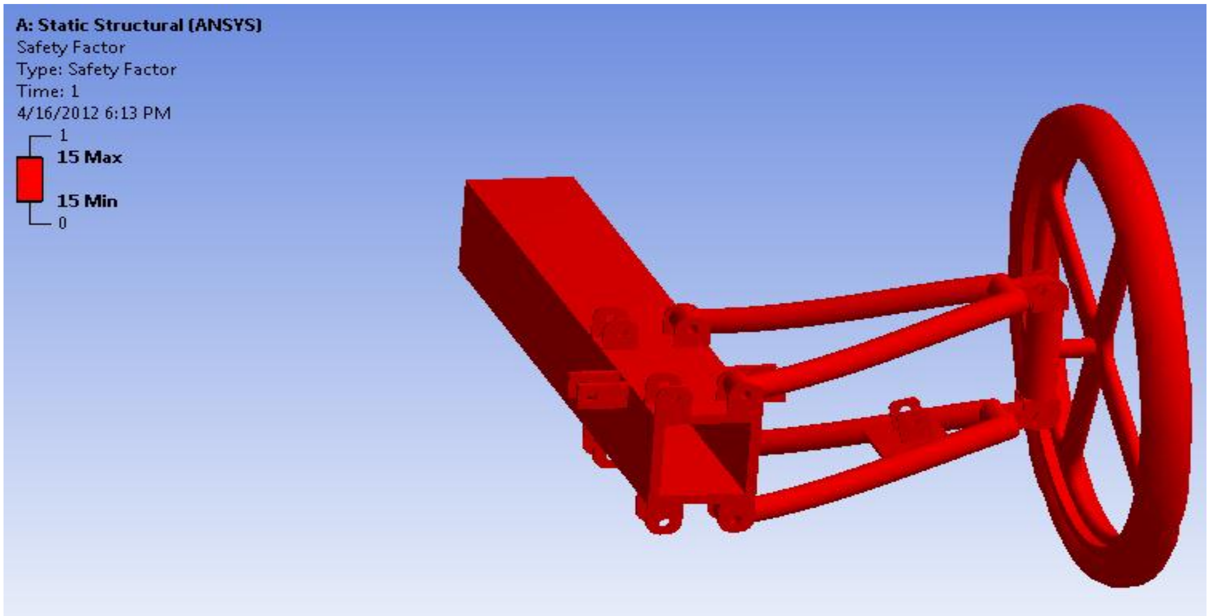


Figure 59 Factor of Safety

Study 2 Mesh Size: 2.3 cm

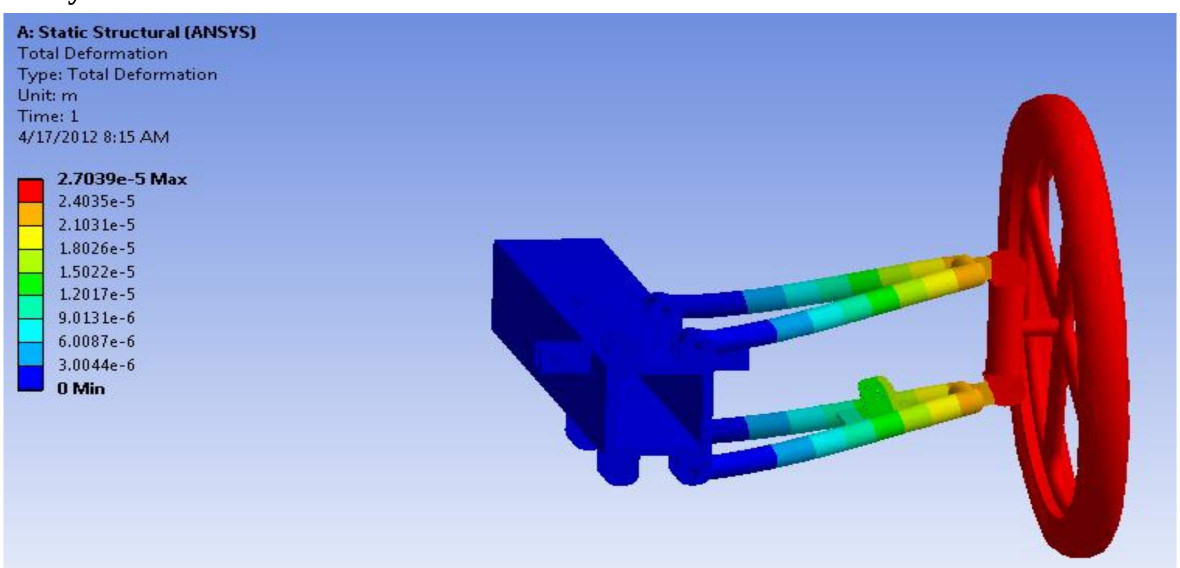


Figure 60 Total Deformation

Factor of Safety is the same as the above Study 1

Study 3 Mesh Size: 3 cm

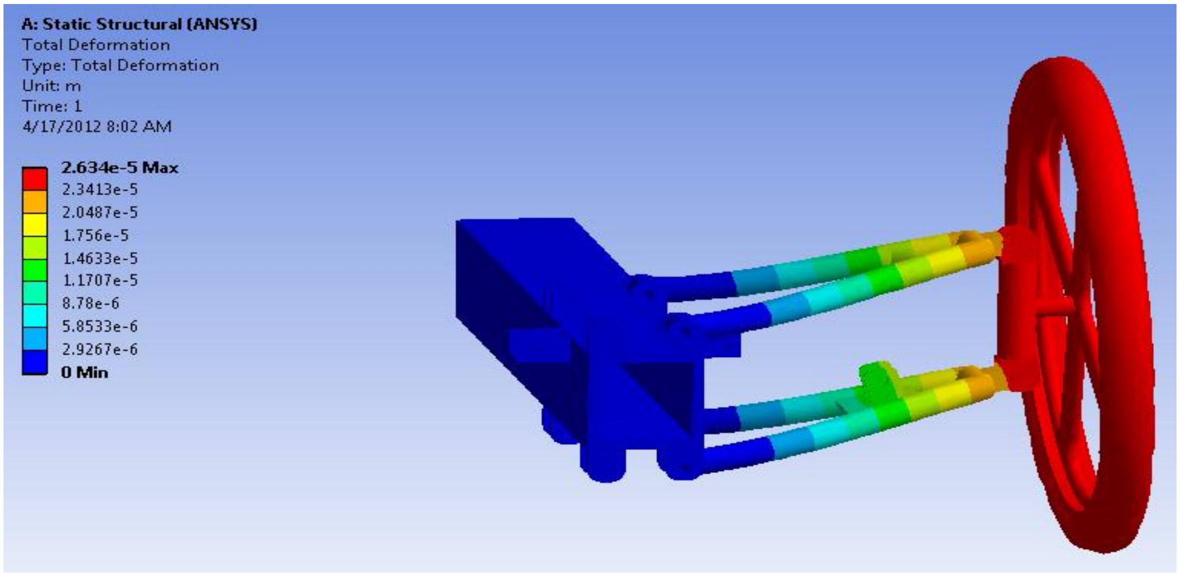


Figure 61 Total Deformation

Factor of Safety is the same as the above Study 1

ANSYS Study Analysis Results			
Study	Mesh Size (cm)	Total Deformation $\times 10^{-5}$ (m)	Factor of Safety
1	1.5	2.7996	15
2	2.3	2.7039	15
3	3	2.6340	15

Table 9 Ansys Study Analysis Results

16.6. Fatigue Test

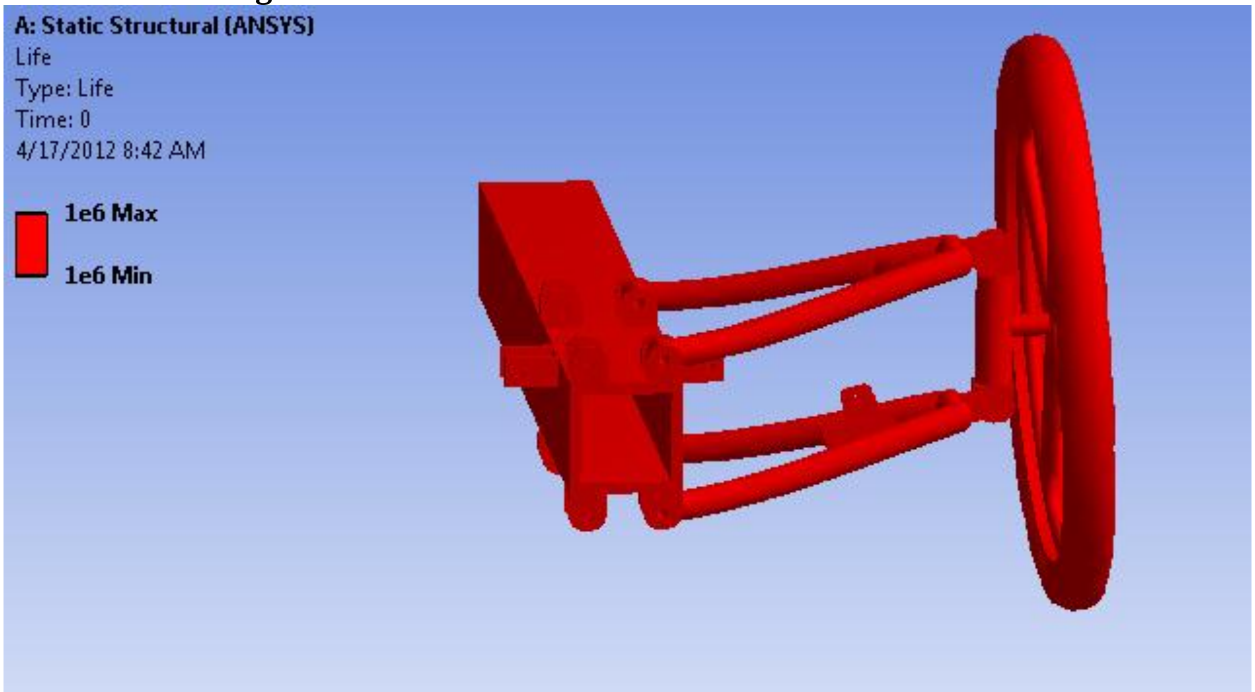


Figure 62 Fatigue Life

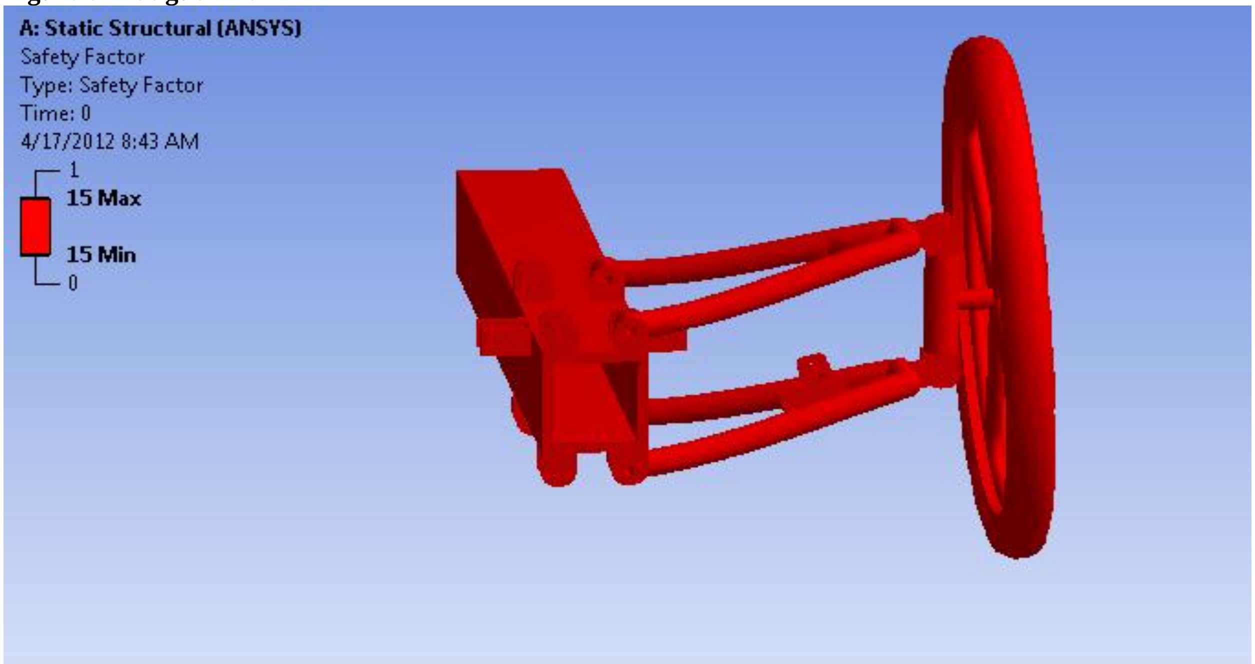


Figure 63 Safety Factor

17. Discussions and Conclusions

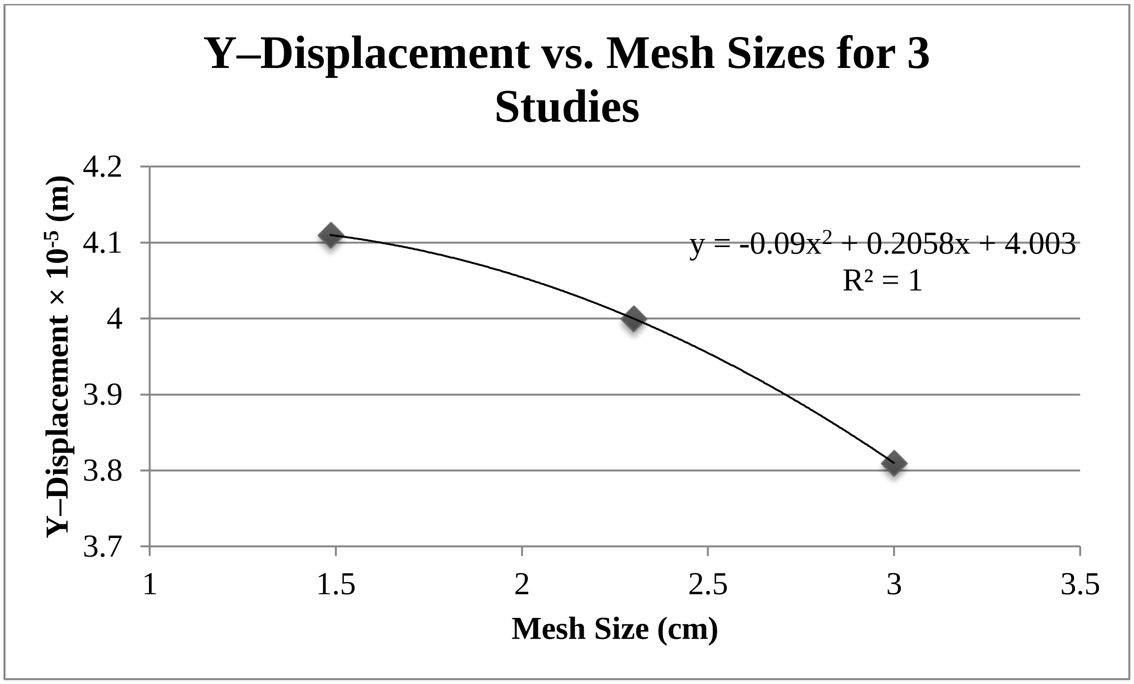


Figure 64 SolidWorks Double A-Arm Y-Displacement Plot

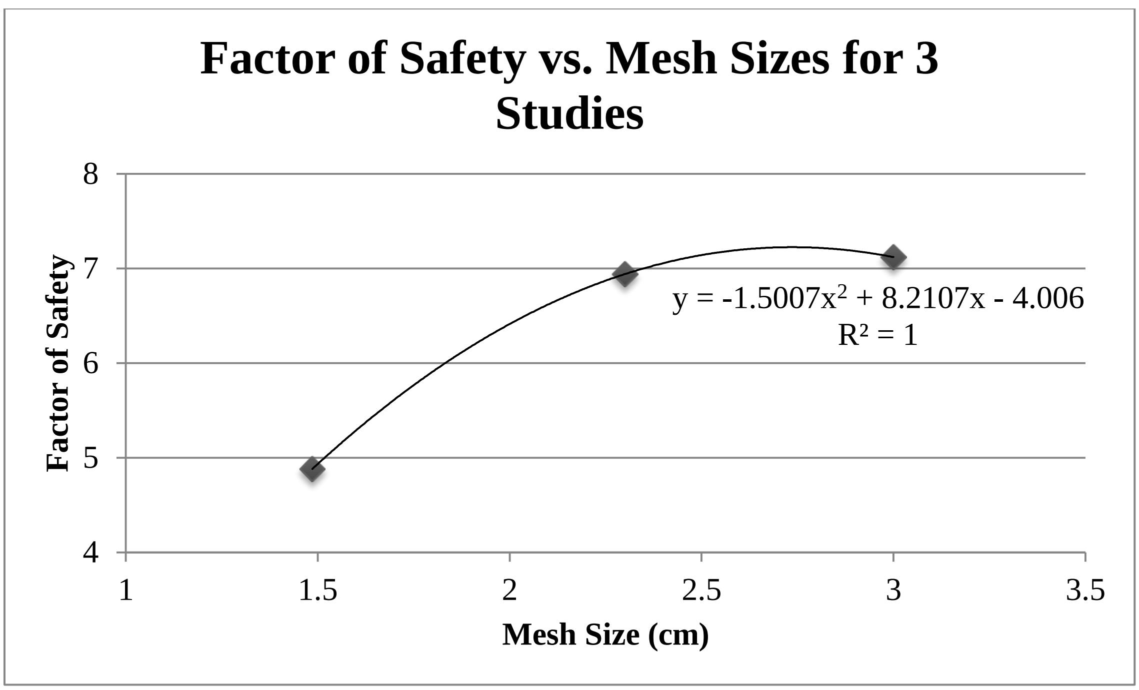


Figure 65 SolidWorks Double A-Arm Plot Factor of Safety

While comparing the SolidWorks analysis with that of the ANSYS analysis, it was concluded that the y–displacement in SolidWorks was very similar to the total deformation produced in ANSYS. Although there were some negligible discontinuities in the data values, the results between SolidWorks and ANSYS were very similar, thus proving that the overall analysis was performed correctly on both programs.

There was an inconsistency in the deformation and displacement of each arm couple of the suspension. The position of one arm couple relative to the other was not an exact mirror image of its counterpart, showing that the forces applied to the shock support and the wheel hub were not exactly the same distance from their linkage. This disparity caused the unexpected variation in the color of the wheels displayed in the displacement plots.

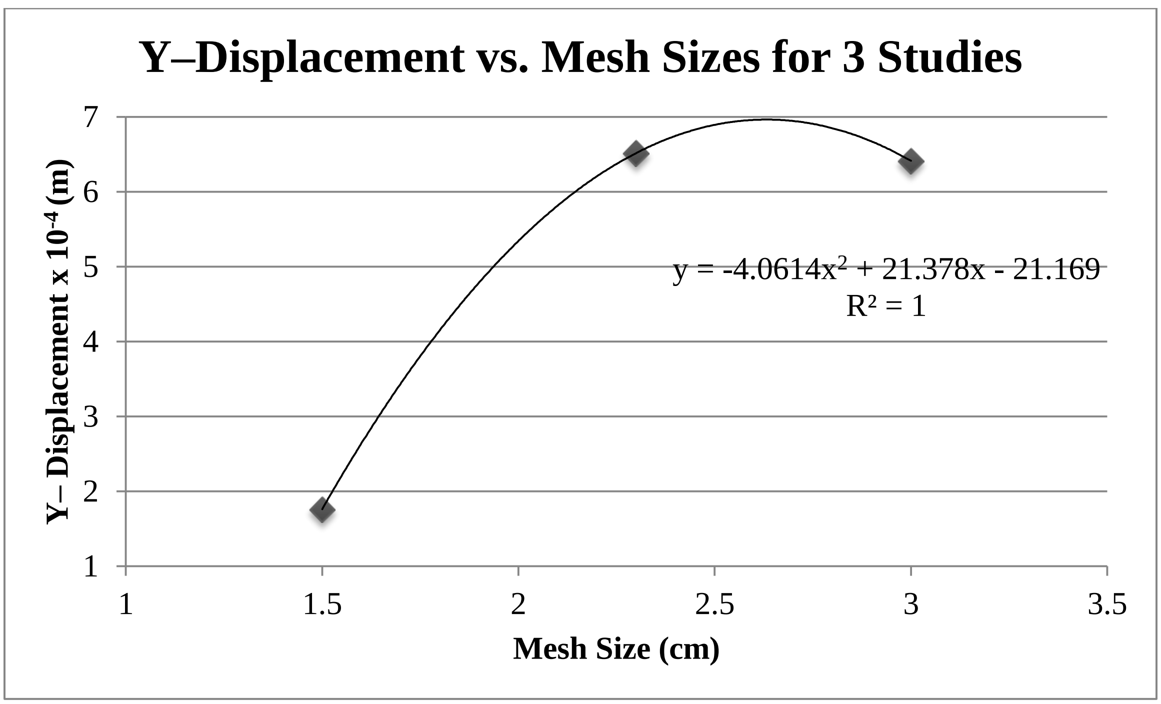


Figure 66 SolidWorks Single A-Arm Y-Displacement

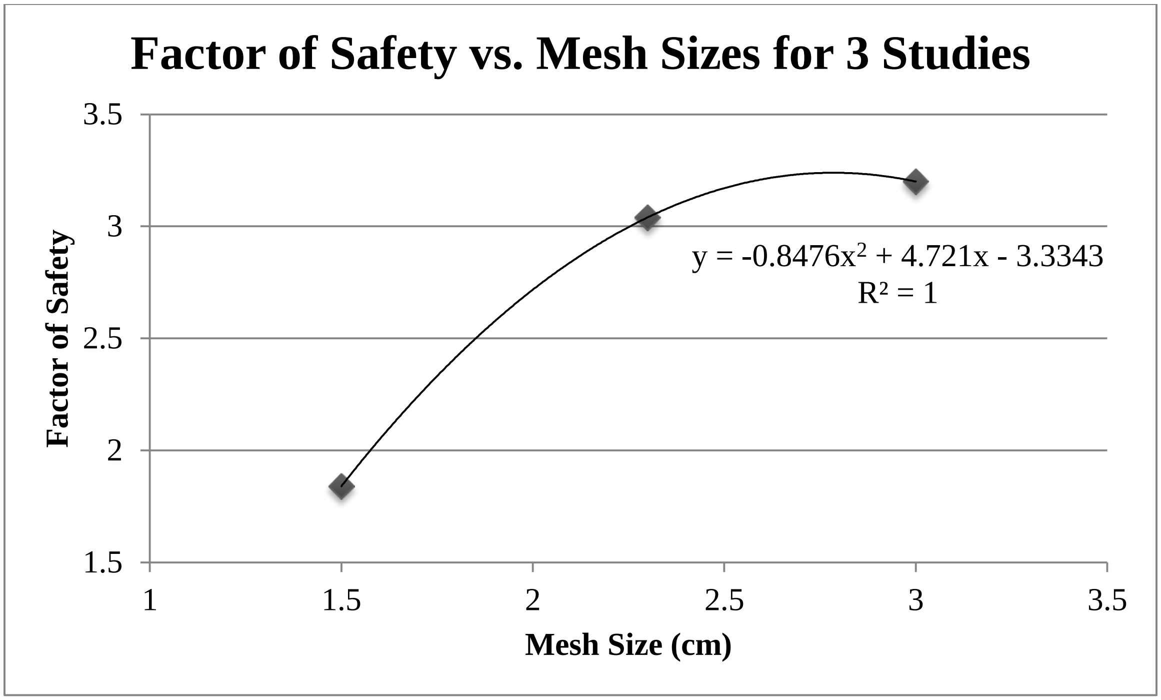


Figure 67 SolidWorks Single A-Arm Factor of Safety Plot

Recognizing this discrepancy in the model, it was decided to analyze one side of the suspension when linked to the frame. Again, the results imply that the slight variations in between both sides of the suspension could also be caused by the missing presence of the frame. So, another model was assembled with the frame along with one couple of arms from the suspension so that the simulation could be analyzed in detail. The displacement results in SolidWorks and ANSYS were similar as seen in the simulation results above.

Finally, by performing the convergence study, where 3 different mesh sizes were used for each model, and implementing a new single–arm frame couple suspension study, it was concluded that the analyses performed were successful and produced values that were within expected ranges satisfying the hypothesis.

18.<u>Manufacturing.</u>

Here in June profesor Zicarelli displayed how to properly use the bandsaw in order to cut the small aluminum cylinders that later on will be inserted with a smaller stainles steel cylinder to work like a bushing. The aluminum cylinders where used at the end of the a-arms in order for them to pivot in the 3/8 bolts that are holding the suspension arms to the frame.

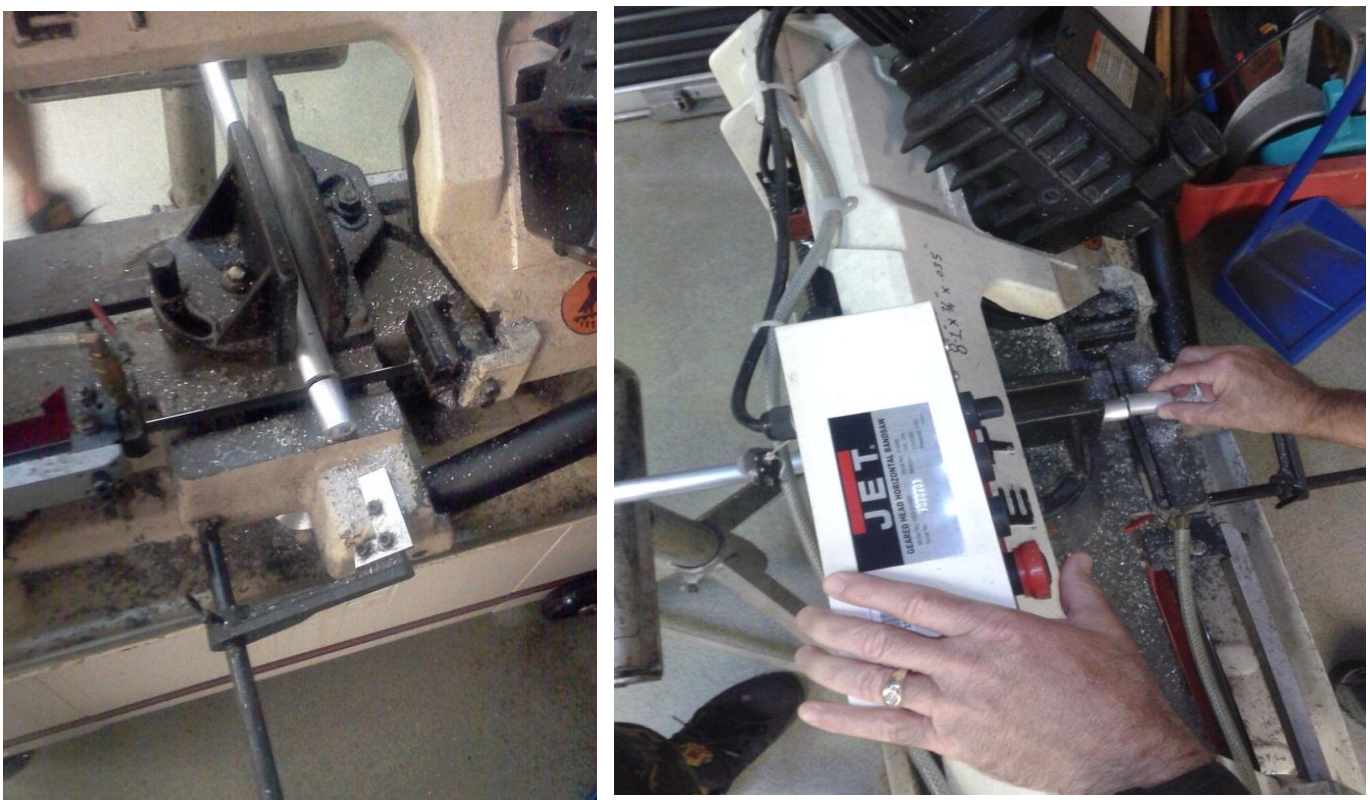


Figure 68, Band Saw

Then the machining began with the 1 inch diameter 1/8 thicknes aluminum rods being bent in the U shape that a-arm suspension is characterized by. This was done using a hydrolic pipe bender provided by Profesor Zicarelli

Figure 69, A-arm parts

Once the pipes where cut to the proper lengths and bended with the hydraulic pipe bender, using the band saw the arms where cut in the middle in order to fit the little aluminum cylinder which was going to hold a bolt to which a ball joint was going to be screwed

Once the arms where cut, the ends where re-shaped with a semi-circle in order to easily weld them with the aluminum cylinder that holds the ball joint. This was done using a 1-inch diameter drill bit.

Figure 70, Knee mill

Once the semi-circles were done, uneven edges were grinded using the table grinder wheel in order to be able to weld the parts easier.

Figure 71, Table grinder

Once the hollow aluminum cylinders used to hold the a-arms to the body where cut, then stainless steel cylinders with the outer diameter slightly bigger than the inner diameter of the aluminum ones where pressed in to the aluminum cylinders to function as a bushing, this way the aluminum would not wear out with the constant swing of the arm.

A-arm steel bushing

Figure 72 A-arm steel bushing

To finalize with the a-arms, the arms were welded together using the ARC welder and between them a solid aluminum rod which was previously drilled in the middle and threaded. A screw was passed through, and with it a universal ball joint was attached to the end of the arm.

Figure 73, Screw tapping

Figure 74, A-arm assembly

One of the main problems which had to be solved during the manufacturing was the fabrication of the wheel hubs. The main problem was that it is very complicated to hold the wheel, the steering, lower and upper suspension arms, while at the same time letting the wheels turn.

Figure 75, wheel hub

Figure 76, Hub & A-arms

The next step was to weld the brackets where the a-arms where going to be located, joining the arms to the body. They were positioned with a 6 degree incline in order to reduce the stress that the brackets were to receive as the wheels when they hit an obticle while going forward. With this setting the forces that the brackets take are distributed through the shock absorber.

Figure 77, Front assembly

Figure 78, Front assembly 2

Ather welding the arm brackets and the shock mounts the shock absorbers were instaled. The shock absorbers used where the ones found on a regular double suspencion bicicle which consists on a damper and a sping of 750N force.

Figure 80, Shock assembly

Figure 79, Front shock absorber

For the rear suspension a bicycle rear shock absorber was used, but this shock is different from the front ones. This spring holds 950N due to the fact that the rear wheel will be holding the weight with only one shock instead of two.

Figure 81, Rear shock assembly

Figure 82, buggy rear view

For the complete frame assembly the vehicle was able to support 350 pounds which is way more than the weight of the passengers that will be participating in the competition.

Figure 83, buggy front view

Next, the steering was a critical part of the project, which isn't complete yet due to the fact that failure occurred while testing it. Failure occurred when the steering system was done from aluminum; since aluminum is a soft material it shears on the weakest point of the system which was the joint area between the steering column and the tie rod end connection. The solution to the problem was to redo the steering system with steel, now the system may be a little heavier, but it is strong enough to resist the shear forces that the torque of the wheels and steering produce.

Figure 84, Aluminum steering

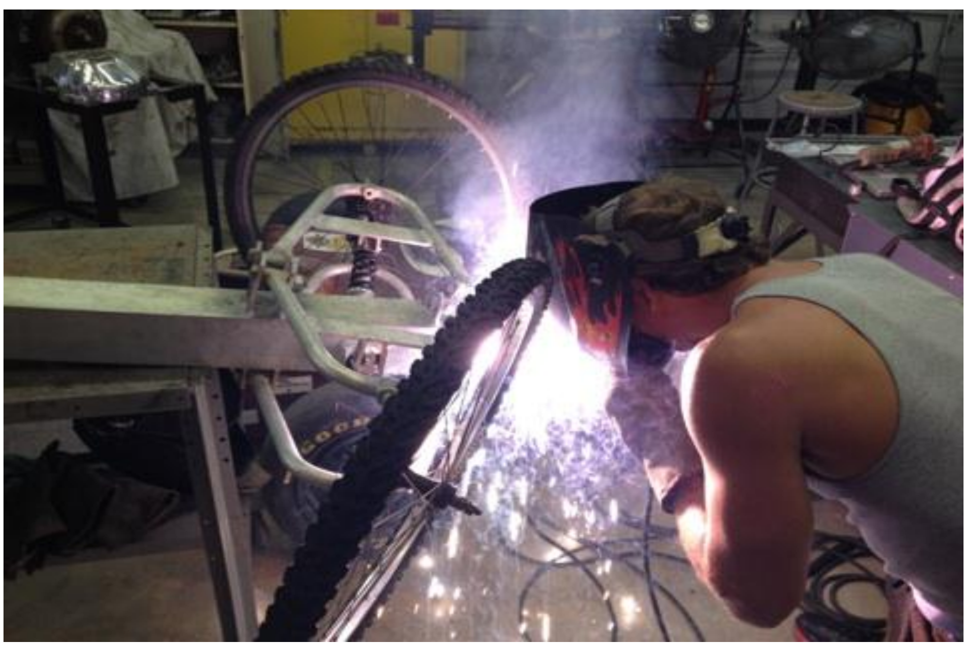


Figure 85, Welding

Figure 86, Aluminum steering assembly

Figure 87, Steel steering assembly

The next problem that came during the manufacturing process was that of the front right wheel hub bearing being damaged and the steering was not complete. Apart from these problems, the seats and power train where not done yet.

Here we can see in these pictures the old wheel hub, which was going to be replaced for a lighter, stronger and more efficient hub

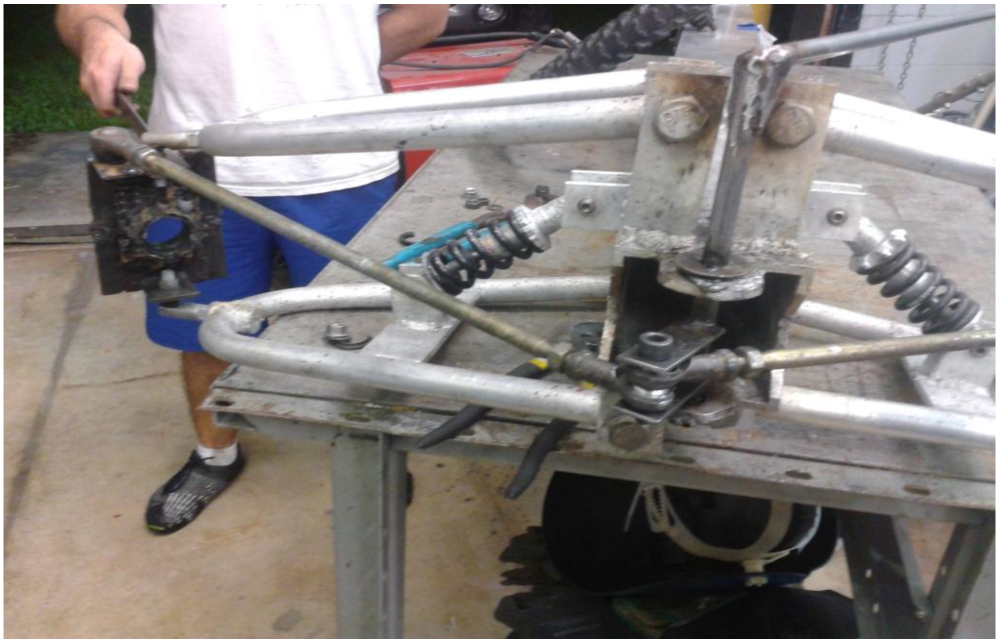


Figure 88, Front Right Wheel Hub

Figure 89, Front Right Wheel Hub

Here there is a picture of the new front right wheel hub which was made out of steel, this hub was design to be much lighter, easier to mount and allowed the inner bearing of the original wheel to work without any problems, with this adjustment a smoother ride with less friction was to be provided.

Figure 90, New front right wheel hub

The next part of the manufacturing process came with the fabrication of the seats where the two riders would be positioned. This was a crucial part of the building because the angle, width and height at which the seats where located was going to severely affect the ability of the rider to pedal or to steer the vehicle. The seats were made out of steel tubes ½ inch in diameter with an inner wall thickness of 1/8 in. These measurement where chosen in order to obtain the strongest frame possible while still being light weight enough to minimize their effect on the performance of the buggy.

Figure 91, Seat fabrication

Figure 92, Seat fabrication

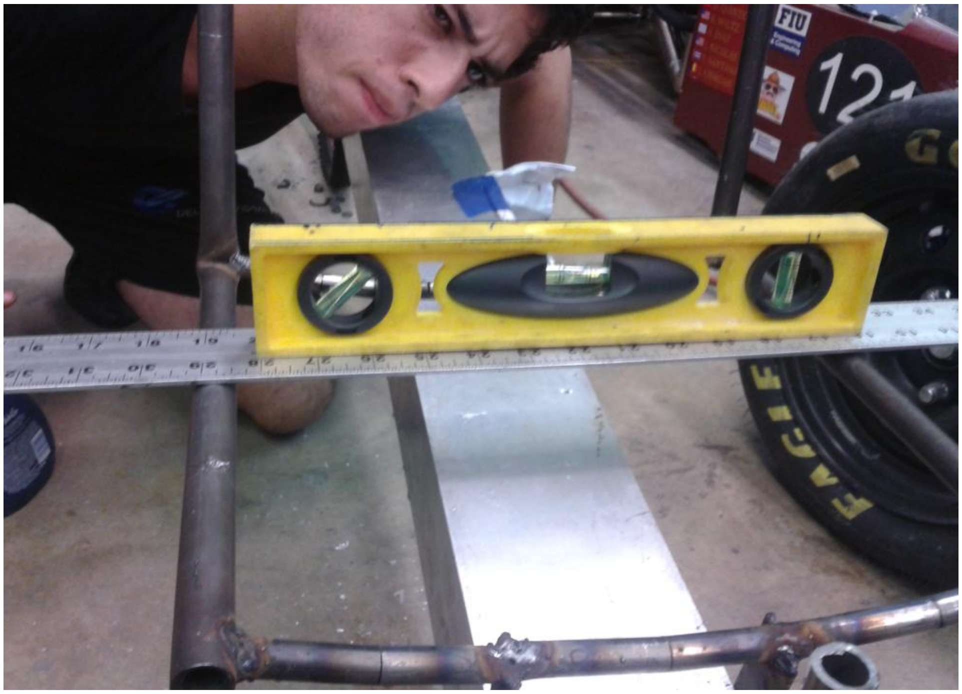


Figure 93, Seat leveling

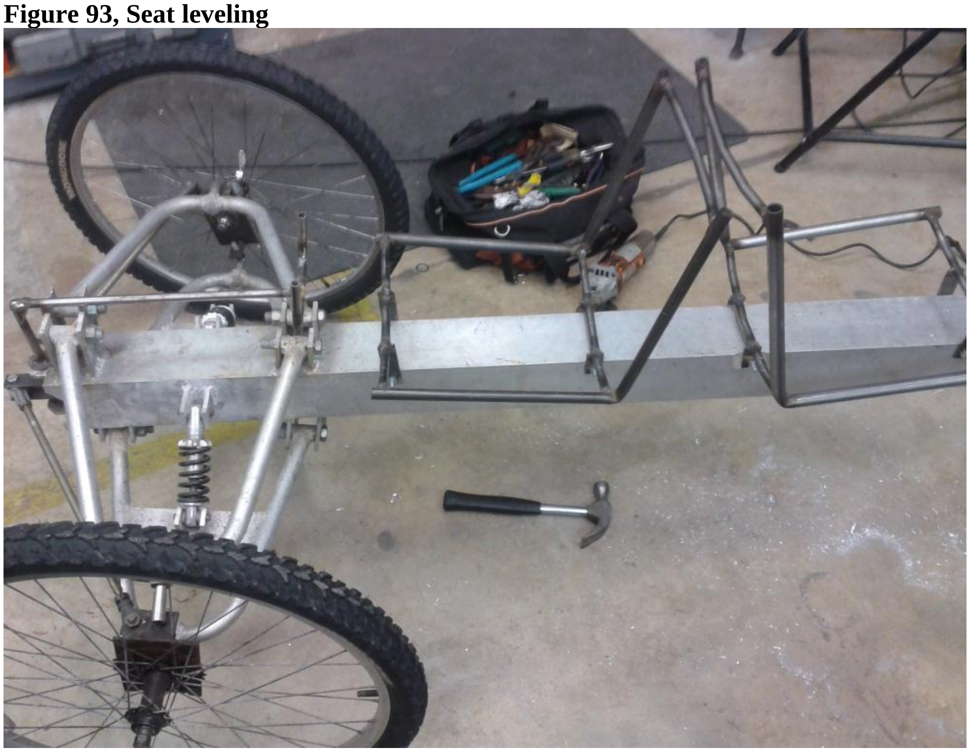


Figure 94, Front and Back Seats

The power train was a complex and elaborated build due to the fact that the rear shock absorber was located in the middle of the frame; this was causing an issue to locate the bar that was going to hold the rear pedals. The solution was to weld a little housing for the shock and use the flat top as a base for the bar that was going to hold the pedals; this bars was made of aluminum 1/16 in thick, this was so thin that the use of a TIG welder was needed in order to welded it without punching a hole through the material.

Figure 95, Rear shock housing, Pedals mount

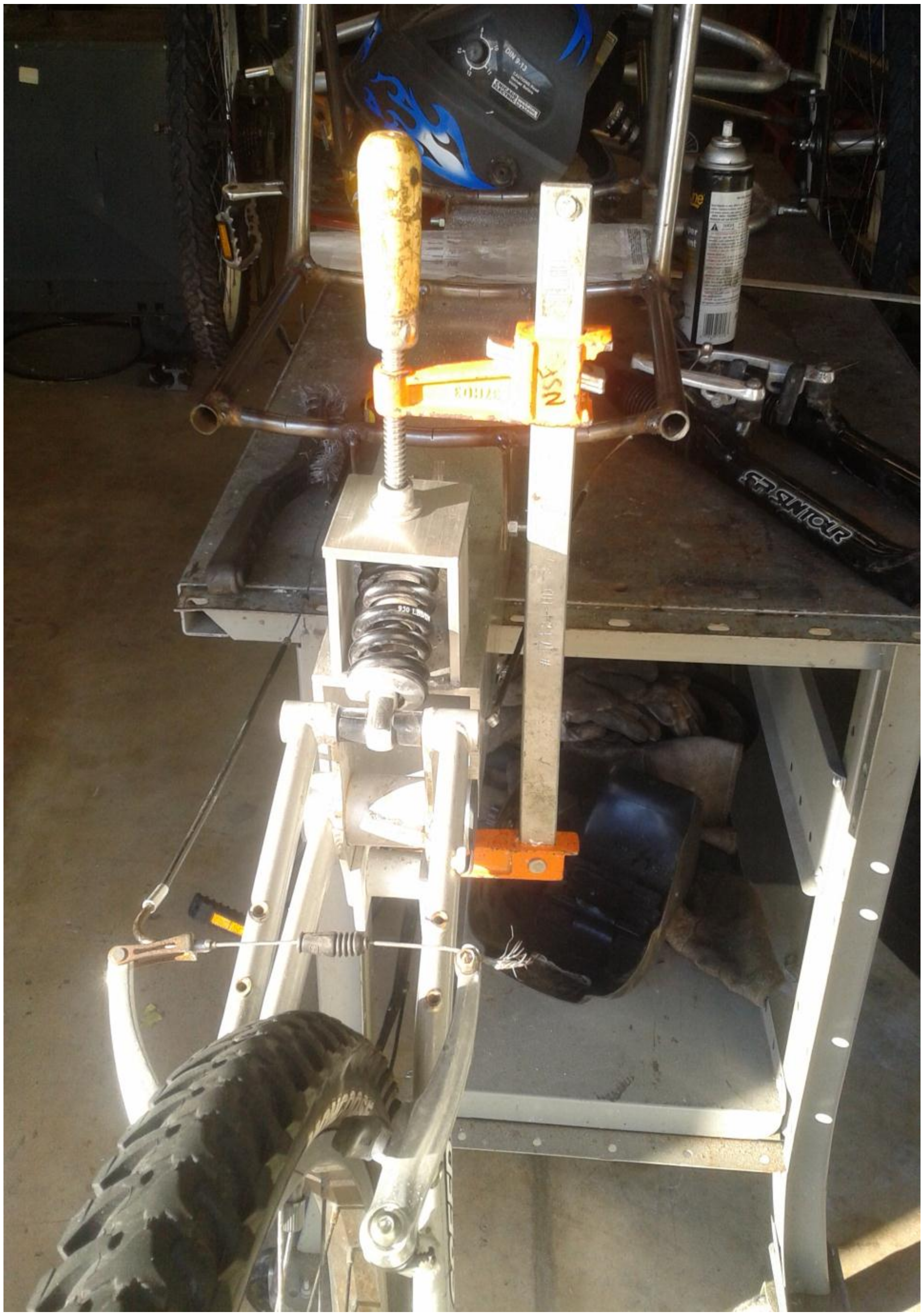


Figure 96, Rear shock housing

Once the housing was welded using the ARC welder, it was ready to weld the bar that was going to hold the pedals on top of it. This is the bar that came out of a bicycle frame meaning that it was very thin aluminum and TIG welding was needed.

As it can be seen in the previous images the power train was almost completed

Figure 97 TIG welding pedal's Bar

After all the welding was done and the power train was completed, the testing process began, so the vehicle was taken out of the machine shop for some over all testing. Here failure occurred and the bottom section of the housing came off; it seemee that the welding was not done deep enough in the aluminum, causing it to come apart.

In the picture below it is clear that the weld came apart and the failure occurred.

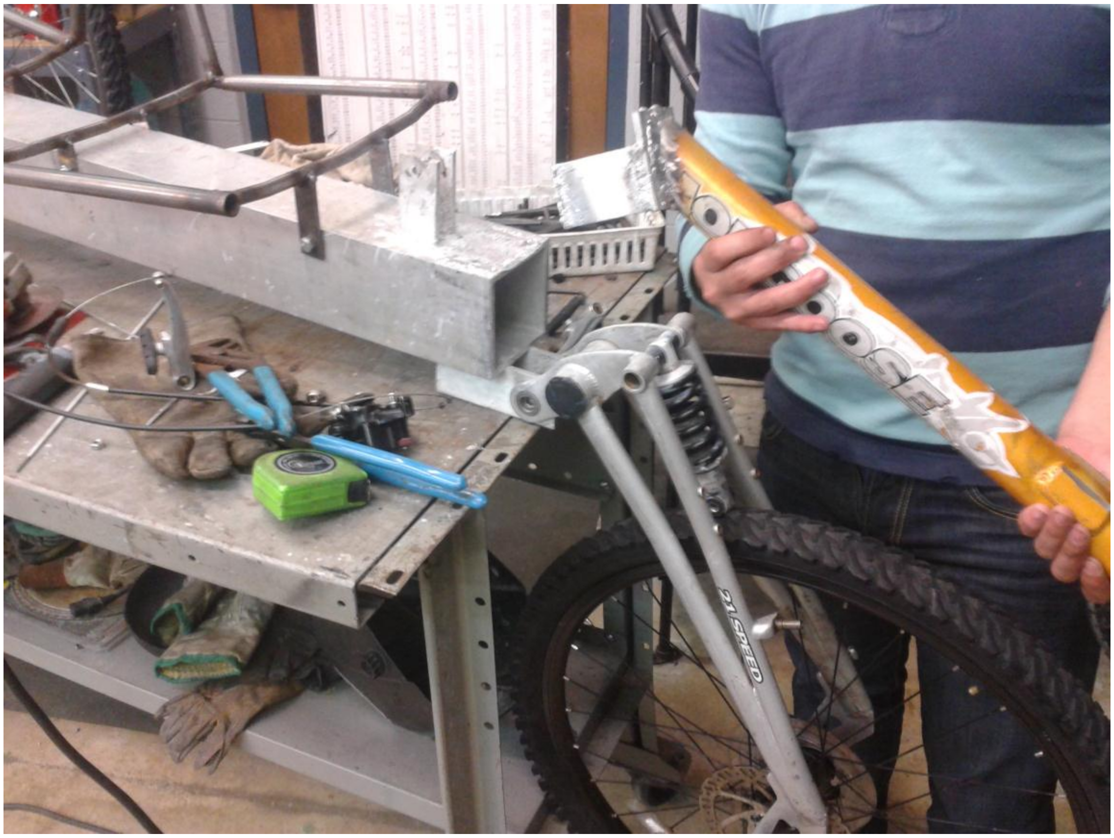


Figure 98, Weld Failure

Figure 99, Weld Failure

Here the picture shows clearly how the failure ocured and how the weld was not deep into the aluminum. Thanks to the testing we can find the problems like this which could end the race in a dissapointing way. A simimalr situation occurred when the testing of the steering was being done where we saw that the aluminum was being fatigued and it was going to fail eventually.

Now that the fail was fixed and reinforced, the whole assembly holds strong and works like it was designed to. On the next pictures it can be apreciated that the vehicle is almost completed and that only little details are missing.

Figure 100, Complete Assembly

Figure 101 Rear View of complete assembly

On the previous pictures it can be seen how the rear power train works; it basically works like a bicycle at 90 degrees. This design was done in order to use the derailleur tension to provide the constant tautness on the chain, which was going to be loose when the suspension goes up; with that the suspension can travel as much as it can and the chain will not get loose.

Finally here is a picture of the final assembly of the vehicle and the final part of the manufacturing process, here only a few things are missing; for example, the seats covers and the paint job, but the overall work is done and we conclude it to be a success.

19. Project Management

19.1. Breakdown of Work into Specific Tasks

- Design of chassis
    - Correct load placement, powertrain location,
- Suspension design
- 10% Paper
- Soft Copy Poster
    - Design of poster
        - Choosing colors, pictures, picture placement, displaying of vital project information.
        - Determine preliminary layout.
- Center of gravity calculations
    - Height
    - Width
- Structural design
    - Pedal Placement
    - Seat and steering placement
- 25% Paper
    - Adhere to all components requested by professor.
- Hard Copy Poster
    - Final adjustments before sending to printing.
    - Final layout.
    - Chose material to place printed poster on.
    - Chose location of printing company.

- Transmission design
    - Torque
        - Determine maximum torque desired for vehicle.
    - Velocity
        - Find the best ratio that allows for the most efficient torque and velocity.
    - Contact stress analysis
        - Perform contact stress analysis on gears and shafts to ensure that no failure will occur.
    - Bending stress analysis
        - Perform stress analysis on gears and shafts along with all portions of the frame.
- 50% Paper
    - Break design
        - Selection of the most efficient braking systems and components
    - Fabrication
        - Begin fabrication of all parts that cannot be purchased and are to be custom designed.
    - Assembly
        - Proceed to assembly of purchased portions along with fabricated portions of the design.
- 75% Paper
    - Manufacturing
        - Begin of the overall assembly.

- Testing
    - Perform some testing of vehicle steering system.

- 100% Paper
  - Manufacturing
    - Finish of the overall assembly.
- Testing
    - Perform live testing of vehicle, through equivalent obstacles that will be faced at the competition.

19.2. Breakdown of Responsibilities

Juan Valencia, in charge of:

- Analysis, and design of suspension system
- Calculations for: center gravity, passenger position and pedal position.
- Brakes, steering analysis and design

Bruno Pinillos, in charge of:

- Gear ratio and frame design
- Vehicle fabrication
- Vehicle animation design

Juan Herrera, in charge of:

- Materials study and gear stress analysis
- Efficient location of simulated equipment
- Supplies ordering

19.3. Gantt Chart

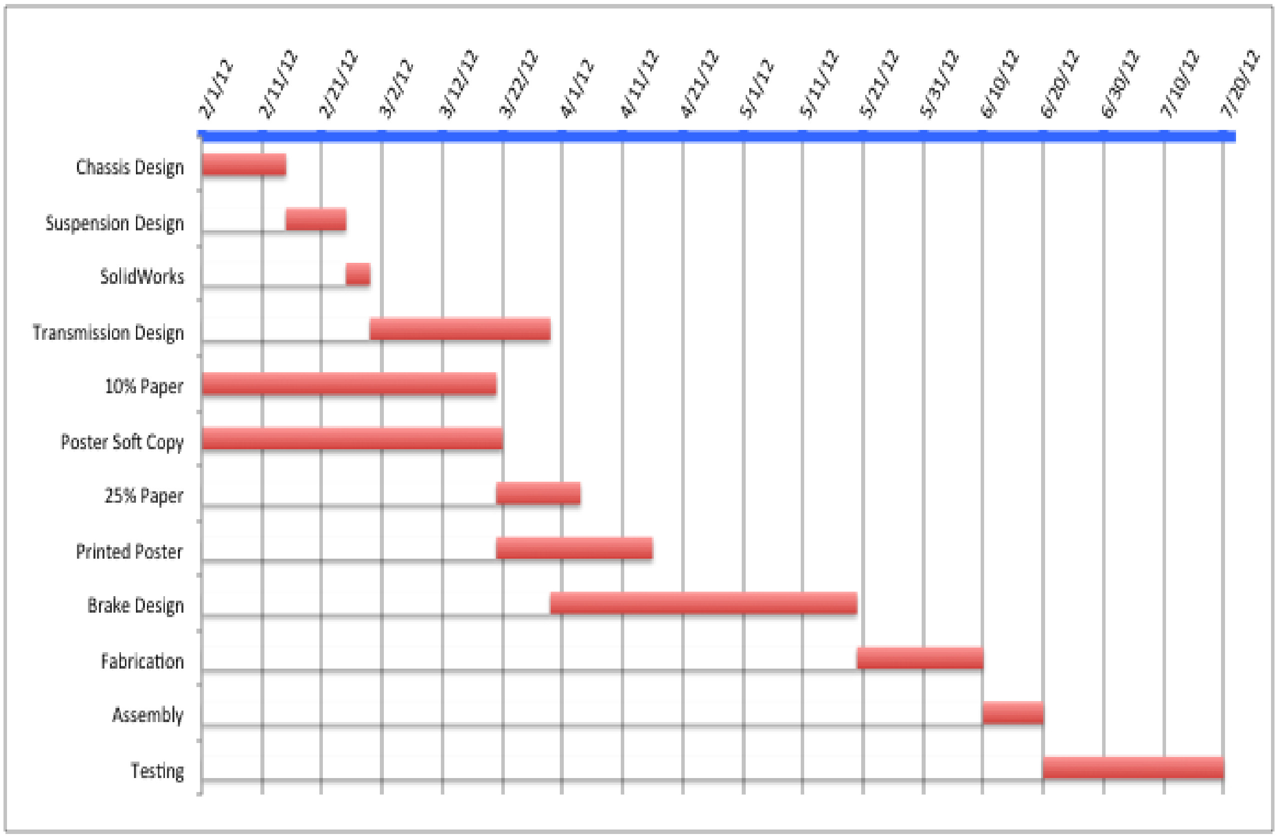


Figure 102 Gantt Chart

19.4. Timeline

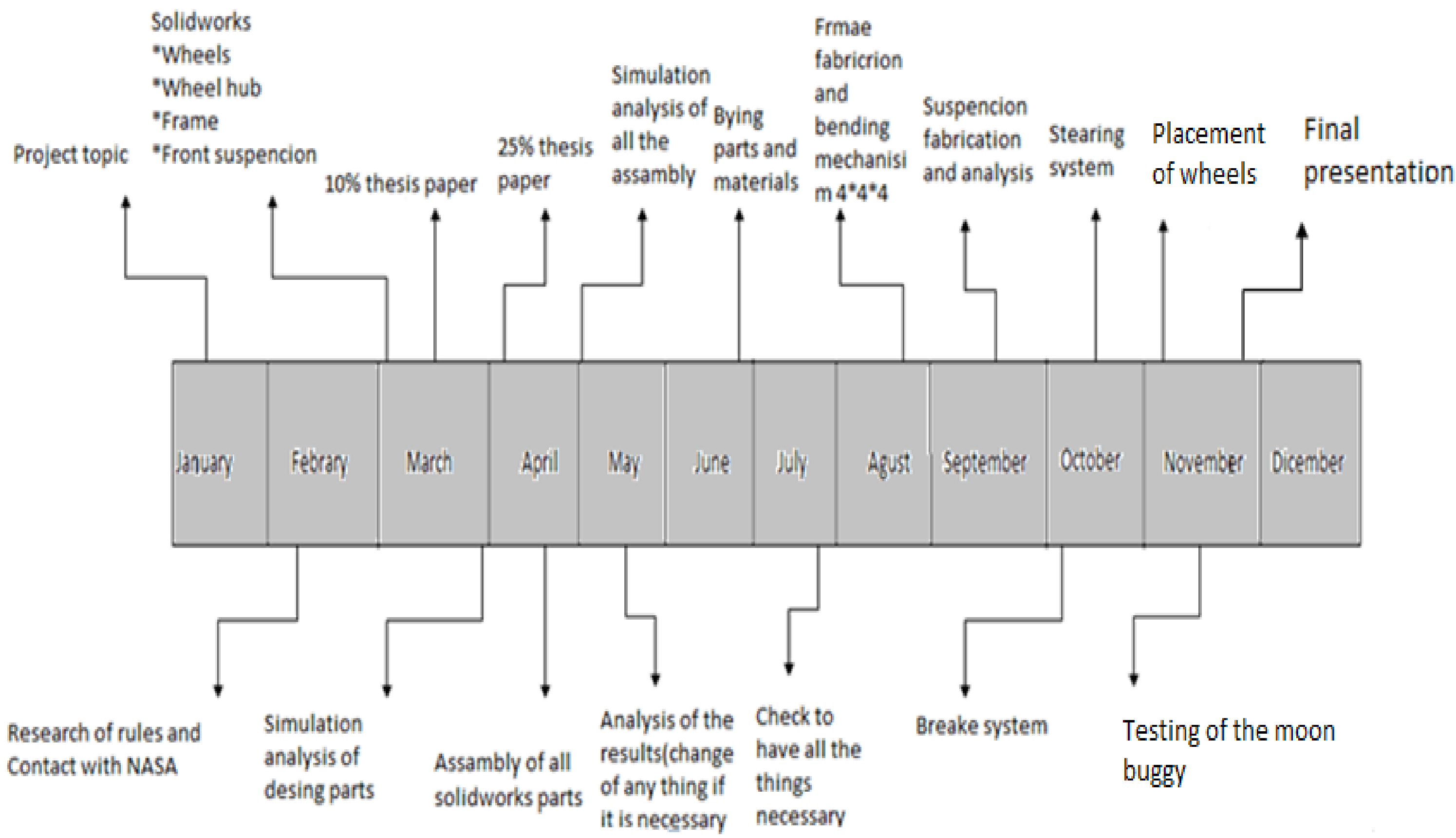


Figure 103 Timeline

20. Conclusion

In the coming weeks various analysis and simulations will be conducted in order to determine the best possible design. Using programs like SolidWorks and ANSYS this will be determined. Various force, stress and strain analysis will also be calculated by hand and excel to confirm consistency with the computer software being used.

These various analyses that will be performed, will allow for the factor of safety of the vehicle to be determined. Depending on the factors of safety obtained, many changes to the design might need to be addresses in order to assure that the vehicle is up to standard as well as being efficient. If a factor of safety is too low or too high, then the design needs to be reevaluated. In the case of the factor of safety being too low, the integrity if the vehicle will be challenged. While if the factor of safety is too high, then the vehicle is said to be “over engineered”, which is just as bad. Over engineering can also lead to increase in total cost as much unneeded material and or items are being unnecessarily used.

Following the schedule stated above the vehicle will be designed and developed within the required time. Knowing that issues and problems might arise, the schedule will also have built in allocated time for this. Some issues that may be encountered are those of materials not being readily available, problems with the selected design that might need modification and course load that the members might be presently dealing with. The vehicle will be fully tested and ready for the competition, within the given guidelines.

21. References

1. Baker, David, Lunar Roving Vehicle: Design Report, *Spaceflight*, 13, 234-240, July 1971.
2. Boeing LRV Systems Engineering, Lunar Rover Operations Handbook, Doc. LS006-002-2H, Huntsville, Alabama, 19 April 1971.
3. Burkhalter, Bettye, and Michael Sharpe, Lunar Roving Vehicle: Historical Origins, Development and Deployment, *History of Rocketry and Aeronautics,* AAS History Series, **22**, 227-261, 1998.
4. Six, Frank. "MoonBuggy Rules and Penalties." http://Moonbuggy.msfc.nasa.gov/rules.html, July 28, 2010 [March 21, 2012]

22. Appendix

22.1. Construction Rules

1. **Moonbuggy Teams-** each Moonbuggy must be the work of a student team of a high school or an accredited institution of higher learning. A group of high schools may also work in collaboration toward building a Moonbuggy entry.
2. **Propulsion System-** must be human powered (one or both passengers); and energy storage devices such as springs, flywheels or others are not allowed.
3. **Collapsed Dimensions-** assembly judging is conducted prior to each Moonbuggy's first run on the course and only on the first day of the race. The collapsed vehicle must fit within a volume having a maximum dimension 4'x 4' x 4' (a cubical space that is 4 feet on a side). A frame of this dimension will be placed over the collapsed Moonbuggy for verification. No contact with the buggy by the team is permitted while it is being measured. Tape, strap, or other device can be used to hold the buggy together in the collapsed configuration; however, all such devices must be part of what is carried (see item 4 below) or, alternatively, any component not to be part of the buggy when racing the course must be left in the "tool area" before the assembly is considered to be complete. The "tool area" is a rectangular area marked with duct tape that is next to the assembly judging location.
4. **Weight-** the vehicle must be lifted and carried 20 feet by the two passengers, without aid of any sort (e.g., no wheels) in the unassembled 4' x 4' x 4' volume configuration. No ground contact of the unassembled (collapsed) buggy is permitted while it is being carried the required distance.
5. **Assembled Dimensions-** the maximum width of the assembled vehicle, with riders onboard, is four (4) feet, measured at the outer surface of the wheels. There are no

constraints for height and length of the assembled vehicle.

6. Vehicles not constructed by the entering team are not acceptable. Vehicles that have been previously entered should contain major modifications that attempt to improve on design and performance. **Students are expected to design, construct and test their own buggies, and the race drivers chosen from each team should also be involved in these activities.**
7. No constraints are imposed in the means of contact between the buggy and the simulated lunar surface. We encourage creativity and participants are open to using wheels, belts, treads, etc.
8. All parts of the buggy, including the seat, steering controls, and pedals, with which the riders have normal contact must be designed such that their lowest surface must be at least 15 ft. (38.1 cm) above the ground when the buggy is at rest on a level surface and with riders onboard. In the case of the pedals and steering controls, which measurement is to be made when that part is in the lowest position possible (not when the buggy is in the collapsed configuration).
9. The vehicle must have a turning radius of 15 ft. or less.
10. For safety reasons, it is recommended that the center of gravity of the "vehicle plus passengers" be low enough to safely handle slopes of 30 degrees front-to-back and side-to-side. Any Moonbuggy exhibiting handling characteristics or other vehicle dynamics that are deemed unsafe or unstable by the judges will be disqualified from the competition and not allowed to run the course. This determination will be made by inspection of the assembled Moonbuggies prior to running the course. Any Moonbuggy that is judged to have become unsafe while racing or passengers who are found to be

injured or bleeding can be disqualified from that race attempt and removed from the course.

11. Each buggy must have seat restraints for each of the two passengers. The restraints must be worn at all times when the buggy is moving on the course. Except when rider(s) are freeing their buggy from being stuck on an obstacle, a buggy can be stopped by a race official if either rider is not secured by a seat restraint and held stopped until the required restraint(s) are firmly in place. The restraints must be capable of preventing the riders from being thrown from their seats should the buggy be forced to a sudden stop. If the pre-race safety judge determines the restraints are inadequate to perform that function, then the team will not be allowed to run the course in that unsafe condition.
12. All sharp edges and protrusions must be eliminated (i.e. padded) or guarded as necessary to the satisfaction of the safety judge.
13. The vehicle must be equipped with a simulated high gain antenna, other simulated equipment as noted below, fenders, and a flag. **The high gain antenna must be approximately circular in shape and no less than 24 inches in diameter**. The **other simulated equipment** is a TV camera, two batteries and an electronic control panel (radio, display, buggy controls) that **together total no less than 1 cubic foot in volume in one or more boxes**. These equipment items can be functional, not just simulated, but must still meet the minimum total volume requirement. A fender (Moon dust abatement device) must be placed over each wheel. The flag must be a national or institution flag and be visible from the front, from the side, or from the rear. The presence and size requirements for all components will be checked prior to each race attempt on the course. The presence of all components will be checked after successful completion of all race

attempts on the course.

14. Backing up is not required, but may be useful.
15. Vehicles that do not satisfy the intent of the Moonbuggy competition to foster creative, student design, fabrication, and operation of Moonbuggies on the simulated Moonscape racecourse at the NASA Great Moonbuggy Race can be disqualified.
16. Only vehicles registered for the competition will be allowed in the pits area.
17. Brakes must be present to ensure the ability to safely stop the vehicle.
18. Appropriate protective equipment, gear and clothing are required when engaged in a construction activity such as welding, handling metal components, and tools. (4)

22.2. Passenger Rules

1. Moonbuggy Passengers- two (2) student team members (one female and one male) must propel the Moonbuggy over the course.
2. Eye protection (e.g. safety glasses, goggles, or face shield), head protection (a bicycle helmet), and appropriate clothing must be worn during operation of the Moonbuggy. Shoes are required. Although at the discretion of adult riders, adult supervisors, and parents of minors, it is recommended that clothing providing some protection against cuts and abrasion is worn (e.g. long sleeved and long torso shirts, long pants, and socks).
3. No appendages such as stilts may be used on the feet of the Moonbuggy passengers.
4. Pushing the Moonbuggy with a pole or other implement is not allowed. A rider's use of their hands on the wheels as with a wheelchair to rock or otherwise facilitate moving the Moonbuggy is permitted.
5. The consumption of alcoholic beverages or controlled substances by any team member at any time during the event is strictly prohibited and is grounds for disqualification of the team.
6. **Only clip less style pedals require compatible and interlocking cleat-style shoes. Standard size pedals that include cleat-style clips do not have to be matched with cleat-style shoes for running the race. The feet of both riders must be on the pedals at the end of the timed assembly, but do not need to be engaged with any included restraints. In addition, riders and buggies are expected to be fully ready to race on the course, including helmets, full fingered gloves, goggles, and attached seatbelts to complete the timed assembly exercise. Be careful in adjusting the chain while racing. Each team will be required to develop a "Signal System" between the two riders to ensure hands are clear of the chain. They will be asked to describe their**

communication plan to the Marshall Safety Action Team (MSAT) member and/or the Starter prior to the race.

7. **Riding Moonbuggy in Parking Lot** - No riding of Moonbuggies in the parking lot. This is a safety hazard. A designated area will be provided for riders to test their Moonbuggies. (4)

22.3. Overall Cost Breakdown

Computer Portion			
Task	**Hrs**	**Cost**	**Total**
Component Analysis	45	0.5	22.5
SolidWorks	205	0.5	102.5
Research	40	0.5	20
Project Formulation	30	0.5	15
Power Point Formulation	10	0.5	5
Design Fromulation	30	0.5	15
Report	60	0.5	30
Product Ordering	10	0.5	5
Assistant Interview	2	0.5	1
Project Organization	20	0.5	10

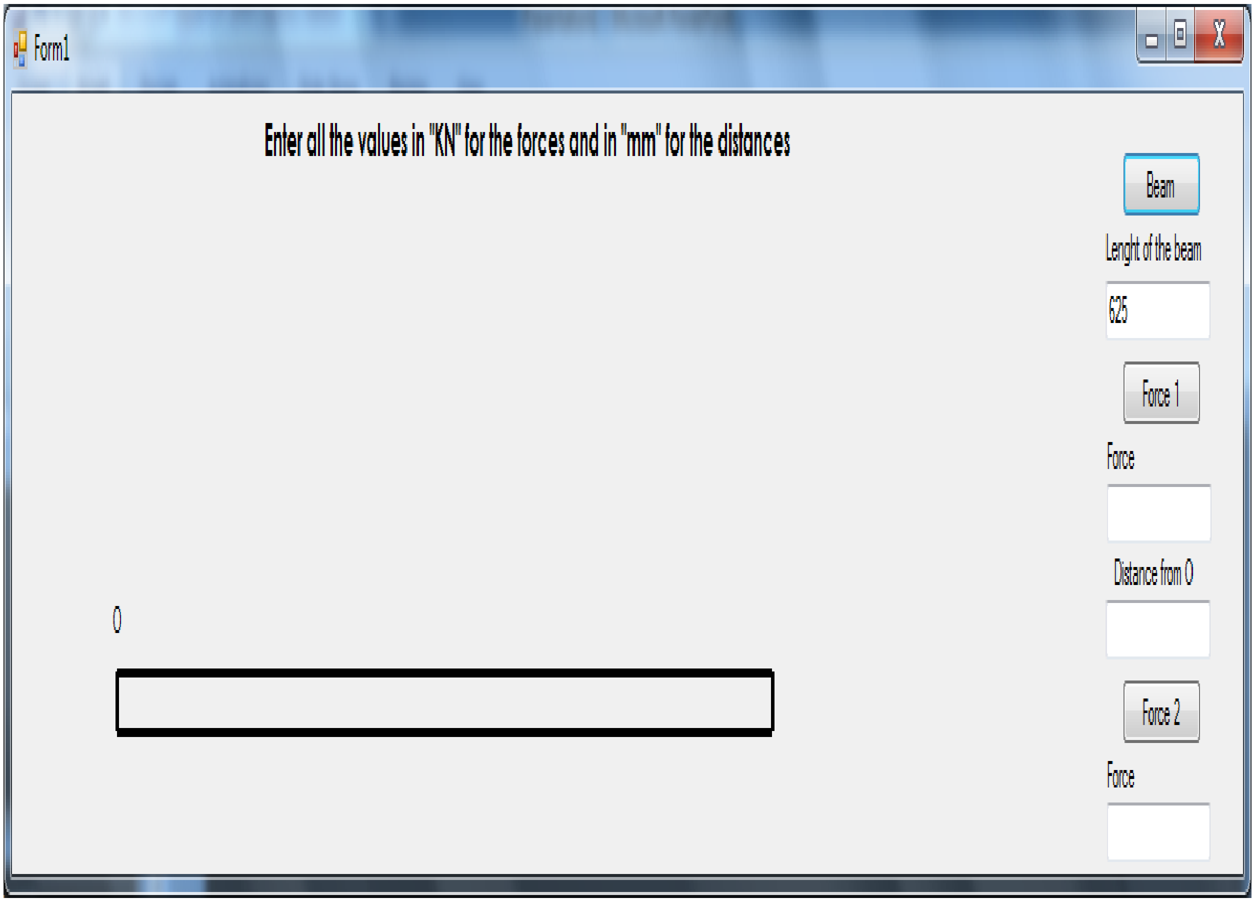
Building Portion			
Task	**Hours**	**Cost**	Total
Welding	17	20	340
Assembly	3	20	60
Pre-Fabrication	4	20	80
Locating Product	4	20	80
Frame Assembly	0.5	20	10
Brake Assembly	0.5	20	10
Suspension Assembly	3	20	60
Overall Assembly	20	20	400
Problem Identification	5	20	100
Tuning	1	20	20

Testing Portion			
Task	**Hours**	**Cost**	**Total**
Course Assembly	1	5	5
Course Testing	2	5	10
Problem Circumventing	1	5	5
Repair	2	5	10
Modification	1	5	5
Replacement Parts	2	5	10

Overall Man Hours		
	Hours	**Cost**
Computer Portion	452	$226.00
Building Portion	58	$1,160.00
Testing Portion	9	$45.00
Overall Hours and Cost	519	$1,431.00
Overall Cost		
Prototype		0
Materials Cost		744.21
Overall Cost		**$2,175.21**

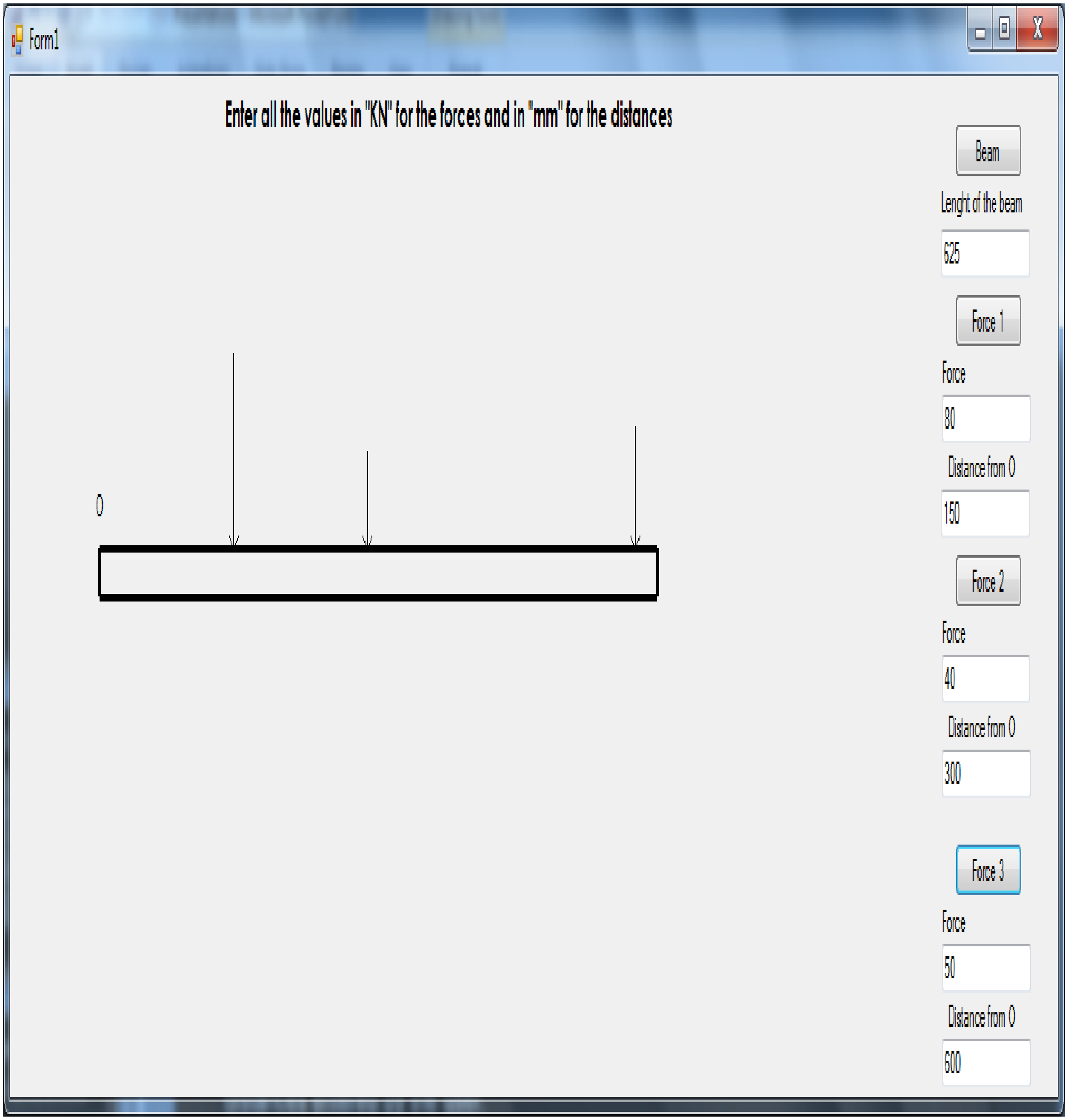
22.4. Stress, Strain and Moment Calculator Program

The user will key in the length of the beam, when he click on the beam button the beam will appear on the screen on scale of the dimension given.



After the beam appears, the user will key in a maximum of 3 forces that will act on the beam with its respective distance from the point O of the beam.

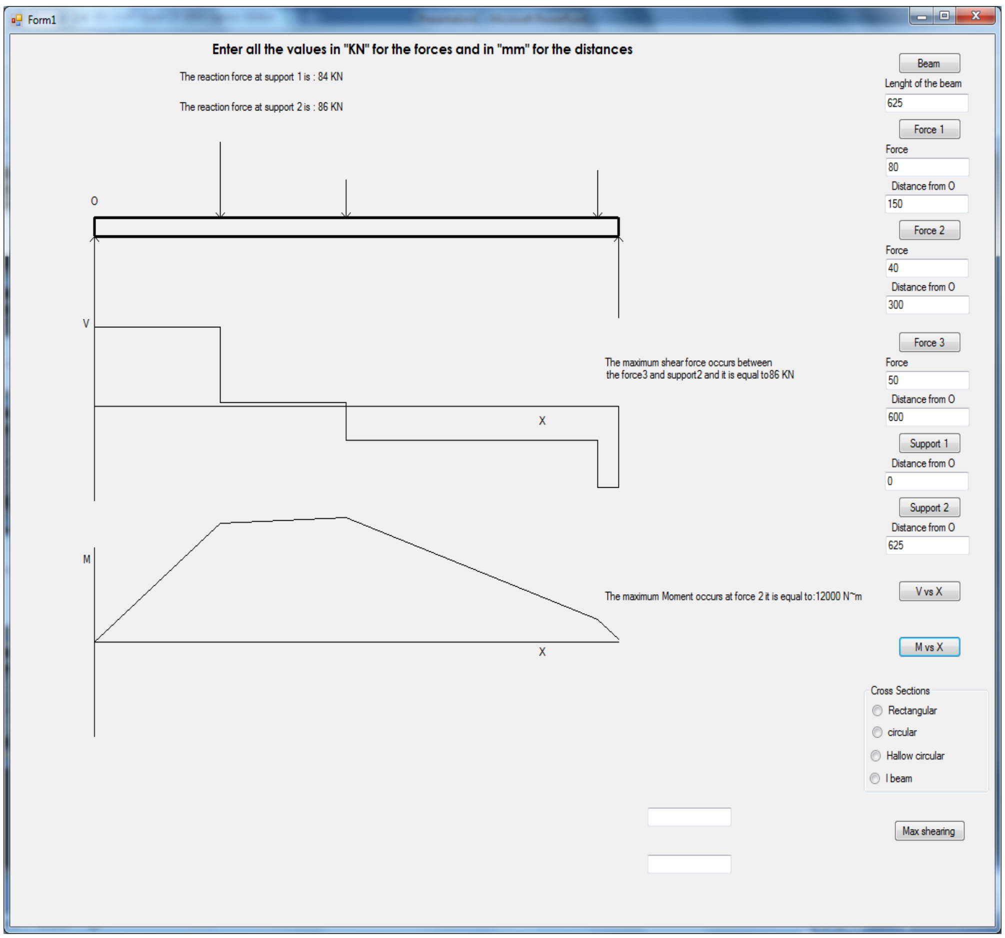
When the user click on the button of each force, the forces will be represented by arrows pointing downwards on different points of the beam depending on the distances entered by the user.



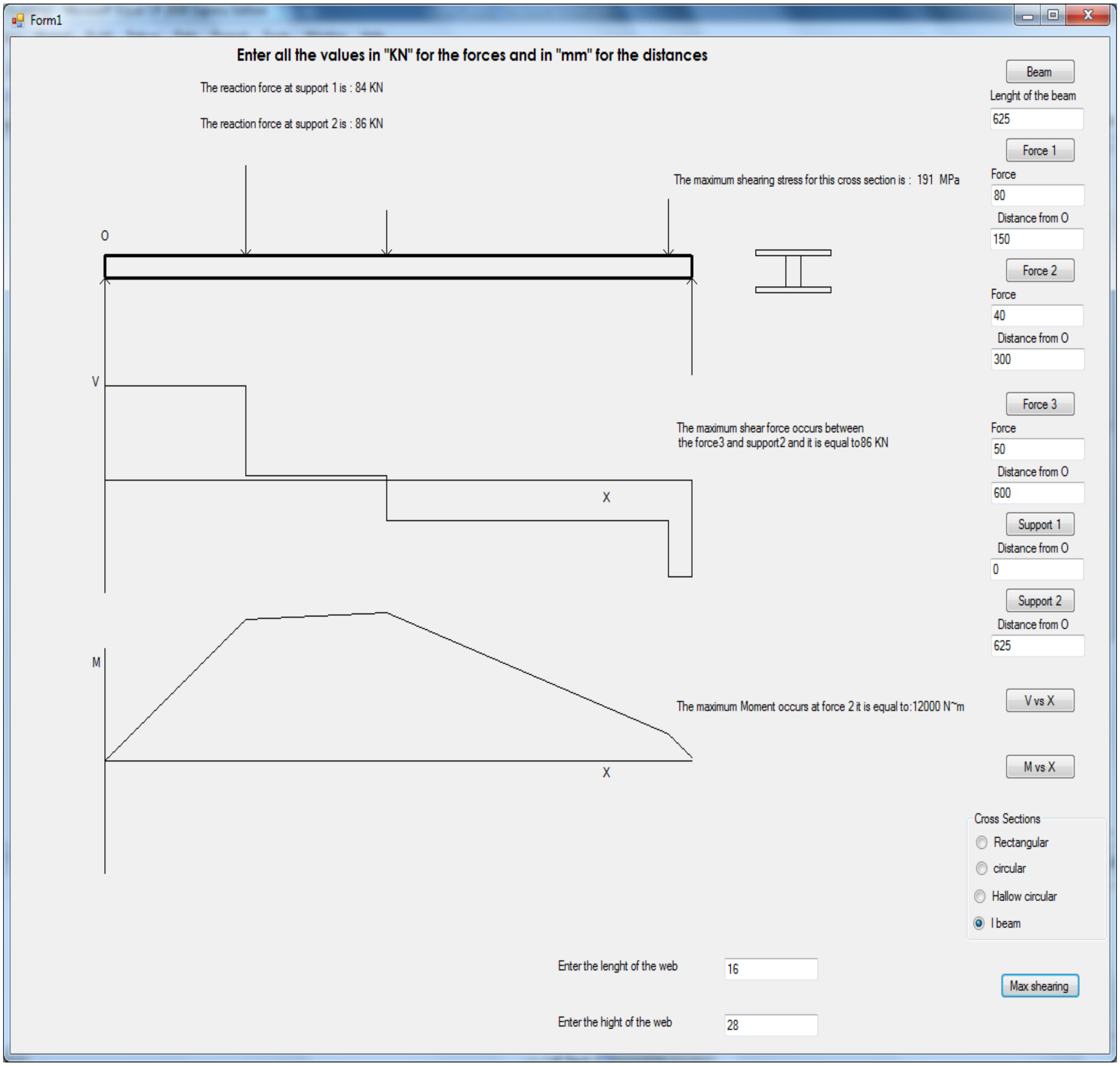
As we know is necessary to have supports in order to maintain the equilibrium on the beam, so the user will key in at what distances from the point O the supports are going to be located (maximum two).

When the distances are entered and the buttons support 1 and support 2 are pressed the program will calculate the exact value of each support and it will be print on the screen on top of the beam, as well as two arrows pointing upwards representing this support reactions.

The program will draw the plots of shear and momentum, and next to them the maximum value on the graph will be shown.

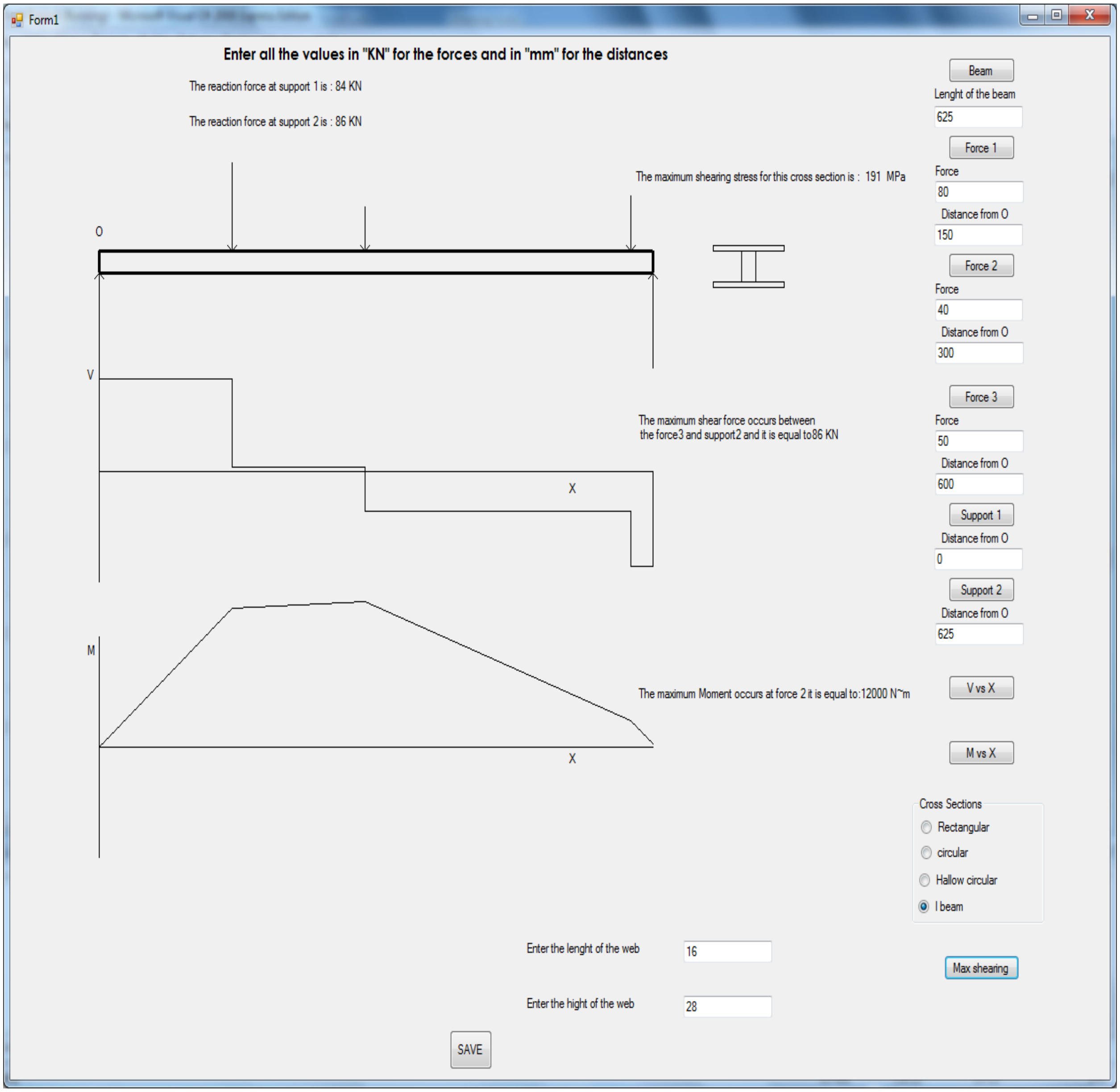


This program also give to the user the option of 4 different and most common cross sections of beams, when the user choose one of them it will ask for specific dimensions of it, when the user enter this dimensions and click on the Max Shearing button, next to the beam will be constructed on scale the cross section chosen and on it's top will be print what is the maximum shearing stress that this beam could support.



After all the results of the data keyed in is shown, the user has the option to save the information given and obtain it on a text pad for future references. With this text the user can play with the dimensions of the beam and its cross section to minimize the shear forces and the moments.

When the button SAVE is clicked the information will save on the text box call trails that can be find on the folder of the debug application.



Trails - Notepad

File Edit Format View Help

lenght of the beam is: 500--Distance of force 1 :100--Distance of force 2 :250--Distance of force 3 :400--Distance of support 1 :0--Distance of support 2 :500--the reaction at support 1 is :50--the reaction at support 2 is :50--the maximum moment is: 1250--the maximum shearing force is : 50--the maximum shearing stress is :111

lenght of the beam is: 450--Distance of force 1 :115--Distance of force 2 :300--Distance of force 3 :345--Distance of support 1 :10--Distance of support 2 :400--the reaction at support 1 is :31--the reaction at support 2 is :91--the maximum moment is: -260--the maximum shearing force is : 91--the maximum shearing stress is :28

lenght of the beam is: 600--Distance of force 1 :100--Distance of force 2 :310--Distance of force 3 :545--Distance of support 1 :10--Distance of support 2 :400--the reaction at support 1 is :25--the reaction at support 2 is :76--the maximum moment is: 2250--the maximum shearing force is : 76--the maximum shearing stress is :10

lenght of the beam is: 350--Distance of force 1 :15--Distance of force 2 :210--Distance of force 3 :245--Distance of support 1 :0--Distance of support 2 :300--the reaction at support 1 is :46--the reaction at support 2 is :74--the maximum moment is: -4380--the maximum shearing force is : 74--the maximum shearing stress is :74

lenght of the beam is: 625--Distance of force 1 :150--Distance of force 2 :300--Distance of force 3 :600--Distance of support 1 :0--Distance of support 2 :625--the reaction at support 1 is :84--the reaction at support 2 is :86--the maximum moment is: 12000--the maximum shearing force is : 86--the maximum shearing stress is :191

- This program will save a lot of time on the calculation and drawing of graphs for a simple beam that can be used as a simplified version of the body frame of the Moon Buggy.

-This program gives the maximum forces that this beam will support.

-The results of each trail can be saved and then can be checked

-With the results of each trial the user can decide what are the most convenient dimensions of the beam and of it cross section to minimize all the stresses that the beam will support.

Finally for more complex shapes, the analysis of its factor of safety and all the stresses will be done by ANSYS and SolidWorks to save time, but the results will be checked to see if they converge and have more accurate values.

Below is the code that was created in order to calculate the stresses, moments and strains.

22.5. Code

```
using System;
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Windows.Forms;

namespace WindowsFormsApplication1
{
  public partial class Form1 : Form
  {
    Bitmap image1 = new Bitmap(1000, 1000);
    public Form1()
    {
      InitializeComponent();
    }

    private void radioButton4_CheckedChanged(object sender, EventArgs e)
    {

      label14.Text = "Enter the lenght of the web";
      label18.Text = "Enter the hight of the web";
    }

    private void radioButton3_CheckedChanged(object sender, EventArgs e)
    {

      label14.Text = "Enter the radius of the outer circle";
      label18.Text = "Enter the radius of the iner circle";
    }

    private void radioButton2_CheckedChanged(object sender, EventArgs e)
    {

      label14.Text = "Enter the radius of the circle";

    }

    private void radioButton1_CheckedChanged(object sender, EventArgs e)
    {


      label14.Text = "Enter the lenght of the rectangle";
      label18.Text = "Enter the hight of the rectangle";
    }

    private void Mdiagram_Click(object sender, EventArgs e)
    {

      int ds1, ds2, fs1, f1, f2, f3, d1, d2, d3, fs2, d;

      d = Convert.ToInt16(txt_d.Text);
      f1 = Convert.ToInt16(txt_f1.Text);
      d1 = Convert.ToInt16(txt_d1.Text);
      f2 = Convert.ToInt16(txt_f2.Text);
      d2 = Convert.ToInt16(txt_d2.Text);
      f3 = Convert.ToInt16(txt_f3.Text);
      d3 = Convert.ToInt16(txt_d3.Text);
      ds1 = Convert.ToInt16(txt_ds1.Text);
      ds2 = Convert.ToInt16(txt_ds2.Text);

      d = d * 100;
      d1 = d1 * 100;
      d2 = d2 * 100;
      d3 = d3 * 100;
      ds2 = ds2 * 100;
      ds1 = ds1 * 100;

      fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
      fs1 = f1 + f2 + f3 - fs2;

      Pen DrawPen = new Pen(Brushes.Black);

      Graphics grf = Graphics.FromImage(image1);

      grf.DrawLine(DrawPen, 100, 550, 100, 750);
      grf.DrawLine(DrawPen, 100, 650, 100+d, 650);
      grf.DrawLine(DrawPen, 100 + ds1, (650 - (fs1 / 100)), 100 + d1, (650 - ((fs1 * d1)) / 100));
      grf.DrawLine(DrawPen, 100 + d1, (650 - ((fs1 * d1)) / 100), 100 + d2, ((650 - ((fs1 * d1)) / 100) - ((fs1 - f1) * (d2 - d1)) / 100));
      grf.DrawLine(DrawPen, 100 + d2, ((650 - ((fs1 * d1)) / 100) - ((fs1 - f1) * (d2 - d1)) / 100), 100 + d3, (((650 - ((fs1 * d1)) / 100) - ((fs1 - f1) * (d2 - d1)) / 100 - ((fs1 - f1 - f2) * (d3 - d2))
/ 100)));
      grf.DrawLine(DrawPen, 100 + d3, (((650 - ((fs1 * d1)) / 100) - ((fs1 - f1) * (d2 - d1)) / 100 - ((fs1 - f1 - f2) * (d3 - d2)) / 100)), 100 + ds2, ((((650 - ((fs1 * d1)) / 100) - ((fs1 - f1) * (d2 -
d1)) / 100 - ((fs1 - f1 - f2 ) * (d3 - d2)) / 100)) - ((fs1 - f1 - f2 - f3) * (ds2 - d3)) / 100));

      pictureBox1.Image = image1;

      label16.Text = "M";
      label17.Text = "X";
```

```
}

private void Vdiagram_Click(object sender, EventArgs e)
{
    int ds1, ds2, fs1, f1, f2, f3, d1, d2, d3, fs2,d;

    d = Convert.ToInt16(txt_d.Text);
    f1 = Convert.ToInt16(txt_f1.Text);
    d1 = Convert.ToInt16(txt_d1.Text);
    f2 = Convert.ToInt16(txt_f2.Text);
    d2 = Convert.ToInt16(txt_d2.Text);
    f3 = Convert.ToInt16(txt_f3.Text);
    d3 = Convert.ToInt16(txt_d3.Text);
    ds1 = Convert.ToInt16(txt_ds1.Text);
    ds2 = Convert.ToInt16(txt_ds2.Text);

    d = d * 100;
    d1 = d1 * 100;
    d2 = d2 * 100;
    d3 = d3 * 100;
    ds2 = ds2 * 100;
    ds1 = ds1 * 100;

    fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
    fs1 = f1 + f2 + f3 - fs2;


    Pen DrawPen = new Pen(Brushes.Black);

    Graphics grf = Graphics.FromImage(image1);

    grf.DrawLine(DrawPen, 100, 300, 100, 500);
    grf.DrawLine(DrawPen, 100, 400, 100+d, 400);
    grf.DrawLine(DrawPen, 100 + ds1, 400 - fs1, 100+d1, 400 - fs1);
    grf.DrawLine(DrawPen, 100 + d1, 400 - fs1, 100 + d1, 400 - fs1+f1);
    grf.DrawLine(DrawPen, 100 + d1, 400 - fs1 + f1, 100 + d2, 400 - fs1 + f1);
    grf.DrawLine(DrawPen, 100 + d2, 400 - fs1 + f1, 100 + d2, 400 - fs1 + f1+f2);
    grf.DrawLine(DrawPen, 100 + d2, 400 - fs1 + f1 + f2, 100 + d3, 400 - fs1 + f1 + f2);
    grf.DrawLine(DrawPen, 100 + d3, 400 - fs1 + f1 + f2, 100 + d3, 400 - fs1 + f1 + f2+f3);
    grf.DrawLine(DrawPen, 100 + d3, 400 - fs1 + f1 + f2 + f3, 100 + ds2, 400 - fs1 + f1 + f2 + f3);
    grf.DrawLine(DrawPen, 100 + ds2, 400 - fs1 + f1 + f2 + f3, 100 + ds2, 400 - fs1 + f1 + f2 + f3-fs2);


    pictureBox1.Image = image1;

    label13.Text = "V";
    label15.Text = "X";
}

private void S2_Click(object sender, EventArgs e)
{
    int ds1, ds2, fs1, f1, f2, f3, d1, d2, d3, fs2;

    f1 = Convert.ToInt16(txt_f1.Text);
    d1 = Convert.ToInt16(txt_d1.Text);
    f2 = Convert.ToInt16(txt_f2.Text);
    d2 = Convert.ToInt16(txt_d2.Text);
    f3 = Convert.ToInt16(txt_f3.Text);
    d3 = Convert.ToInt16(txt_d3.Text);
    ds1 = Convert.ToInt16(txt_ds1.Text);
    ds2 = Convert.ToInt16(txt_ds2.Text);


    d1 = d1 * 100;
    d2 = d2 * 100;
    d3 = d3 * 100;
    ds2 = ds2 * 100;
    ds1 = ds1 * 100;

    fs2 = ((f1 * (d1-ds1)) + (f2 * (d2-ds1)) + (f3 * (d3-ds1))) / (ds2-ds1);
    fs1 = f1 + f2 + f3 - fs2;

    Pen DrawPen = new Pen(Brushes.Black);
    Graphics grf = Graphics.FromImage(image1);

    grf.DrawLine(DrawPen, 100 + ds2, 220, 100 + ds2, 220+fs2);
    grf.DrawLine(DrawPen, 100 + ds2 - 5, 225, 100 + ds2, 220);
    grf.DrawLine(DrawPen, 100 + ds2 + 5, 225, 100 + ds2, 220);

    pictureBox1.Image = image1;

    label12.Text = "The reaction force at support 2 is : " + Convert.ToString(fs2 + " KN");
}

private void S1_Click(object sender, EventArgs e)
{
    int ds1,ds2,fs1,f1,f2,f3,d1,d2,d3,fs2;

    f1 = Convert.ToInt16(txt_f1.Text);
    d1 = Convert.ToInt16(txt_d1.Text);
    f2 = Convert.ToInt16(txt_f2.Text);
    d2 = Convert.ToInt16(txt_d2.Text);
    f3 = Convert.ToInt16(txt_f3.Text);
```

```
    d3 = Convert.ToInt16(txt_d3.Text);
    ds1 = Convert.ToInt16(txt_ds1.Text);
    ds2 = Convert.ToInt16(txt_ds2.Text);


    d1 = d1 * 100;
    d2 = d2 * 100;
    d3 = d3 * 100;
    ds2 = ds2 * 100;
    ds1 = ds1 * 100;

    fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
    fs1 = f1 + f2 + f3 - fs2;
    Pen DrawPen = new Pen(Brushes.Black);

    Graphics grf = Graphics.FromImage(image1);

    grf.DrawLine(DrawPen,100+ds1, 220, 100+ds1, 220+ fs1);
    grf.DrawLine(DrawPen, 100+ds1-5, 225, 100+ds1, 220);
    grf.DrawLine(DrawPen, 100+ds1+5, 225, 100+ds1, 220);

    pictureBox1.Image = image1;

    label11.Text ="The reaction force at support 1 is : " + Convert.ToString(fs1 + " KN");
}

private void Force3_Click_1(object sender, EventArgs e)
{
    int f3, d3, x, y;

    f3 = Convert.ToInt16(txt_f3.Text);
    d3 = Convert.ToInt16(txt_d3.Text);


    d3 = d3 * 100;


    x = 100 + d3;
    y = 200 - f3;

    Pen DrawPen = new Pen(Brushes.Black);

    Graphics grf = Graphics.FromImage(image1);

    grf.DrawLine(DrawPen, x, 200, x, y);
    grf.DrawLine(DrawPen, x - 5, 195, x, 200);
    grf.DrawLine(DrawPen, x + 5, 195, x, 200);

    pictureBox1.Image = image1;
}

private void F2_Click(object sender, EventArgs e)
{
    int f2, d2, x, y;

    f2 = Convert.ToInt16(txt_f2.Text);
    d2 = Convert.ToInt16(txt_d2.Text);


    d2 = d2 * 100;


    x = 100 +  d2;
    y = 200 - f2;

    Pen DrawPen = new Pen(Brushes.Black);

    Graphics grf = Graphics.FromImage(image1);

    grf.DrawLine(DrawPen, x, 200, x, y);
    grf.DrawLine(DrawPen, x - 5, 195, x, 200);
    grf.DrawLine(DrawPen, x + 5, 195, x, 200);

    pictureBox1.Image = image1;
}

private void F1_Click(object sender, EventArgs e)
{
    int f1,d1,x,y;

    f1 = Convert.ToInt16(txt_f1.Text);
    d1 = Convert.ToInt16(txt_d1.Text);


    d1 = d1 * 100;


    x = 100 +  d1;
    y = 200 - f1;

    Pen DrawPen = new Pen(Brushes.Black);

    Graphics grf = Graphics.FromImage(image1);
```

```
    grf.DrawLine(DrawPen, x, 200, x, y);
    grf.DrawLine(DrawPen, x-5, 195, x, 200);
    grf.DrawLine(DrawPen, x+5, 195, x, 200);

    pictureBox1.Image = image1;
}

private void Form1_Load(object sender, EventArgs e)
{

}

private void Shearing_Click(object sender, EventArgs e)
{

    int  d, h, l,r, r1, r2, Lw, Hw,tmax;
    int pi;
    int ds1, ds2, fs1, f1, f2, f3, d1, d2, d3, fs2;

    if (radioButton1.Checked == true)
    {
        l = Convert.ToInt16(txt_1.Text);
        h = Convert.ToInt16(txt_2.Text);
        d = Convert.ToInt16(txt_d.Text);
        f1 = Convert.ToInt16(txt_f1.Text);
        d1 = Convert.ToInt16(txt_d1.Text);
        f2 = Convert.ToInt16(txt_f2.Text);
        d2 = Convert.ToInt16(txt_d2.Text);
        f3 = Convert.ToInt16(txt_f3.Text);
        d3 = Convert.ToInt16(txt_d3.Text);
        ds1 = Convert.ToInt16(txt_ds1.Text);
        ds2 = Convert.ToInt16(txt_ds2.Text);

        d = d * 100;
        d1 = d1 * 100;
        d2 = d2 * 100;
        d3 = d3 * 100;
        ds2 = ds2 * 100;
        ds1 = ds1 * 100;

        fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
        fs1 = f1 + f2 + f3 - fs2;

        tmax = (3 / 2) * (fs1 / (l * h));
        lbl_out.Text ="The maximum shearing stress for this cross section is : \t "+ Convert.ToString(tmax + "  KN/m^2");
        Pen DrawPen = new Pen(Brushes.Black);
        Graphics grf = Graphics.FromImage(image1);

        grf.DrawLine(DrawPen, 200 + d, 200, 200 + d + l, 200);
        grf.DrawLine(DrawPen, 200 + d + l, 200, 200 + d + l, 200 + h);
        grf.DrawLine(DrawPen, 200 + d + l, 200 + h, 200 + d, 200 + h);
        grf.DrawLine(DrawPen, 200 + d, 200 + h, 200 + d, 200);

        pictureBox1.Image = image1;

    }
    else if (radioButton2.Checked == true)
    {
        r = Convert.ToInt16(txt_1.Text);
        d = Convert.ToInt16(txt_d.Text);
        f1 = Convert.ToInt16(txt_f1.Text);
        d1 = Convert.ToInt16(txt_d1.Text);
        f2 = Convert.ToInt16(txt_f2.Text);
        d2 = Convert.ToInt16(txt_d2.Text);
        f3 = Convert.ToInt16(txt_f3.Text);
        d3 = Convert.ToInt16(txt_d3.Text);
        ds1 = Convert.ToInt16(txt_ds1.Text);
        ds2 = Convert.ToInt16(txt_ds2.Text);

        d = d * 100;
        d1 = d1 * 100;
        d2 = d2 * 100;
        d3 = d3 * 100;
        ds2 = ds2 * 100;
        ds1 = ds1 * 100;

        fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
        fs1 = f1 + f2 + f3 - fs2;

        pi = 3;


        tmax = (4 / 3) * (fs1 / (pi * r * r));
        lbl_out.Text = "The maximum shearing stress for this cross section is : \t " + Convert.ToString(tmax + "  KN/m^2");

        Pen DrawPen = new Pen(Brushes.Black);
        Graphics grf = Graphics.FromImage(image1);


        grf.DrawEllipse(DrawPen, 200+d, 200, 2*r, 2*r);

        pictureBox1.Image = image1;
```

```
    }
    else if (radioButton3.Checked == true)
    {
        r1 = Convert.ToInt16(txt_1.Text);
        r2 = Convert.ToInt16(txt_2.Text);
        d = Convert.ToInt16(txt_d.Text);
        f1 = Convert.ToInt16(txt_f1.Text);
        d1 = Convert.ToInt16(txt_d1.Text);
        f2 = Convert.ToInt16(txt_f2.Text);
        d2 = Convert.ToInt16(txt_d2.Text);
        f3 = Convert.ToInt16(txt_f3.Text);
        d3 = Convert.ToInt16(txt_d3.Text);
        ds1 = Convert.ToInt16(txt_ds1.Text);
        ds2 = Convert.ToInt16(txt_ds2.Text);

        d = d * 100;
        d1 = d1 * 100;
        d2 = d2 * 100;
        d3 = d3 * 100;
        ds2 = ds2 * 100;
        ds1 = ds1 * 100;

        fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
        fs1 = f1 + f2 + f3 - fs2;

        pi = 3;

        tmax = 2 * (fs1 / (pi * ((r1 * r1) - (r2 * r2))));
        lbl_out.Text = "The maximum shearing stress for this cross section is : \t " + Convert.ToString(tmax + "  KN/m^2");

        Pen DrawPen = new Pen(Brushes.Black);
        Graphics grf = Graphics.FromImage(image1);


        grf.DrawEllipse(DrawPen, 200 + d +r1-r2, 200 +r1-r2, 2 * r2, 2 * r2);
        grf.DrawEllipse(DrawPen, 200 + d, 200, 2 * r1, 2 * r1);

        pictureBox1.Image = image1;
    }
    else if (radioButton4.Checked == true)
    {
        Lw = Convert.ToInt16(txt_1.Text);
        Hw = Convert.ToInt16(txt_2.Text);
        d = Convert.ToInt16(txt_d.Text);
        f1 = Convert.ToInt16(txt_f1.Text);
        d1 = Convert.ToInt16(txt_d1.Text);
        f2 = Convert.ToInt16(txt_f2.Text);
        d2 = Convert.ToInt16(txt_d2.Text);
        f3 = Convert.ToInt16(txt_f3.Text);
        d3 = Convert.ToInt16(txt_d3.Text);
        ds1 = Convert.ToInt16(txt_ds1.Text);
        ds2 = Convert.ToInt16(txt_ds2.Text);

        d = d * 100;
        d1 = d1 * 100;
        d2 = d2 * 100;
        d3 = d3 * 100;
        ds2 = ds2 * 100;
        ds1 = ds1 * 100;

        fs2 = ((f1 * (d1 - ds1)) + (f2 * (d2 - ds1)) + (f3 * (d3 - ds1))) / (ds2 - ds1);
        fs1 = f1 + f2 + f3 - fs2;


        tmax = fs1 / (Lw * Hw);
        lbl_out.Text = "The maximum shearing stress for this cross section is : \t " + Convert.ToString(tmax + "  KN/m^2");

        Pen DrawPen = new Pen(Brushes.Black);
        Graphics grf = Graphics.FromImage(image1);

        grf.DrawLine(DrawPen, 200 + d, 200, 200 + d + Lw, 200);
        grf.DrawLine(DrawPen, 200 + d + Lw, 200, 200 + d + Lw, 200 + Hw);
        grf.DrawLine(DrawPen, 200 + d + Lw, 200 + Hw, 200 + d, 200 + Hw);
        grf.DrawLine(DrawPen, 200 + d, 200 + Hw, 200 + d, 200);

        grf.DrawLine(DrawPen, 200 + d -(2 * Lw), 200, 200 + d + (3 * Lw) , 200);
        grf.DrawLine(DrawPen, 200 + d + (3 * Lw), 200, 200 + d + (3 * Lw), 200 - (Hw/5));
        grf.DrawLine(DrawPen, 200 + d + (3 * Lw), 200 - (Hw / 5), 200 + d - (2 * Lw), 200 - (Hw / 5));
        grf.DrawLine(DrawPen, 200 + d - (2 * Lw), 200 - (Hw / 5), 200 + d - (2 * Lw), 200);

        grf.DrawLine(DrawPen, 200 + d - (2 * Lw), 200 + Hw, 200 + d + (3 * Lw), 200 + Hw);
        grf.DrawLine(DrawPen, 200 + d + (3 * Lw), 200 + Hw, 200 + d + (3 * Lw), 200 + Hw + (Hw / 5));
        grf.DrawLine(DrawPen, 200 + d + (3 * Lw), 200 + Hw + (Hw / 5), 200 + d - (2 * Lw), 200 + Hw + (Hw / 5));
        grf.DrawLine(DrawPen, 200 + d - (2 * Lw), 200 + Hw + (Hw / 5), 200 + d - (2 * Lw), 200 + Hw);



        pictureBox1.Image = image1;

    }

}
```

```
        private void txt_d_TextChanged(object sender, EventArgs e)
        {

        }

        private void Beam_Click_1(object sender, EventArgs e)
        {
            int d;




            d = Convert.ToInt16(txt_d.Text);

            d = d * 100;

            Pen DrawPen = new Pen(Brushes.Black, 3);

            Graphics grf = Graphics.FromImage(image1);

            grf.DrawLine(DrawPen, 100, 200, 100, 220);
            grf.DrawLine(DrawPen, 100, 200, d+100 , 200);
            grf.DrawLine(DrawPen, 100, 220, d+100, 220);
            grf.DrawLine(DrawPen, d+100, 200, d+100, 220);


            pictureBox1.Image = image1;
            label3.Text = "O";
        }

        private void lbl_out_Click(object sender, EventArgs e)
        {

        }

        private void pictureBox1_Click(object sender, EventArgs e)
        {

        }

        private void label11_Click(object sender, EventArgs e)
        {

        }

        private void groupBox1_Enter(object sender, EventArgs e)
        {

        }

        private void txt_f1_TextChanged(object sender, EventArgs e)
        {

        }
    }
```