Utility Terrain Vehicle (UTV)

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
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in partial fulfillment of the
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Bachelor of Science

in Mechanical Engineering Technology

by

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Abstract

The concept of a utility terrain vehicle has been around for many years and has been helping people in all types of environments such as farming, warehouse, and construction. We planned to design UTV for maintenance people where they would need some bed space for tools. Using ATV frame base vehicle from last year's capstone to design UTV where it would use most out-of-shelf parts and also stay in budget. I was responsible for the braking system of UTV. During my research, I found that the hydraulic brake system is most effective and uses electronics to get most of it. Last year's team members also were using the hydraulic brake for their ATV. After designing a few concepts to deliver the force from paddle to caliper, the hydraulic came up to be most effective with the highest force.

Problem Statement

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

Research

Background of the Problem

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

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

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

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

Applicable Standards (3)

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

State of the Art

We divided the UTV project into four parts and I was tasked with the braking system. There are many types of braking systems that are being used in the auto industry. Ultimately, there are two main types of systems, disk and drum brakes. They both have advantages and disadvantages over one another that mainly depend on the application they are being used for. Disk brakes are more common on lighter vehicles like cars, pickup trucks, and modern UTV’s. The drum brakes are mostly used for more heavy-duty vehicles like semi-trucks and military vehicles.

For our UTV capstone, I decided to use disk brakes and learn more about them. I also wanted to learn about how the auto industry utilizing the disk brake with newer technology. There have been many inventions over the years by using newer technology that is integrated with disk braking systems. There are two main components to the braking system. The first component is the master cylinder that is connected to the pedal mechanism and the second component is the disk/drum brake. The disk brake is a straightforward system and the drum brake has more parts and required more room.

1. Brake-By-Wire (BBW)

   A brake-by-wire system uses an electronic module to control the braking system. It does not have a physical connection between the brake pedal and the caliper. It uses an electronic module to sense the braking force is being applied on the pedal and convert the electric signals into braking force. In the front, it could use the traditional hydraulic or electromechanical caliper to push the cylinder in/out for braking force. The rear wheel calipers are driven by electromechanical that is directly connected to the caliper for better performance. This way the e-brake can be utilized in the same system using an electronic module. Figure 1, shows the brake-by-wire system layout and how it works. Also, it shows how the system has a different setup in the front vs in the back with the traditional hydraulic and electromechanical caliper. The front and back both have separate modules that receive the signals from the pedal and send them to calipers.

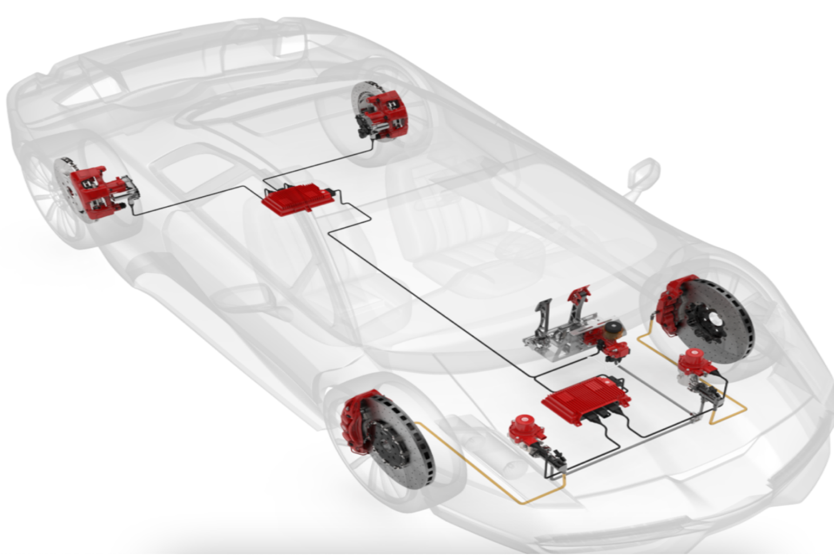


Figure 1 (5): Shows how Brake-By-Wire work

Pros:

- Can adjust the sensitivity of brake pedal
- Reduce weight and emission
- Cut the cost of the e-brake system
- Less distance required to stop
- Increase pads life
- Intelligent driving

Cons:

- The initial cost of system and maintenance
- No backup in case of malfunction of pedal
- Two separate master cylinder for hydraulic
- Cannot intrigued by traditional hydraulic
- Proper maintenance required

2. Electronic Hydraulic Braking System (EHB)

   This EHB system works very similarly to BBW expect it has a backup valve in case of any malfunction of electronics such as sensor, pedal position, ECU, and other parts. The driver won't even have to do anything because the system will detect the malfunction and open the backup valve automatically and it will start using the traditional hydraulic system. And also use the electromechanical hydraulic in all four wheels for more sport editions cars. It helps slow/stop the car much faster with different configurations like comfort/sport. In figure 3, it shows the layout of each part and how it is connected.

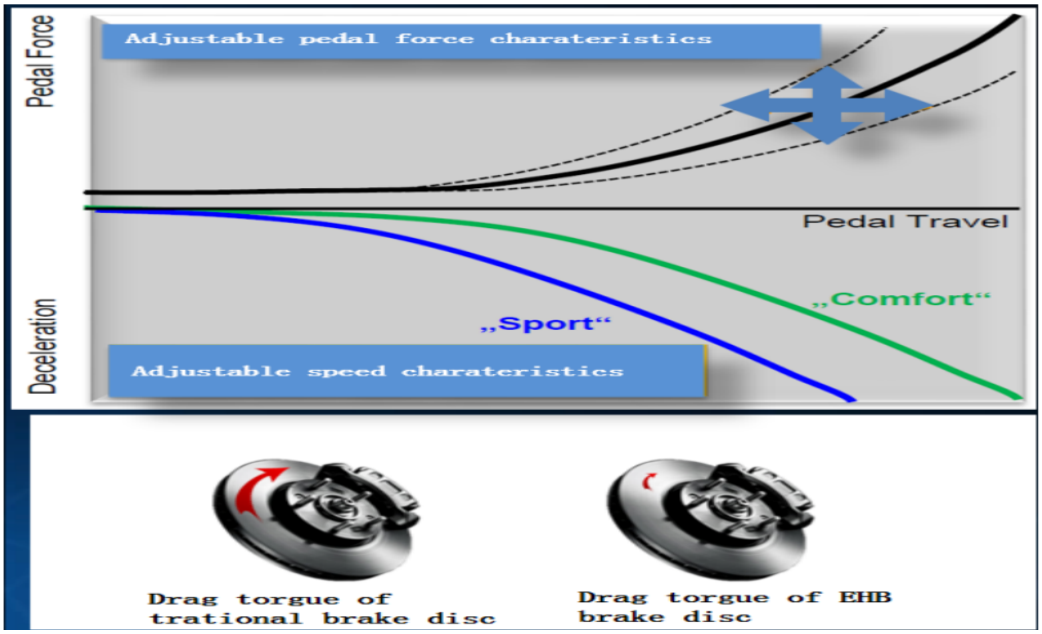


Figure 2: Adjustable pedal force characteristics

In figure 2, it shows the relationship between different types of driving styles and how fast the car is able to stop. Also, it shows the adjustability of the pedal affects the driving mode and stopping. With the EHB system car can really make huge differences in stopping distance when it is in sport mode vs comfort. The adjustable speed characteristics and adjustable pedal force characteristics can really make a huge difference in the car's performance overall.

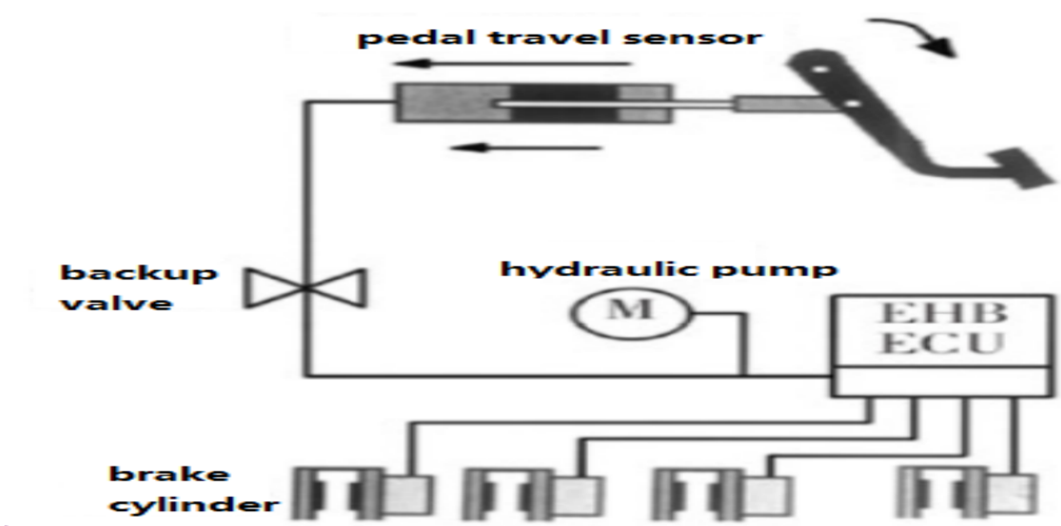


Figure 3 (6): Shows how Electronic Hydraulic Braking System work

Pros:

- Can work with traditional hydraulic system
- Less distance required to stop
- Increase pads life
- Different driving modes
- Has backup valve in case of electronic malfunction
- Intelligent driving

Cons:

- Hydraulic can leak and cause safety issues
- The initial cost of system and maintenance
- Proper maintenance required

3. Hydraulic Brake System

   It is a very common and current state of art braking system in the world with a simpler mechanical system. Almost all the auto industry uses this system in their vehicles from light to heavy-duty trucks. It has been around for a while and it has the best performance when comparing to other systems. It is cost-effective since all the major companies use them and readily available. It is consisting of two main parts, the master cylinder, and caliper. When the driver pushes the pedal it pushes the booster that moves the fluid through the master cylinder to the caliper. In the caliper, the cylinder moves out and creating friction between pads and rotator. The more friction is there and less heat what allows the car to slow/stop. Since pads play a big role during friction so the type of material makes a huge difference. Ceramic pads are the most up-to-date that heat up at super high temperatures so it makes them perfect for this application.

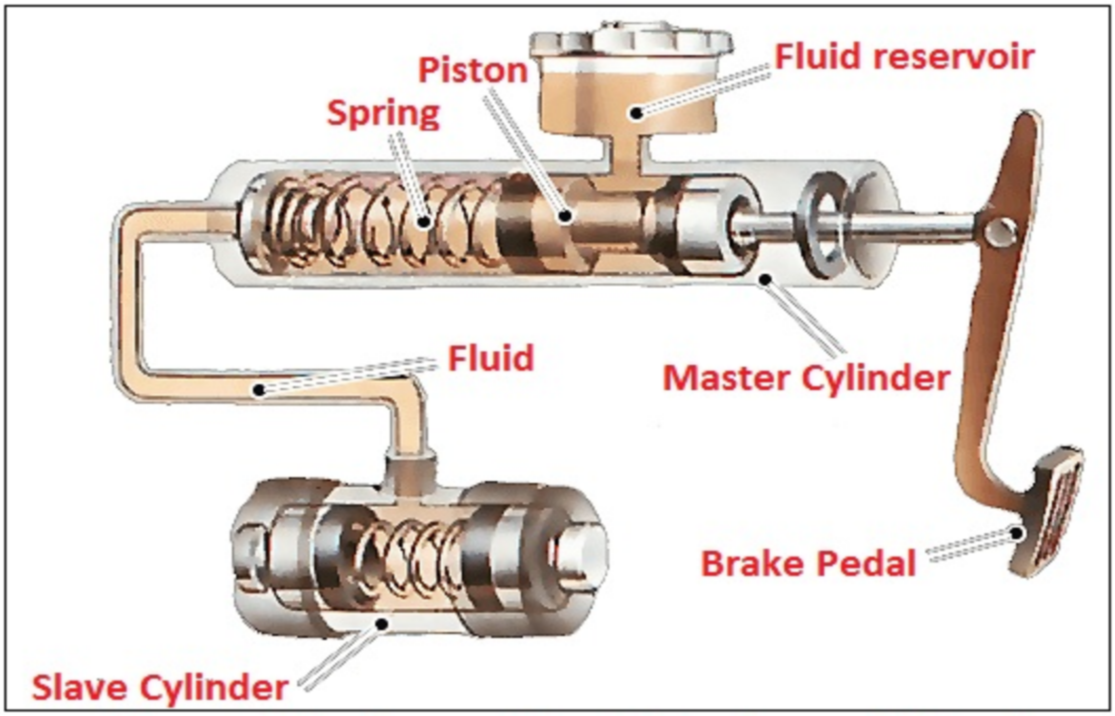


Figure 4: Shows how Hydraulic Brake System work

In figure 4 it shows how the hydraulic brake system works. Since it is a simple mechanical system so there are more reliable than newer electronics braking system.

Pros:

- Simple mechanical braking system because fewer less moving parts
- Cost affective
- Reliable and most effective performance
- Only hydraulic can deliver constant force regardless of speed changes
- Easy to spot leakages
- The system do not cause the spark
- Easy to repair

Cons:

- Use a special type of fluid
- Proper maintenance required
- Hydraulic can leak and cause safety issues

End User

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

Summary of Research

From my research, I have learned a lot about the design of basic to high tech UTV. Over the years different companies have invented new ways to implement new designs. These designs includes drivetrain, suspension, body, and braking system. I have gained more knowledge about the braking system through my state of art to understand them in more details. The Hydraulic Braking System will work for our UTV project while meeting our end goal for end user. It is very simple and mechanical system that allows us to meet the end user requirements while still capable of stopping the UTV at moderate distance. This system does not require any electrical modules that complicate the overall braking system and very expensive. Overall the hydraulic brakes are best choice and use state of art braking system.

Quality Function Deployment

Customer Features

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

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

Engineering Characteristics

Using our data found via our survey, we decided upon the engineering characteristics below

1) Material Strength (psi).

2) Unit cost ($)

3) Turn Radius (ft)

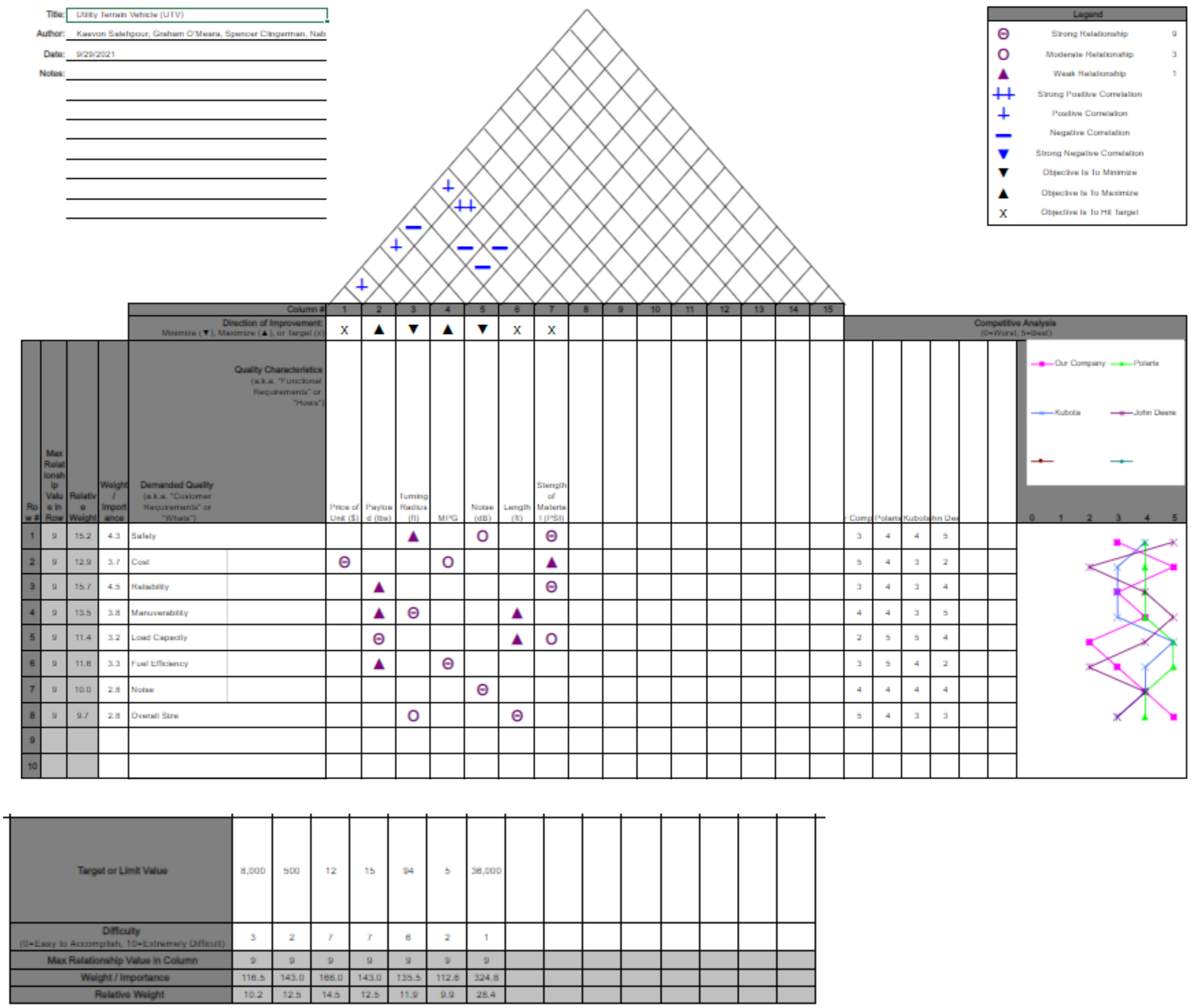
4) Weight (lbs.)

5) Fuel Efficiency (mpg)

6) Decibels (dB)

7) Length (ft)

House of Quality



Product Objectives

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

1. Strength of Materials (28.4%)

- Select strong metals and plastics for framing/siding that meets our requirements

2. Turning Radius (14.5%)

- Include smooth, reliable suspension and steering column to increase the angle of rotation

3. MPG (12.5%)

- Limit unnecessary weight

4. Payload (12.5%)

- Design the space for tool/equipment storage
- Install supports at crucial weight bearing locations

5. Noise (11.9%)

- Equip some sort of muffler to decrease engine roar

6. Price (10.22%)

- Eliminate unneeded expenses

7. Length (9.9%)

- Remain mindful of size of frame and meet UTV standard

Concepts Drawings

I have selected the disk braking method for our UTV design. There are many ways to transfer the force from the brake paddle to the caliper in a disk brake system. Different concepts of making this happen are to use mechanical, electrical, or hydraulics to squeeze the pads against the rotor. They all have their advantages and disadvantages over each other.

Concept 1: Transferring the force by cable

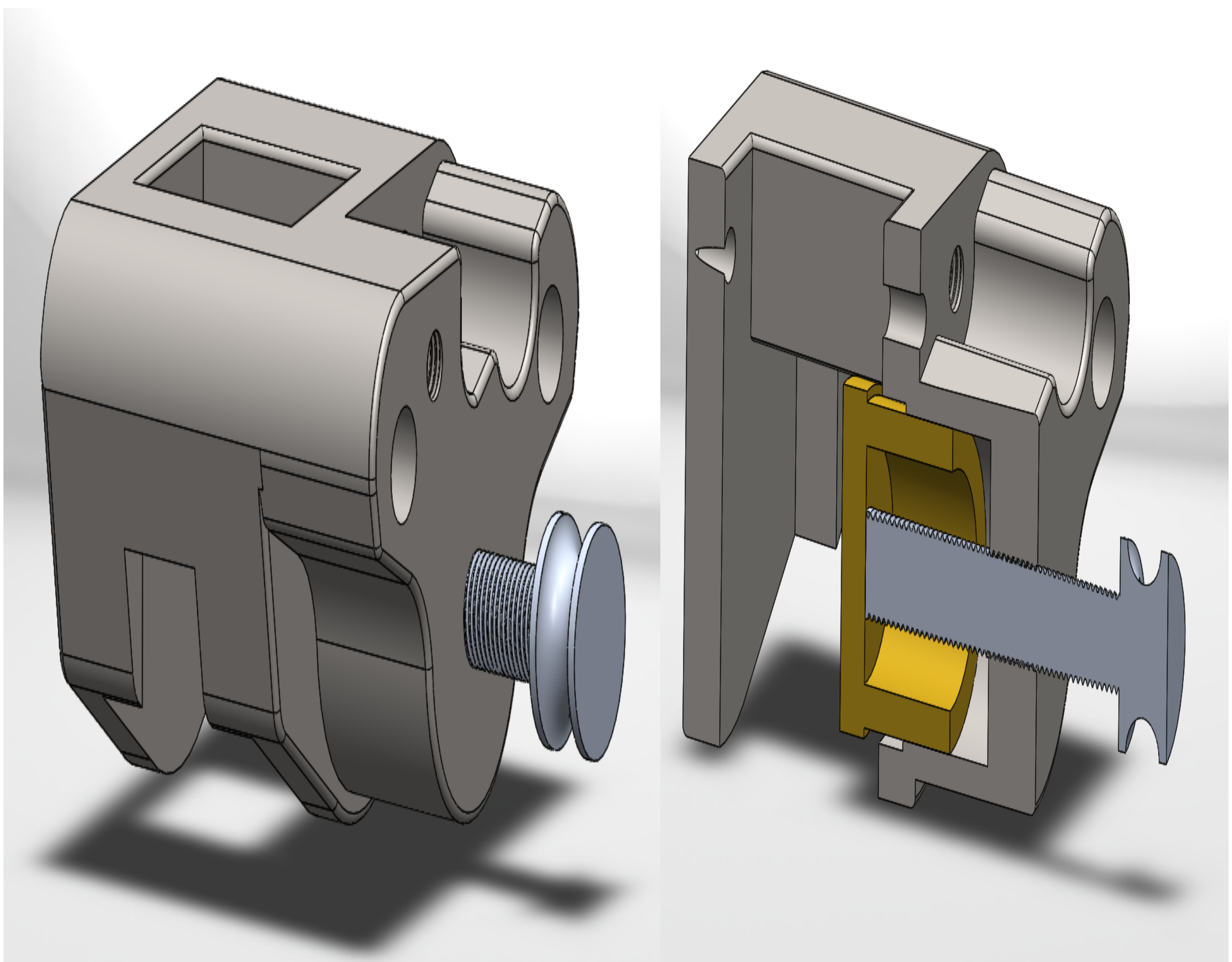


Figure 5: Shows concept 1 design (Transferring the force by cable)

The first concept began with a step file of a disk brake caliper. It is the most common caliper used in the automotive industry. In this concept, I wanted to keep the mechanism very simple but effective to work with our disk brake design. I designed the mechanism this way to work with a regular caliper with minimum modifications. The caliper has a threaded hole against the piston for the ball screw. There is a physical connection between the caliper and brake paddle that is connected with a steel cable. The ball screw has threads on it so when you push the brake paddle, the cable turns the ball screw. The piston in the caliper is pushed in/out by a ball screw to engage the brake mechanism as shown in figure 5.

Concept 2: Transferring the force by electric motor

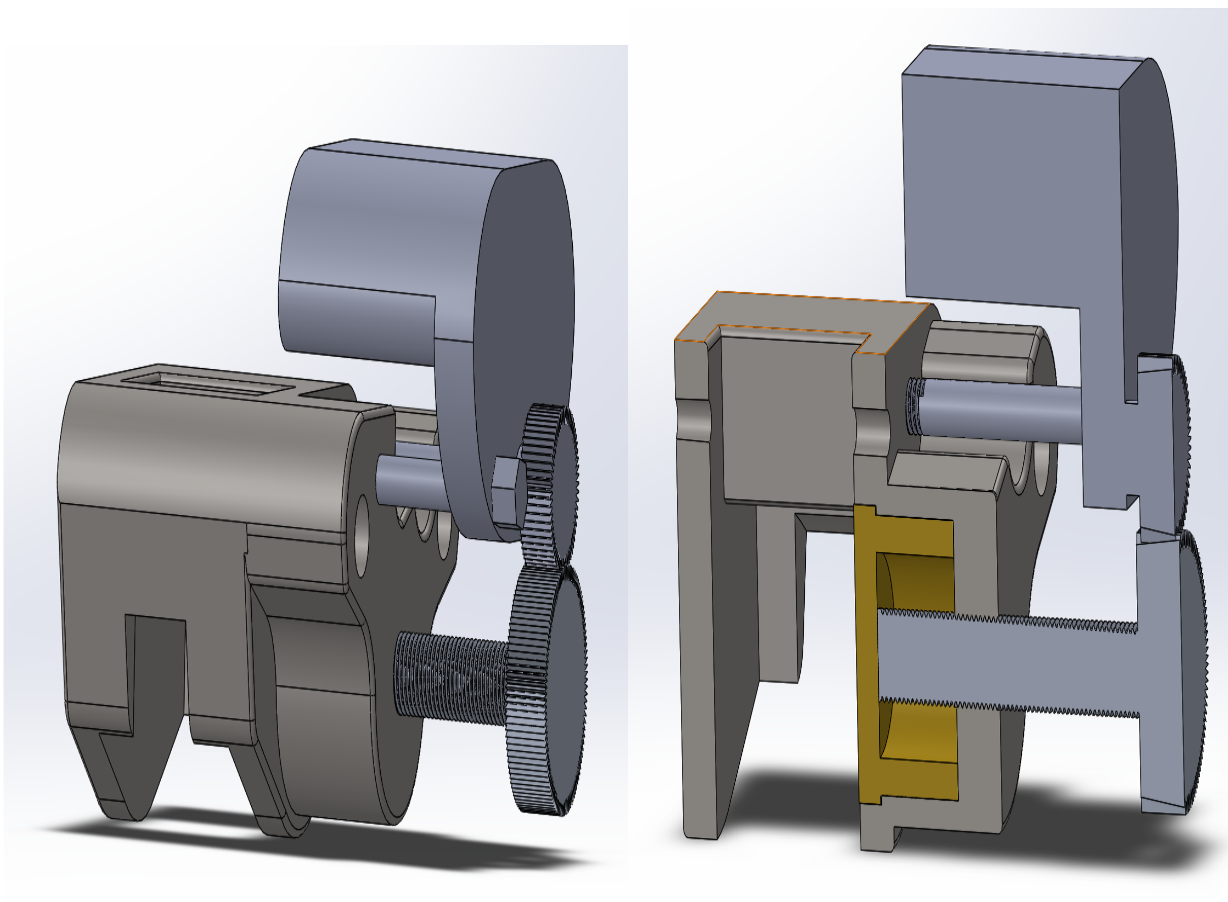


Figure 6: Shows concept 2 design(Transferring the force by electric motor)

In this concept, I wanted to use a mechanism to adjust the sensitivity of the braking system. This brought to me use newer technology because I found that in the state of art. The second concept works very similarly to the first concept using the same ball screw to push the piston in/out but the only difference is using an electric motor to turn the ball screw. The electric motor slides with a ball screw as shown in figure 6 to keep the gears engage. There is an electric module that controls the braking paddle position to send the signal to the electric motor. This way we can adjust the braking paddle sensitivity while still using the same configuration. The electric motor is capable of applying more torque on ball screw to squeeze the pads against the rotor for better performance.

Concept 3: Transferring the force by hydraulic

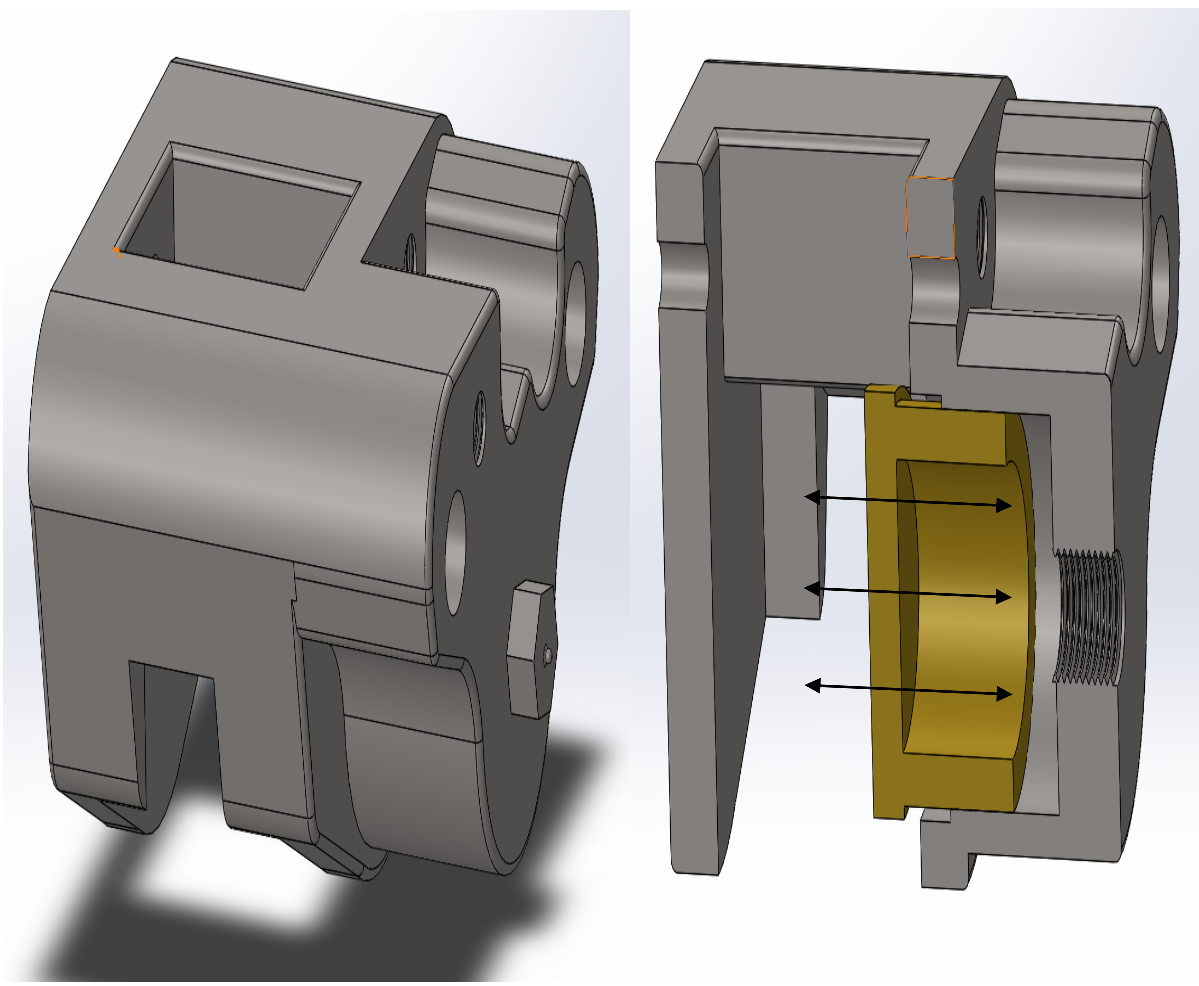


Figure 7: Shows concept 3 design(Transferring the force by hydraulic)

The third concept is different from the other two concepts. I wanted to design something that is a simple mechanical system but still uses the most innovative way to transfer the force from paddle to caliper. In this configuration, I will be using a master cylinder, brake lines, and caliper. The brake paddle will push the fluid in the master cylinder through brake lines to the caliper, where the piston will move by fluid flow rate as shown in figure 7. In the caliper, the cylinder moves out and creating friction between pads and rotator. Since the fluid is impressable because the overall system will be closed and not to let any air in the system. If there is air in the system anywhere than the brakes won't work properly.

Calculations

Given factors include:

Vehicle weight = 1800 lbs or 56lbm

Stopping distance = 30 ft

Starting speed = 30 mph

Coefficient of Friction for road and rubber = 0.6

I first calculated the kinetic energy that the vehicle would have at a speed of 30 mph

$$E_k = \frac{1}{2} * m * v^2$$

$$E_k = \frac{1}{2} * 56 * 44^2$$

$$E_k = 54208 \text{ ft } - \text{ lbs}$$

Kinetic energy to calculate the overall force in the system.

$$F_v = \frac{E_k}{Distance}$$

$$F_v = \frac{54208}{30}$$

$$F_v = 1806.9 \text{ lbs}$$

Coefficient of friction and the vehicles weight to find the force lost due to friction.

$$F_f = \frac{weight}{4\ tires} * u$$

$$F_f = \frac{1800}{4} * 0.6$$

$$F_f = 270 \text{ lbs}$$

Now I am able to find the total force that must be exerted by the brakes.

$$F_T = F_v - F_f$$

$$F_T = 1806.9 - 270$$

$$F_T = 1536.9 \text{ lbs}$$

Total breaking force will be applied

Master cylinder from wildwood with 5/16 Bore size – Part Number (260-3372)

Average human force on break paddle around 70 Ibs

Surface area of each break pad is 1.7 in^2

$$\frac{\text{Human Input Force}}{\text{Master Cylinder Area}} = \frac{\text{Total Braking Force}}{\text{Total Output Area}}$$

$$\frac{70 \text{ lbs}}{0.31\ in^2} = \frac{\text{Total Braking Force}}{1.7\ in^2 * 8}$$

$$\text{Total Braking Force} = 3071 \text{ lbs}$$

Total force needed to stop = 1537 Ibs

Force will be applied = 3071 Ibs

It has one to two factor of safety ratio.

3D Model

- Mounting Bracket

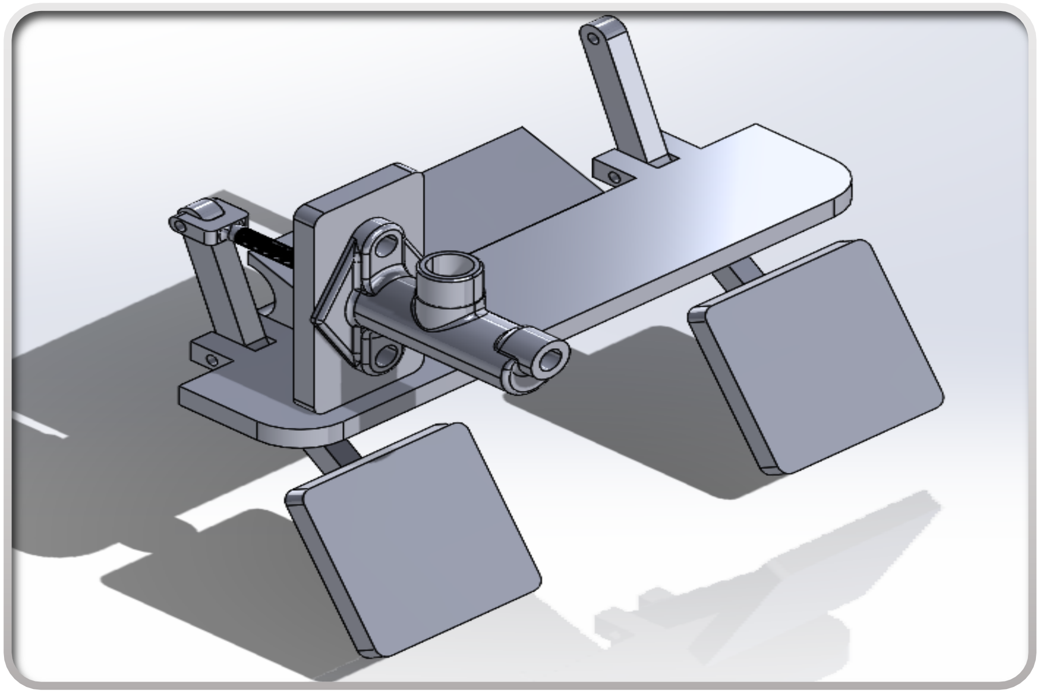


Figure 8: Shows mounting bracket assembly

- Caliper and rotor

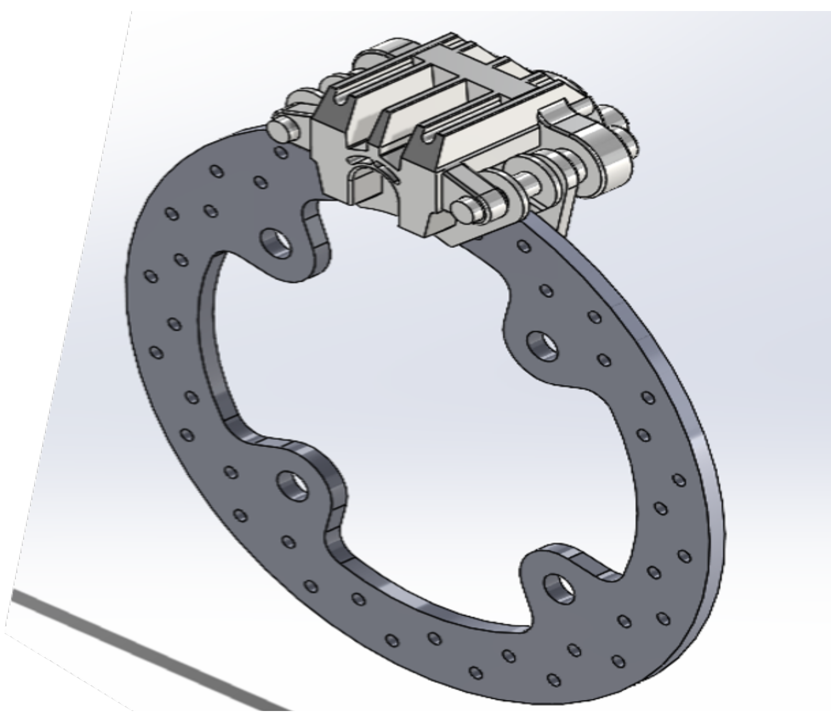


Figure 9: Shows calipers and rotor

Design Analysis

For the stress analysis on the mounting bracket, I used the finite element analysis (FEA) program in solid works to calculate the displacement and factor of safety (FOS). The reason for using this FEA was to make sure the bracket can handle the stresses without bending or deforming limits.

First I used fixed geometry on the mounting bracket at position 1 in figure 10, where it will be welded to the frame tube and act as a rigid body. Then I applied the external forces at holes where the paddle will be mounted by bolts. The force was multiplied by the dynamic factor to make sure the bracket can handle extreme stresses. The force is 210Ibs is being applied all the way around in the holes at position 2 in figure 10 below. After the meshing, I found the displacement shown in figure 10 is very small 6.89x10^(-6) in and the factor of safety shown in figure 11 came out to be 21. The result of these figures 10 and 11 shows that the bracket won't be damaged if it went through these stresses.

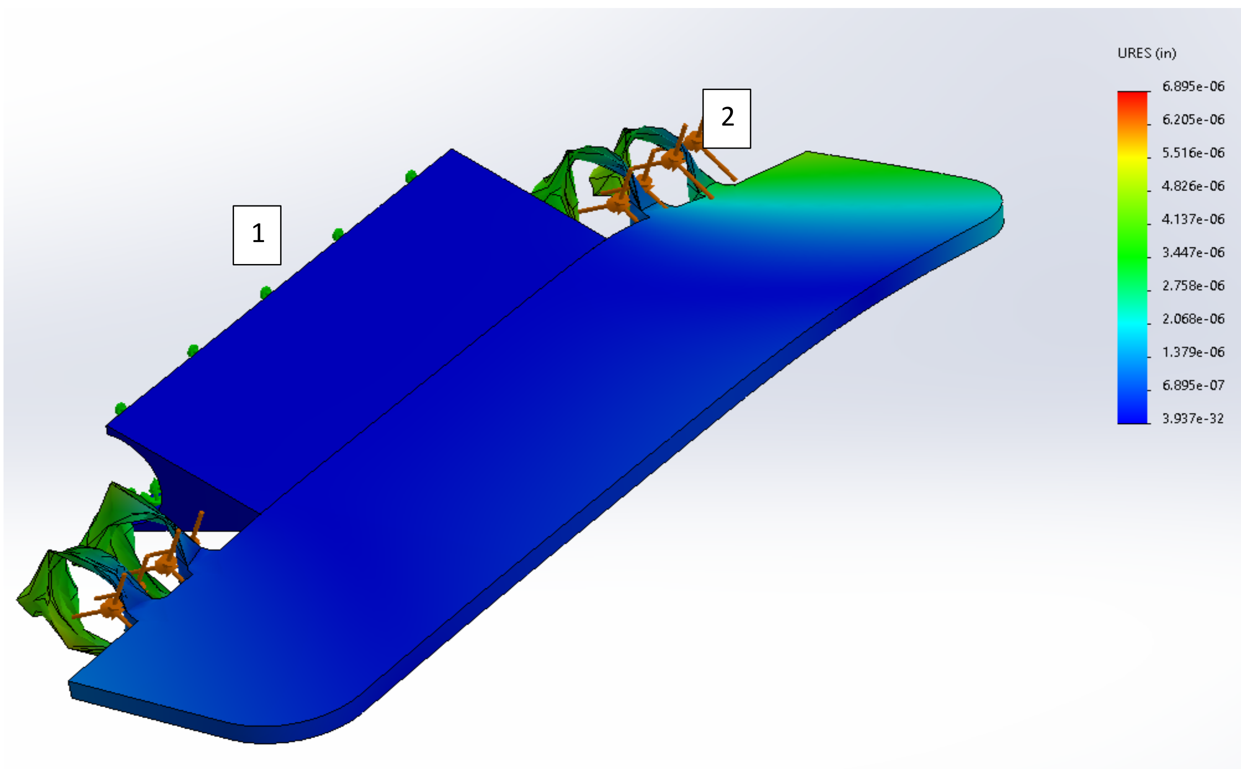


Figure 10: Shows design analysis displacement

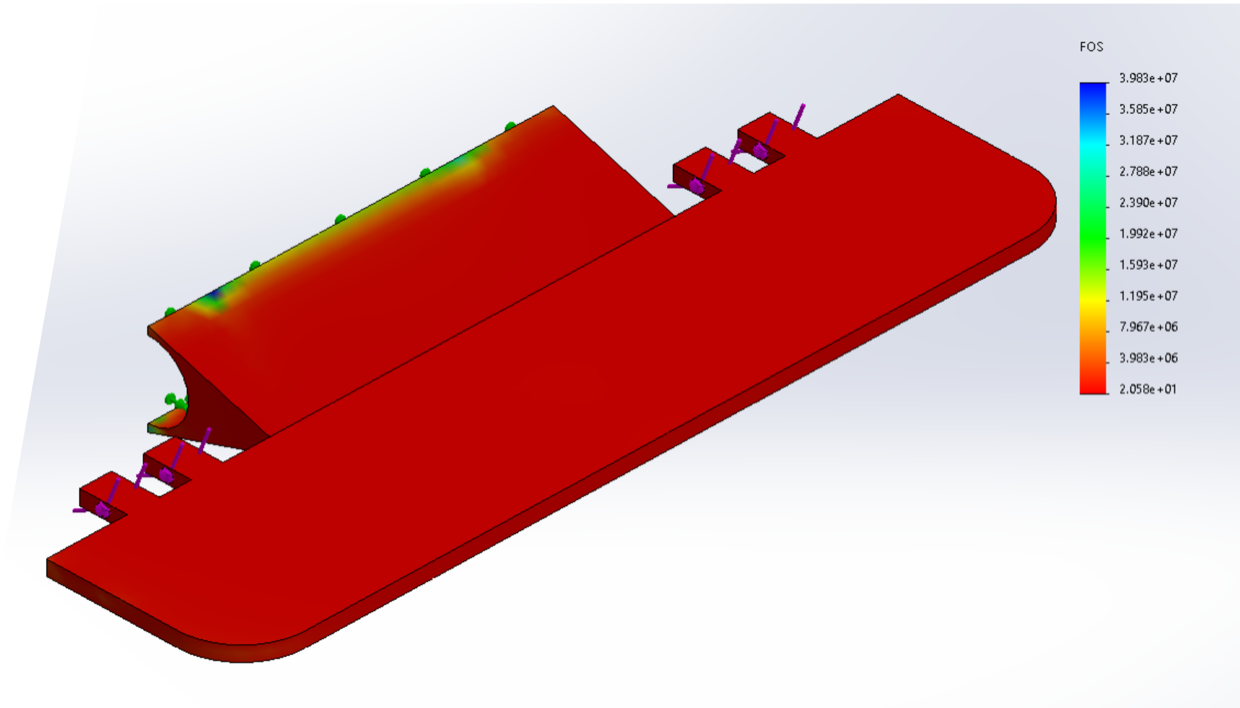


Figure 11: Shows design analysis Factor of Safety

Selected Parts

- Polaris RZR all four caliper
- Polaris RZR rotors
- Polaris RZR pads
- Polaris RZR brake light switch
- Polaris RZR axle driveshaft CV
- Polaris RZR front and back full knuckle assemblies
- Wildwood master cylinder
- 3AN brake lines fittings
- ASTM A36 Steel

Bill of Material(BOM)

The BOM is include the other parts that I was responsible to complete the UTV.

Part Name	Manufacturer Part Number	OEM Part Number	Quantity	Price
POLARIS - NUT	7547237	164103	16	2.9
POLARIS - RIM, FLAT BLACK, 8 inch wide	1520263-463	164104	4	133.92
POLARIS - VALVE, RIM	1525017	102703	4	2.9
POLARIS - NUT, CASTLE	7547337	123952	4	2.18
POLARIS - PIN, COTTER	7661404	102708	4	2.18
POLARIS - WASHER, CONE	7555796	102706	8	5.44
POLARIS - KIT-SERVICE HUB W/BEARING	2204717	548821	2	76.12
POLARIS - STUD, Front	7518654	164106	8	2.9
POLARIS - DISC, BRAKE, FRONT	5250068	164107	2	47.12
POLARIS - RING, RETAINING	7710440	132032	2	11.2
POLARIS - CARRIER, BEARING, RH	5135443	164110	1	105.31
POLARIS - CARRIER, BEARING, LH	5135442	164111	1	157.54
POLARIS - HUB, REAR WHEEL	5135113	130783	2	75.24
POLARIS - STUD, Back	7518378	133220	8	1.45
POLARIS - DISC, BRAKE, REAR	5248250	130782	2	54.38
POLARIS - BOLT, Back	7515522	103326	8	2.54
POLARIS - BEARING, CARRIER, WHEEL	3514635	132030	2	42.05
26X8-12 Tires			4	100
POLARIS - ASM., FRONT BRAKE CALIPER, LH	1911186	121132	1	252.29
POLARIS - ASM., FRONT BRAKE CALIPER, RH	1911187	121133	1	252.29
POLARIS - ASM., REAR BRAKE CALIPER, RH	1911545	162714	1	243.59
POLARIS - ASM., REAR BRAKE CALIPER, LH	1911544	300260	1	243.59
FRONT Brake, Caliper Mounting, BOLT	7518760	122057	4	6.16
REAR Brake, Caliper Mounting, SCREW, CAP	7512365	102879	4	1.45
REAR Brake, Caliper Mounting, WASHER STEEL	7558402	102877	4	0.72
REAR Brake, Caliper Mounting, LOCK WASHER	7552901	102878	4	0.72

Figure 12: Bill of Material

Fabrication and Assembly

There are three main parts that needed to be fabricated to finish the braking assembly.

I. Fabricating mounting bracket
II. Connecting caliper and brake lines to wheel assembly
III. Assembling the master cylinder, paddle, and brake lines

Fabricating mounting bracket

I needed a bracket that would attach to the frame on one side and on the other side mount the master cylinder and paddle. I used the same material as we are using for the rest of the TUV project. For this mounting bracket, I had to redesign it to make it work with our steering system yet still meet the FOS originally I had. As you can see I used cardboard as a templet to check for clearance with the frame and steering system. I used the plasma cutter to cut those plates and the Mig welder to make it as one piece. The top two bolts are where the master cylinder would mount and the bottom left is where paddle would pivot.

Figure 13: Paddle and Master cylinder mounting bracket

Connecting caliper and brake lines to wheel assembly

During our design process we used the Polaris wheel hub assemblies to meet the UTV standard requirements. Since we are using Polaris wheel assembly from differential to transfer the power to tires. So it would make sense to use the Polaris caliper, rotors, and pads to keep it simple and would work with other components.

For the brake lines, I couldn't use Polaris because we have longer length compare to Polaris RZR. I had to use 3/16 inch brake lines for rear wheel but able to use front Polaris. I used the 3N fitting for connections and covered with spring around the corners.

Figure 14: Brake line connecting to caliper

Assembling the master cylinder, paddle, and brake lines

The last step to finish the braking system I had to connect all the parts together and make sure they would work as they design. First I welded the mounting bracket to frame and install the master cylinder and paddle. I made the custom brake lines for rear to clear through drive train and other parts.

The main part of braking was to bleed the brakes and make sure there was no air in the system to work properly. I bleed the all for corners few times using automotive industry techniques.

Figure 15: Master cylinder and Paddle assembly with brake lines

Here are the list of tools we used during the manufacturing UTV.

- Utilized available tools and machines at the Victory Parkway Campus to machine parts
    - MiG welder
    - Lathe
    - Drill presser
    - Bench presser
    - Tube bender
    - Sheetmetal cutter and bender
    - Power tools for assembling
        - Impact gun
        - Drill
        - Metal saw
        - Angle grinder
- Use fabricated parts and purchased parts to assemble the final UTV

Testing and Proof of Design

Testing Methods

Engineering characteristics to be tested upon completion of the UTV:

- Speed (to get at 30mph)
- Braking Distance (can stop form 30mph to zero in 30ft)
- Payload Capacity (able to carry 300Ibs and still get at 30 mph)
- Turning Radius (still able to turn in 21ft)
- Overall Dimensions (does not exceed 5ft)
- Fuel Efficiency (get better gas millage than competitors)

Results

Unfortunately, during initial testing, we broke the drive train and then weren't able to perform any test that required movement. We weren't able to perform the braking distance test with the current situation but we did a few other tests like turning radius, overall dimension, payload capacity, and such that did not require any movement.

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

Table 1

Project Management

Project Budget

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

Proposed Schedule

Remaining Components Put on Order	12/10/21
Components Arrive	01/10/22
Assembly Start	01/10/22
Finish Assembly	04/01/22
Begin Testing	04/04/22
Tech Expo	04/14/22

Actual Schedule

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

Plan to Finish

As we found out during testing phase that we needed to rework on our drive train to make it more simpler and use more standard parts. After going through many calculations we found out that we should have transfer power from engine to differential and that's where it is able to perform forward/backward also. We found out the matching parts that works for application and able to handle the torque provided by our chosen engine. For the time constrains we could not meet all the set objects but we tested to make sure run at the desired speed.

Conclusion

Overall in this project, I got to learn a lot of new things as we made progress day by day. Used previous senior students' projects to finish with their design but ended up redesigning from scratch. The only thing we kept from them was body cab and scrape the rest of the parts as our end goal was different from theirs. Building from the ground up and with very small manufacturing or fabricating experience was the tough challenge we faced but learned a lot of new tooling to finish it up.

As we designed in the 3D CAD model and had all the analysis with FEA and we were sure it would work. During our testing phase, we had a big failure in the drive train(forward/backward gear) shaft that broke. This issue caused us main concern in the designing drive train system. We spend more time redesigning the drive train with simpler parts. The new system will be able to handle the torque and perform under the intense situation.

After redesigning the new drive train system with much simpler to eliminate extra parts. This gave much more rigidity overall. Due to time constrain we were not able to do much but it did drove much better than before than the old drive train system. The lesson we learned through this that make sure you know what is the state of art solutions out there to use the most effective methods. Also when designing a new product, always look at different many angles to eliminate any weak points. Despite all the issues we had, we were still able to finish our project with all the ANSI standards to be called UTV.

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