2020 BUV (Basic Utility Vehicle): Steering and Suspension

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Bachelor of Science

in Mechanical Engineering Technology

by

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ABSTRACT

The main objective of the project was to design and build a basic utility vehicle (BUV) to aid less developed communities around the world meet their general needs. The vehicle had to be durable, inexpensive, efficient, and low maintenance. A steering and suspension system were designed under these conditions for the vehicle. According to the research, there are currently around 250 BUVs operating in 33 different countries and 2 different continents, primarily Africa and Latin America. These BUVs show a similar trend as far as the design of the suspension and steering go. The majority of these vehicles have opted to go with a three wheel and handlebar design, much like a tricycle. Taking this into consideration, modifications to the existing 2017 BUV vehicle were made in order to optimize both sub-systems. Upon further research, a hybrid between the Macpherson strut and Uni-strut design was decided upon. This system would be simple in design but would be just as effective as the Earle's Fork design for supporting static and dynamic loads. The rear was equipped with two leaf springs, one on either side, capable of supporting the loads exerted on the vehicle when at full load capacity. The steering was designed for an increased turning radius and a decrease in effort for turning the vehicle by shortening the existing steering shaft. Structural square tubing was used for the front suspension as well as 1026 DOM tubing that helped integrate the front wheel hub & assembly to the front suspension assembly. Using finite element analysis with the use of SolidWorks the final design concept was analyzed for the calculated loads acting on the vehicle. Taking a factor of safety of at least 2 into consideration, the geometry of the entire front suspension components was adjusted accordingly. Fabrication of the suspension and steering was commenced but was forced to stop indefinitely right before completion due to the Covid-19 pandemic.

Even though the project was not completed and was behind schedule by about a week before coming to a stop, the vehicle would have been completed, testing included, before the Tech Expo. Better time management as a team would have been beneficial to getting farther along in the project. Overall, this project was able to give some insight into what it is like working with a team and trying to accomplish a specific task withing a given timeline. There are many working parts when working with a team and making sure all these parts are moving in unison is essential to completing the task.

PROBLEM DEFINITION AND RESEARCH

PROBLEM STATEMENT

Designing a Basic Utility Vehicle (BUV) to aid less developed countries meet their general needs. The vehicle needs to be durable, inexpensive, efficient, and low maintenance. (BUV Steering and Suspension)

BACKGROUND

The Institute for Affordable Transportation (IAT) made it their mission to relieve daily burdens and empower sustainable economic development to help transform communities (1). One way of achieving this was through the design and manufacturing of Basic Utility Vehicles or BUV's. These vehicles are to be made for developing countries, which means they have to be inexpensive and easy to maintain while still being able to perform the duties that are required of them.

The University of Cincinnati will partake in a BUV competition where the vehicle will have to complete a 2.2-mile-long course (2). The vehicle will have to go through three sections, which will contain hills and obstacles for the vehicle to try and overcome. One of the tasks involve the vehicle backing up to the pond located in the middle of the course to extract or dump water either manually or by means of an automatic pump every third lap from the last irrigation task (2). This course will run from 9 a.m. to 4 p.m. (2). The vehicle will be able to obtain 10 points for every lap completed and an additional 15 points for every drum of water carried on the lap (2).
*For detailed design specification please refer to Appendix A.

Since its inception in 2001 the IAT has worked alongside local business leaders, corporations, universities, volunteers, and non-profits to deliver BUV's to countries in need (1). Annual competitions are held by the IAT to help both students and the organization develop durable vehicles that might eventually be used in various locations around the globe. As of now the IAT has sold 150 vehicles that operate in 28 different countries (1).

RESEARCH

SCOPE OF THE PROBLEM

As part of the Mechanical Engineering Technology senior design capstone project me and 4 others have taken up on the BUV challenge. Each member is responsible for designing and improving upon their own respective sub-system. In my case, I will be taking care of designing an efficient and optimized steering and suspension system for the vehicle.

The suspension is mainly responsible for the control and ride quality by optimizing the friction between the tires and the road surface (3). A properly designed suspension system is able absorb energy from bumps in the terrain and dissipate it to reduce road shock, maintain optimum tire contact, and minimizes tire roll by transferring the weight of the vehicle during cornering from the high side to the low side of the vehicle (3). Having an efficient suspension will also aid in having optimal steering characteristics and improved handling (3). My goal is to optimize the BUVs suspension for optimal performance in fairly rough terrain, as would be found in the majority of developing countries.

Steering take its place in importance for obvious reasons. Without a properly designed steering system the vehicle will not go in the desired direction. Above steering the vehicle in a desired location, the system allows the driver to use a fairly small amount of force to maneuver a heavy vehicle with ease (4). The basic functions a steering system provides is stability, minimal wear to the tires, and proper maneuverability of the vehicle (4). Having a properly designed steering system in hand with an optimized suspension system allows for optimal handling and performance.

CURRENT STATE OF THE ART

It seems the majority of designs for BUVs have gone with a three wheeled vehicle, handlebar steering and a uni-strut type suspension. The advantages to having these types of systems are simplicity, ease of maintenance, and ease of operation. Having one wheel at the front will make for a less complicated system. Pair the one-wheel design with the handlebar steering and you get a simpler method of turning the vehicle without the hassle of the various parts that come with two-wheels and a steering wheel. Compared to a Mercedes or BMW this design layout may not be too appealing to the eye. However, this vehicle is designed with the most important features kept in mind. These features include great gas mileage (30+ mpg diesel), low/easy maintenance, cargo capacity, and great handling in rough terrain (1). Manufacturers that offer utility vehicles are far too expensive because they contain unnecessary features that would not be beneficial to developing countries (1). Low demand for utility vehicles means there is a small market for these types of vehicles. This contributes to the cost of current utility vehicles to go up, ultimately making it too expensive for developing countries to purchase.

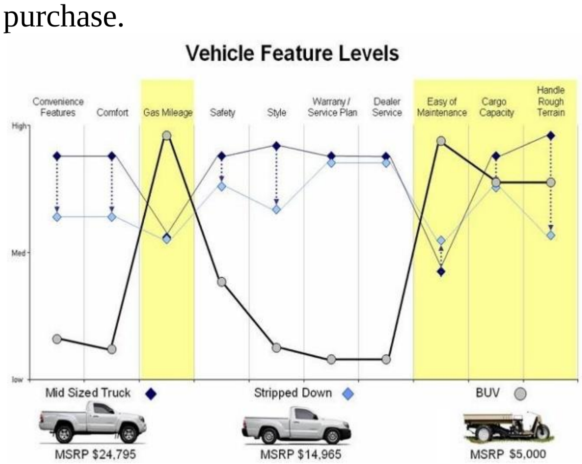

Figure 1 Key Features for a BUV Vehicle (1)

There are four types of suspensions in use today. There is the MacPherson strut, double wishbone system, multi-link suspension, and anti-roll bars (3). The MacPherson strut is among the most popular used for past BUV projects. According to UC's 2018 BUV team design the uni-strut system was chosen for its simplicity, low-cost, and its performance (5). The 2017 BUV project had also provided them with a one-wheel hub that they were able to incorporate into their design and aid with their three-wheel design (5). Although there was some speculation as to whether this type of suspension would work, the 2017 BUV team was able to design the suspension successfully because it was able to sustain the impact loads subjected to it during the competition (6). The 2011 BUV design team also selected a uni-strut design for their front suspension. According to various parameters set, they weighed out different designs and the uni-strut was the one that came out on top (7). The 2013 BUV team also went with a uni-strut design similar to how 2011 had done theirs except that 2011 had included a guard for blocking debris and protecting the driver (7). The 2013 design team decided to install the spring on the steering shaft (without a strut) to reduce the bending stresses that would have been caused by the spring inside of a strut (8). The 2014 BUV team decided to go with the same design mainly because of the amount of success previous teams had shown using the same design (9). It seems the uni-strut suspension is amongst the most desirable type of suspension due to its low-cost and fair performance, which is highly desirable for a BUV.

Fundamentally there are three types of steering arrangements: Bicycle steering, turntable steering (center pivot steering), or Ackarman steering (side pivot steering) (4). The 2011, 2013-14, and 2017-18 BUV teams decided to go with a bicycle style steering system due to its simplicity, low-maintenance, and good performance. There have been other styles used, for example, Calvin College went with four wheels and a steering wheel design (9). However, this design is not the norm as it comes with more parts, complexity, which in turn would mean driving up maintenance.

Common features for past BUVs and current ones include having a bicycle type steering system as well as having a uni-strut suspension system. This is also popular among current IAT BUVs used. However, past teams as well as the IAT website do not go into detail as to why the type of steering was chosen. It seems the main focus was on the suspension. I could not find any analysis on the steering or detailed arguments as to why they "Y" shaped steering system is preferred above all others besides simplicity.

END USER

The BUV is mainly for communities located in rural areas of developing countries. These communities are looking for simple, low-cost utility vehicles to meet their general needs. These general needs include delivery of food and/or water, medical purposes, farming, general transportation and construction (1).

Applications:	Medical Applications	15%
	Schools / Orphanages	15%
	Farm	10%
	Income-generation	15%
	Construction	15%
	General Mission	30%

Figure 2 Typical Uses for a BUV (1)

CONCLUSIONS AND SUMMARY OF RESEARCH

The BUV is meant to be operated in locations with underdeveloped infrastructures and developing communities. Keeping this in mind, these vehicles have to be relatively low-cost so that countries are able to purchase them and use them to meet their general needs. Not only do they need to be low-cost, but they need to be low-maintenance, durable, efficient, easy to operate, have a high cargo capacity relative to their size, and safe. By optimizing the suspension and the steering the BUV will be that much closer to becoming the best option for these communities.

All the features listed are common throughout the majority of the BUVs used today. Considering these vehicles will be bought and used by underdeveloped countries, it makes sense to make these vehicles to be high functioning rather than including convenient features like how most manufacturers are doing.

CUSTOMER FEATURES

Between 5 people on the BUV team a total of 30 people were surveyed. These people were composed of mainly engineers as well as friends/family. Research from previous BUV designs allowed us to come up with a list of key features that we thought a customer would like to see in a BUV vehicle. From that list, a survey was created to figure out what features should be prioritized. The list below shows what features were come up with as well as their rated importance, out of 5, relevant to the customer.

Customer Features	Weighted Score
1. Price	4.2
2. Ease of Assembly	3.3
3. Ease of Maintenance	4.1
4. Reliability	4.6
5. Safety	4.2
6. Cargo Capacity	3.5
7. Off-Road Capability	3.8
8. Maneuverability	3.3

Table 1 Customer Features & Weighted Scores

PRODUCT OBJECTIVES

Customer features are features that a customer would like to see presented in the end product. For example, if safety is top priority for a customer, a design would be built around that feature. This would be the case when presented for all customer features given. The way the build/design is conveyed will be from the engineering characteristics that were derived from the customer features.

Based on the surveys conducted for the BUV, a list of customer features and engineering characteristics was made. A HOQ (House of Quality) was then used to prioritize what features would be implemented in the build of the BUV. Based on the weight for each feature, price, ease of maintenance, reliability, and safety seemed to be the most important. In order to help achieve these features in the end design the engineering features listed above were made.

The engineering characteristics that will be prioritized are shown in the HOQ shown above. These weights have been assigned a relative weight, out of a total of 100, to show where each one falls in the sense of priority for the BUV design.

QUALITY FUNCTION DEPLOYMENT

Engineering Characteristics

Based on this list, a list of engineering characteristics was made to make sure the customer features will be represented in the final design. For example, in order to prioritize the ease of assembly feature an engineering characteristic to target this would be making a design with as little parts as possible. This would be ideal since these vehicles are meant to operate in areas of developing countries and don't have access to tooling or shops that would be easily accessible in modern countries. A final list of our engineering characteristics is shown in Table 2 below.

Engineering Characteristics	
1. Common Material Selection – Rel. Weight 15.0	7. Fuel Economy - Rel Weight 6.2
2. Number of Parts - Rel. Weight 13.6	8. Metric Fasteners - Rel Weight 14.8
3. Overall Weight - Rel Weight 7.8	Total Weight : 100
4. Overall Size -Rel Weight 6.4	
5. Ground Clearance - Rel Weight 17.6	
6. Max Payload - Rel Weight 10.2	

Table 2 Engineering Characteristics

House of Quality

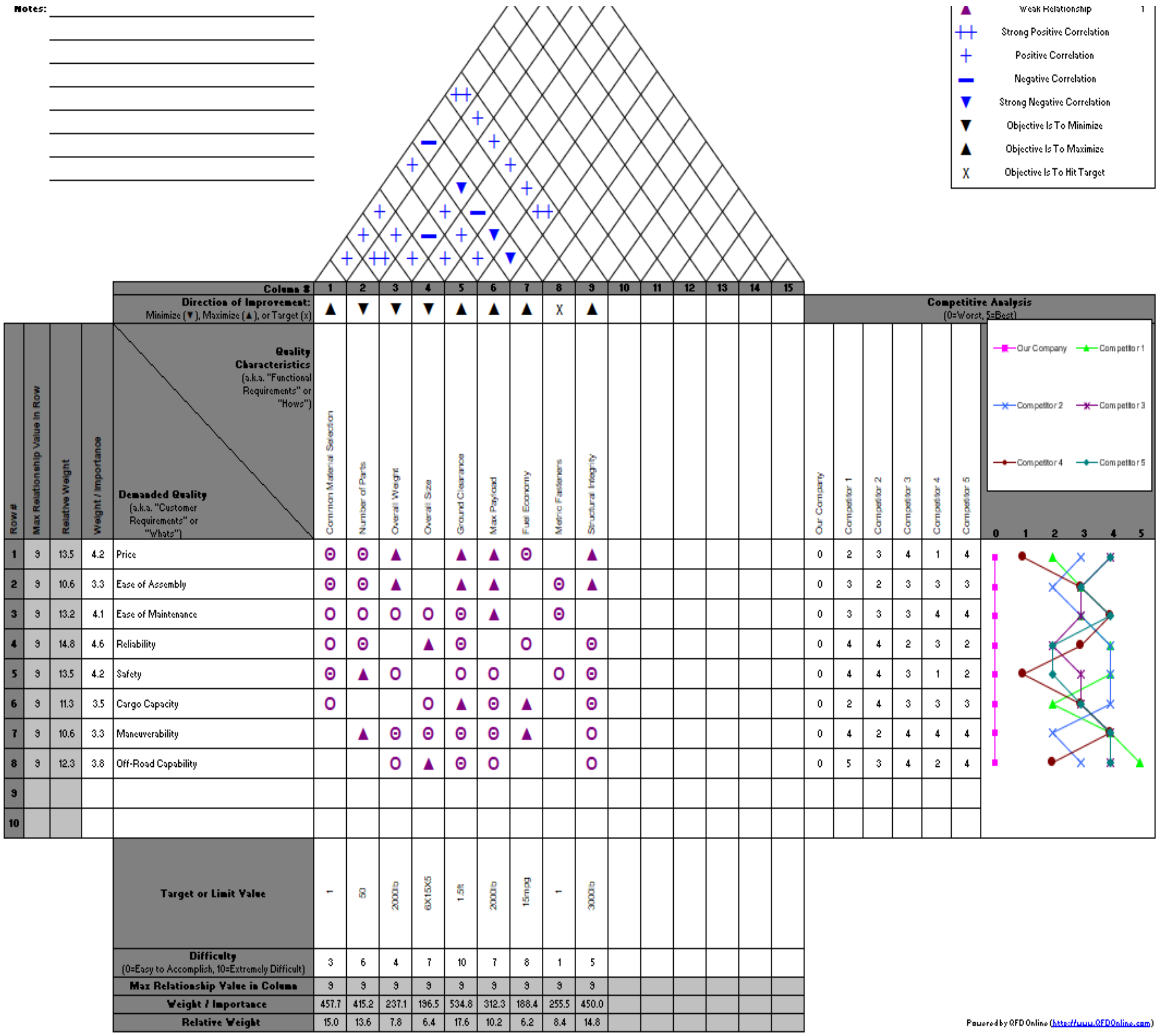

Figure 3 House of Quality

DESIGN

CONCEPTS

Steering Concepts:

Figure 4 Steering Design 1

Figure 5 Steering Design 2

Figure 6 Steering Design 3

For the steering system, two main design concepts were taken into consideration. From Figure 4 and Figure 5 above, the first design concept was a handlebar and steering shaft much like a bicycle with a total of three wheels. The second design consideration is a steering wheel design, as shown in Figure 6, with four wheels instead of three. I decided to take the handlebar and steering shaft approach. Research from past BUV designs have steered me towards this concept mainly because of budgeting, ease of assembly, and ease of operation. Implementing a steering wheel design would add on to the complexity of the vehicle, which would be the opposite of the initial design consideration for this vehicle. The thought here is to have a shaft or column attach the handlebar to the singular front wheel. This will allow for simple turning of the entire vehicle by means of just turning the desired direction.

Suspension System Concepts:

Figure 7 Earle's Fork Design

Figure 8 Macpherson Strut Design

Figure 9 Uni-Strut with Suspension Spring

For the suspension system, three concepts were considered. These concepts include Earle's Fork, the Macpherson Strut design, and an alternative to the Macpherson strut design, which includes a spring on the steering column instead of using a strut. For this design I planned to use Earle's mainly because I thought it would help tremendously with the load of the vehicle in an efficient way as compared to the other two methods.

After further analysis of the design concepts, I decided to go with a design that would implement both the Macpherson Strut design and the Unistrut design. Upon further research, current vehicles tend to go with this design. This is mainly due to the low complexity of the component which would allow easier repairs and builds to be done in developing areas around the globe. Although Earle's fork would be just as effective, it contains too many parts which raises the complexity level of having to maintain.

Loading Conditions:

<u>Loading for the Rear: Static</u>

$$1\,Barell = 55\frac{gal}{water}$$
$$1\frac{gal}{water} \sim 8.33\,lbs$$
$$1\,steel\,drum \sim 60\,lbs$$

$$3(8.33 \times 55) + (3 \times 60) = 1554.45\,lbs$$

The total weight for the three steel drums filled with water is around 1554.45 lbs. However, the rear leaf springs well be designed with a safety factor of 1.8 which means the suspension will be designed around 2800 lbs. of static loading. This will give enough room to install any necessary equipment in the rear. Since there will be a leaf spring on either side of the vehicle, each leaf spring will have a capacity of 1400 lbs.

$$Design\,Weight = 1554.45 \times 1.8 = 2798.01\,lbs = 2800\,lbs$$
$$Leaf\,Spring = \frac{1}{2(2800)} = 1400\,leaf\,sprin\,capacity$$

Loading for the Front: Static

$$(2\ passengers\ \times 180lbs) + (engine\&drivetrain\ 200lbs) + (Frame\ 1500\ lbs) = 2060\ lbs$$

$$2060lbs \times 1.5\ design\ factor = 3090lbs$$

The front suspension will not consist of leaf springs but rather A36 structural square steel tubing that will be bolted to the front wheel hub. It will look similar to what the 2018 BUV team designed, but with some modifications made. Instead of using a c-channel, square tubing will used instead.

The design will resemble a square cut in half. The loading will consist of two passengers, seats, the engine, the frame, and any other components that will be found in the front of the vehicle. Taking the passengers, the engine and drive train into consideration the front loading will be approximately 500 lbs. on top of the actual frame. From a static perspective the weight of the frame will only be considered for the part of the vehicle from the beginning of the cargo bed to the front of the vehicle. It is at this location where the center of gravity of the vehicle is located (beginning of the cargo bed).

The front suspension will be designed for a static load of 3100 lbs. The loading will be applied to the top surface where the steering column attaches to the suspension as well as where the suspension attaches to the hub of the wheel. I believe past years failed to take this into consideration and that is why their front suspension came apart (See Figure 10). However, one of the specifications for the BUV is making sure the suspension can withstand the force exerted on it by a 3-foot drop. This will also play a part in the final design.

Figure 10 BUV 2018

Solving for Impact force for a 3-foot drop

$$v = \sqrt{2gh}$$
$$v = \sqrt{(2 \times 32.2 \times 3)}$$
$$v = 13.899\,\frac{ft}{sec}$$
$$v = 4.236\,\frac{m}{s}$$
$$E = 0.5 \times 1406.136kg \times 4.236 = 12615.64J$$

Assume front wheel travels 0.1 m after impact with muddy terrain. Using the work-energy principle:

$$\frac{12615.64J}{0.1m} = 126156.4N = 28{,}362.50 \text{ lbf}$$

From the equations above, I concluded that an impact force of 28,362.50 lbf will be exerted on the front suspension from a three-foot drop.

DESIGN ANALYSIS

Material Selection

A36 structural steel will be used. This material was chosen because of its relatively low cost and its high strength and toughness. A36 steel is a widely used metal, it is used for such things as making bridges, supporting structures for vehicles and for heavy equipment. See Appendix D for more details on the material.

Final Design Concept

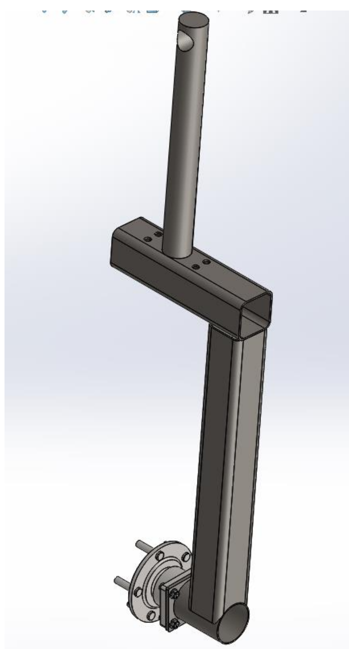

Figure 11 Final Design Concept

The final front suspension concept can be seen above. For the final design, I ended up purchasing a wheel hub and bearing assembly for a 1993-2002 Chevrolet Camaro. This wheel hub was necessary to be able to connect the front wheel to the front suspension assembly. In order to connect the square “L” tubing to this subassembly, a separate piece of 1026 steel tubing had to be purchased and welded onto a ¼” thick adapter plate. However, in order to make this work, the tube had to be 0.083” thick which caused some concern in regard to the structural integrity of the adapter plate assembly. So, in order to remedy this, a smaller sized tube with the OD of the inside of the original tubing was used. This tube was hammered into the existing tubing to help structurally. This original 1026 tubing was necessary to help get past the circular protrusion on the wheel hub assembly (normally where the ABS sensor is connected), which prevented me from using all square tubing and fabricating something unnecessarily complex and expensive. Both the wheel hub assembly and the adapter plate can be seen below. The necessary metric fasteners were purchased, and torque specs were obtained from the manufacturer for proper installation of the wheel hub assembly.

Figure 12 93' - 02' Wheel Hub & Bearing Assembly

Figure 13 Steel Adapter Plate 1/4" THK

FEA for both the plate and the “L” shaped front suspension was done through SolidWorks to make sure it was able to sustain the applied loads and not be pushed to failure. As seen in the pictures below both the plate and the front suspension assembly would have been able to sustain these loads with a minimum factor of safety of 2 using A-36 square structural tubing and plate.

The steering was to be composed of a 2.5” rod welded onto the top of the front suspension. This rod would be attached to the frame using the existing bracket on the vehicle and the existing hole pattern by using two flanged self-locking bearings placed on either side of the bracket. At the top of this rod a hole would be drilled through for a smaller 2.0” rod that would be the steering shaft, which would have been shorter in length than what was designed for an increased turning radius and easier effort turning the vehicle. This smaller rod would be attached by bolt and nut. At the end of the steering shaft the handlebar for the steering would be welded to the steering shaft.

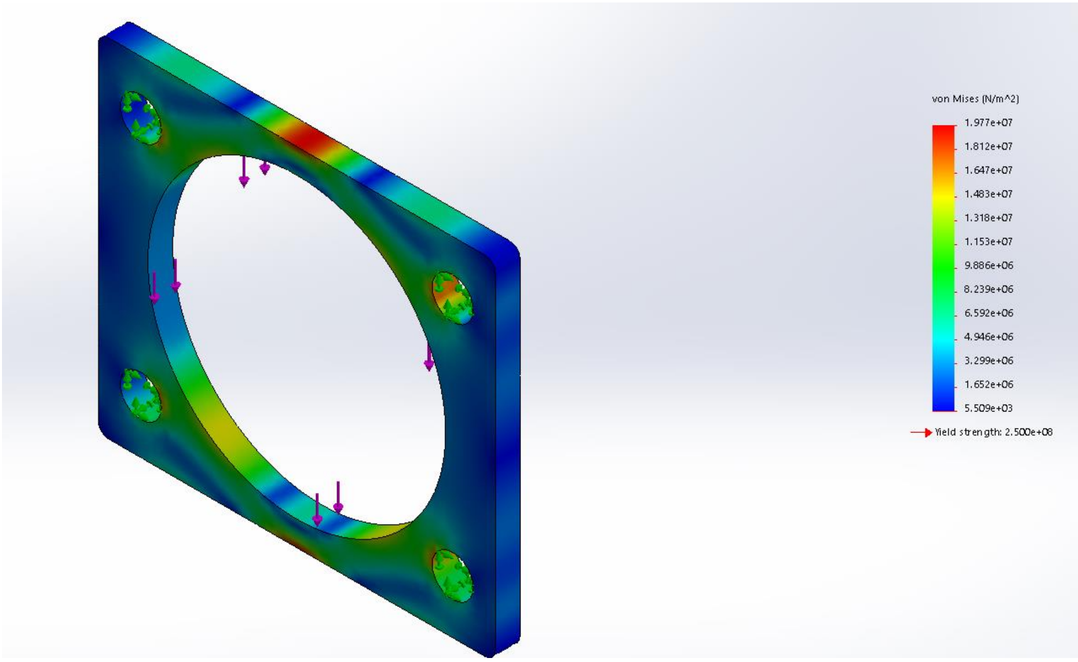

Figure 14 FEA for Adapter Plate

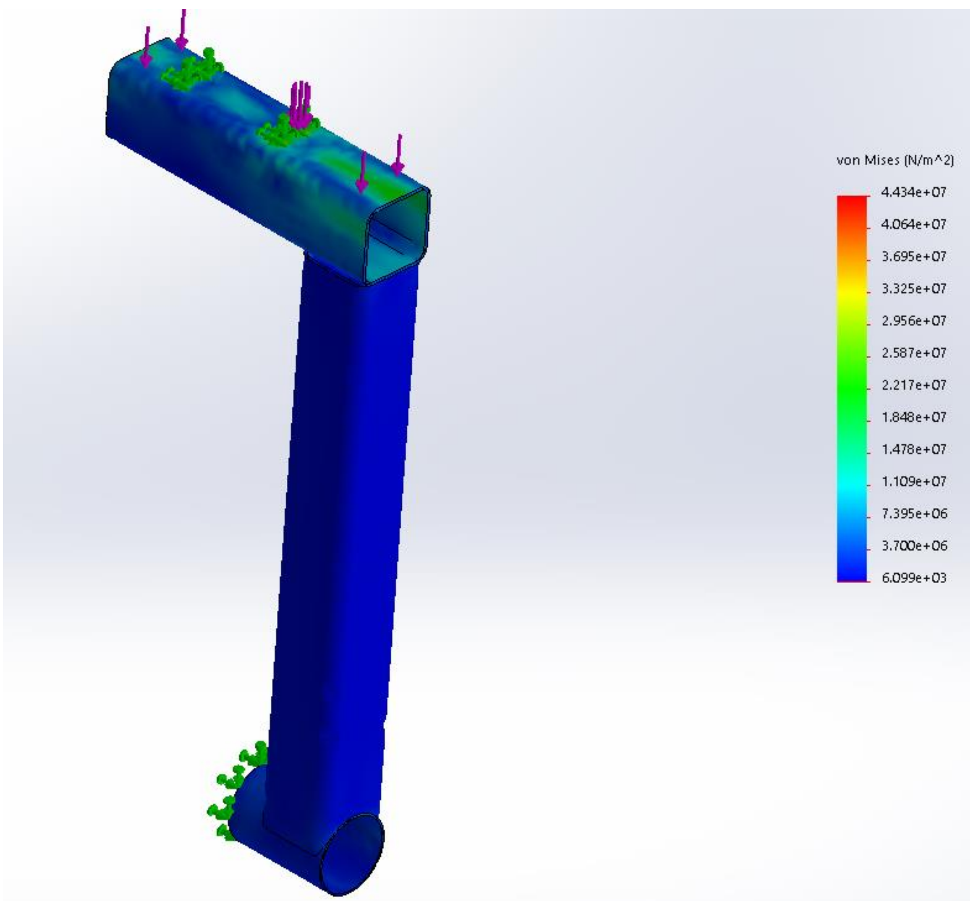

Figure 15 FEA for "L" Suspension

PROJECT MANAGEMENT

BUDGET, PROPOSED/ACTUAL

Project Budget Limit: Proposed

	Estimated Cost
Part	
Frame	400
Braking	150
Suspension	175
Power Train	200
Irrigation	200
Steering	200
Controls	100
Miscellaneous	400
Total	1825

Table 3 Proposed Budjget for Each Subsystem

Project Budget for Suspension/Steering: Proposed

ITEM	APPROXIMATE PRICING
A36 Square Structural Tubing	$85.50
Bearings	$15.00
Fasteners	~ $20.00
Suspension to HUB Bracket	TBD
Steering Column (steel rod)	$40 - 70
Handlebar	$50
Bracket for steering column to chassis	TBD
TOTAL	~$230 - ~$300

Table 4 Proposed Spending on Suspension/Steering

Project Budget for Suspension/Steering: Actual

A-36 Structural Square	$39.38
Wheel Hub Assembly	$46.00
Fasteners	$27.78
DOM Tubing	$74.52
Lug Nuts	$10.91
TOTAL	$198.59

Table 5 Actual Spending on Suspension/Steering

Shown in the tables above are the estimated costs for the BUV subsystems, the proposed budget for the steering and suspension, and the actual amount spent. In the beginning, the suspension and the steering combined would have totaled to about $375. What I ended up spending, was about $200 total for just the suspension, just $25 over what was estimated. I did not get to the steering components due to the Covid-19 pandemic, but I believe I would have spent around what was estimated since all I had to purchase were a couple of flanged self-locking bearings, a 2.5" DIA round tube, a 2.0" DIA round tube, and some material for the handle bars.

SCHEDULE, PROPOSED /ACTUAL

BUV Schedule: Proposed

Milestone	Estimated Date
Design Agreement	10/4/2019
1st Submodel Iteration	10/18/2019
Development Sharing	10/25/2019
2nd Model Iteration	11/1/2019
BOM	11/8/2019
System Integration/ Complete CAD Model	11/15/2019
Fabrication	1/17/2020
Testing 1	3/2/2020
Modifications 1	3/4/2020
Testing 2	3/16/2020
Modification 2	3/18/2020
Testing 3	3/25/2020
Modifications 3	3/30/2020
Tech Expo	April_2020
Compete/ Win	4/20/2020

Table 6 Proposed Schedule

Tech Expo was set for 04/09/20

BUV Steering and Suspension Schedule: Actual

Milestone	Estimated Date
Design Agreement	10/04/2019
1st Sub-model Iteration	10/21/2019
Development Sharing	10/25/2019
2nd Model Iteration	11/15/2019
Complete CAD Model	11/25/2019
3rd Model Iteration	12/08/2019
4th Model Iteration	12/20/2019
Fabrication	1/21/2020

Table 7 Actual Schedule

Above are the proposed schedule for the BUV and the actual schedule for the suspension/steering sub-assembly. Compared to the proposed, I was behind on schedule due to difficulties with the first few iterations of my sub-system. By the time I was able to decide on a final concept, I still needed to order some materials and components that I would be needing. By the time I was able to get a good amount of my materials I was only about a week behind schedule. Once fabrication started, I was able to streamline future planning as far as what needed to be machined and manufactured. However, as fabrication was nearing to an end Covid-19 pandemic had caused a halt to the project, indefinitely. Testing was not able to be done and the final assembly of the vehicle was never able to be achieved.

PLAN TO FINISH

Unfortunately, because of the Covid-19 pandemic, the University of Cincinnati was required to shut down person to person instruction and any meetings. This meant my team and I were not able to finish the BUV project. We were able to get as far as finishing modifying and fabrication of the chassis and finish modifications to the drivetrain sub-system. However, the front suspension and steering still had a bit of work to get done before being considered finished.

Before everything hit the fan, I had managed to fabricate the steel adapter plate, purchase the square and round tubing, purchase the wheel hub & bearing assembly, and purchase necessary fasteners. My next steps of action would then have been cutting the square tubing to the desired lengths and welding everything that needed welding. This would have given me a completed front suspension assembly. I then would have installed the steering rod via welding and fasteners to the existing bracket on the BUV. Once this was completed, the steering shaft would have been bolted to the rod and that would have been welded to the handlebar that would have been salvaged from an existing product or fabricated. This would have been done in the span of 1 week. The remaining time up until the Tech Expo would have been used for testing of the vehicle to make sure the suspension and the steering held up. For testing, the vehicle would have been taken to a team member's friend's farm, where a variety of terrain and a good amount of land was available.

Planned testing for the suspension and steering along with the rest of the components of the vehicle would have included a series of test runs. Some runs would have been conducted without any load; other runs would have been conducted with full loads on the vehicle. The vehicle would also have been tested for endurance by running different timed runs. The front suspension and the rear suspension would also have been tested by running the vehicle through different sized drops and rises, with both a full load and without any load. Steering would have been tested as the vehicle ran its course.

Figure 16 Existing Bracket on the Frame

Figure 17 Close up of Brakcet

Sustainability and Material Usage

Planning goes a long way. Making sure there is a detailed schedule for what has to be done and sticking it will help in having a sustainable and manageable project. Using time wisely will help take away loads of stress when everything starts to wrap up. Making sure you plan for any delay times when it comes to materials will also help the entire process. It is not ideal to be running around last second trying to cram everything in last minute. If working with a team, making sure there is clear and concise communication amongst all team members is important. With this specific project all of these could apply. I believe we could have done a better job sticking to our schedule and staying on top of ordering materials. Even though we would have finished fabrication and testing, it was too close for comfort.

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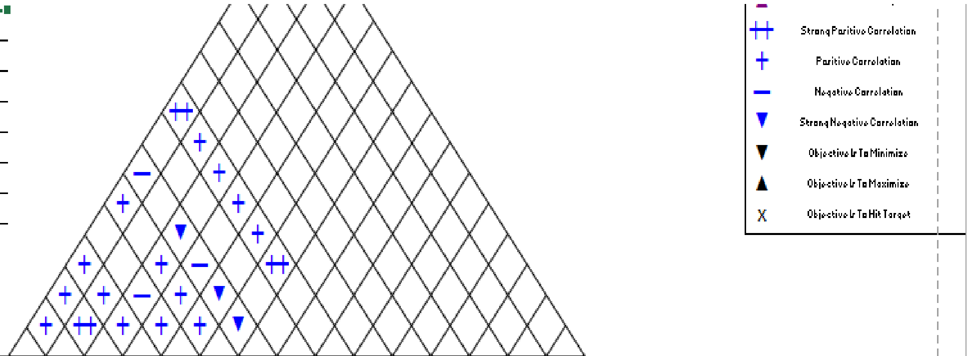
APPENDIX A: HOUSE OF QUALITY



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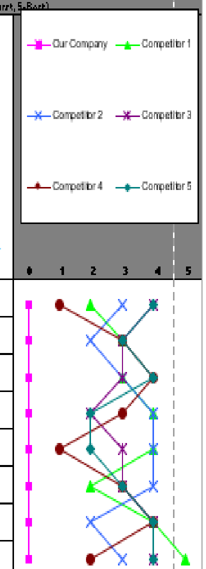
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	▼	▼	▼	▲	▲	▲	X	▲							Competitive Analysis (0=Worst, 5=Best)					
				Demanded Quality (a.k.a. "Customer Requirements" or "Whats") / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	Common Material Selection	Number of Parts	Overall Weight	Overall Size	Ground Clearance	Max Payload	Fuel Economy	Metric Fasteners	Structural Integrity												
1	9	13.5	4.2	Price	Θ	Θ	▲		▲	▲	Θ		▲							0	2	3	4	1	4
2	9	10.6	3.3	Ease of Assembly	Θ	Θ	▲		▲	▲		Θ	▲							0	3	2	3	3	3
3	9	13.2	4.1	Ease of Maintenance	O	O	O	O	Θ	▲		Θ								0	3	3	3	4	4
4	9	14.8	4.6	Reliability	O	Θ		▲	Θ		O		Θ							0	4	4	2	3	2
5	9	13.5	4.2	Safety	Θ	▲	O		O	O		O	Θ							0	4	4	3	1	2
6	9	11.3	3.5	Cargo Capacity	O			O	▲	Θ	▲		Θ							0	2	4	3	3	3
7	9	10.6	3.3	Maneuverability		▲	Θ	Θ	Θ	Θ	▲		O							0	4	2	4	4	4
8	9	12.3	3.8	Off-Road Capability			O	▲	Θ	O			O							0	5	3	4	2	4
9																									
10																									
				Target or Limit Value	1	50	2000lb	6X15X5	1.5ft	2000lb	15mpg	1	3000lb												
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	6	4	7	10	7	8	1	5												
				Max Relationship Value in Column	9	9	9	9	9	9	9	9	9												
				Weight / Importance	457.7	415.2	237.1	196.5	534.8	312.3	188.4	255.5	450.0												
				Relative Weight	15.0	13.6	7.8	6.4	17.6	10.2	6.2	8.4	14.8												



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APPENDIX B SURVEY

BASIC UTILITY VEHICLE
CUSTOMER SURVEY

We are a group of five Mechanical Engineering Technology seniors at University of Cincinnati. For our senior design project, we have chosen to design and build a Basic Utility Vehicle that can be used in developing countries to help improve daily life. Please answer the following questions:

How important to you is each BUV design feature?
Please circle the appropriate answer.

1 = low importance 5 = high importance

Price	1	2	3	4	5	
Ease of Assembly	1	2	3	4	5	
Ease of Maintenance	1	2	3	4	5	
Reliability	1	2	3	4	5	
Safety	1	2	3	4	5	
Cargo Capacity		1	2	3	4	5
Maneuverability	1	2	3	4	5	
Off-Road Capability	1	2	3	4	5	

How satisfied are you with current BUVs?
Please circle the appropriate answer.
1 = very UNsatisfied 5 = very satisfied

Price	1	2	3	4	5	
Ease of Assembly	1	2	3	4	5	
Ease of Maintenance	1	2	3	4	5	
Reliability	1	2	3	4	5	
Safety	1	2	3	4	5	
Cargo Capacity		1	2	3	4	5
Maneuverability	1	2	3	4	5	
Off-Road Capability	1	2	3	4	5	

How much would you be willing to invest in a BUV?
$500-$1500 $1500-$2500 $2500-$3500 $3500-$4500

APPENDIX C BUV SPECIFICATIONS

BUV Farm Tanker & Transporter
2020 Design Specifications:

Engine Use up to 11 horsepower unmodified engine. An auxiliary fuel tank may be added.

Exhaust Stock muffler, which may be relocated, with additional heat shields as needed.

Gauges An engine temperature indicator located in view of the driver.

Fuel Retail pump fuel and oil with provisions to prevent spilling fuel on a hot engine.

Transmission It is builder's choice, to meet event conditions, but should have reverse**** and should have at least two forward speeds**** not counting any variable drive features.

Power Takeoff The ability to power auxiliary equipment**** at approximately 1000 rpm.

Electrical A 12 volt 35 amp or larger automotive alternator and an automotive battery are required****.

Cargo Bed The bed must hold two, but may hold three 55 gallon standard steel drums**. The drums must be located on their sides with features to verify they are full. The drums must be located as low as possible in the bed. The drums must not be stacked in any manner. The front of the cargo bed must have a 16 inch minimum high bulkhead between the driver and the cargo. The other sides of the bed must be a minimum of 8 inches high. Drums should be easily removable for cargo**and not have any holes that would leak water.

Roll Bar A minimum height of 36 inches above the surface the driver will sit upon. The roll bar must be completely padded above the seat height. It must have a cross member that covers the ends of the vertical structures, and adequate bracing to prevent the roll bar from collapsing.

Driver Safety A helmet is required for each person aboard the vehicle. Seat belts are at the option of the team and the team advisor.

Safety Items To participate in the event, you must have the following safety items:

1. An engine shutoff device marked with a nine-inch red streamer located within reach of the driver.
2. A ***dead man*** throttle with the spring located directly on the throttle linkage of the engine and not on the throttle control devices of vehicle. A ***dead man*** to neutral directional control valve is required on hydraulic powered vehicles.
3. Guarding from all moving parts and Padding of all sharp or dangerous areas.
4. Automotive horn, a fire extinguisher with a rating of 5 B-C or higher, and a high visibility safety flag above the vehicle.

Brake System A redundant brake system**** that will prevent total brake failure if a brake line is severed anywhere on the vehicle. The brakes must be located at the wheels and not on the drive-line. A front wheel brake is not required on three wheeled vehicles. The parking brake is not considered the redundancy that is required. Hydraulic drives may use reverse for redundancy.

Parking Brake A parking brake capable of overcoming the engine power. It may be on the drive-line.

Tires Agricultural tread, or aggressive tire chains are required. Chains must remain with the vehicle.

Towing Each vehicle must have a 20 foot looped-end tow strap. No hooks allowed. There must be an attachment point at the front of the vehicle for towing. The trailer ball will be the rear attachment point for towing.

Trailer Hitch	A 1-7/8 inch trailer ball must be mounted at a height of 15 inches above the ground when the vehicle is unloaded.
Speed	Maximum of 20 MPH.
Load	Maximum of 165 gallons of water, weighting roughly 1376 pounds.
Water Pump	Ability to fill 55-gallon drums from within 15 feet of a pond. All pumping equipment and hoses must be carried on the vehicle during the event. Pump driven form PTO device only.
Name Plate	The school name and team number displayed in 4-inch font on all sides of the vehicle.

**** See Tech Inspection Sheet for deductions if this feature is missing**

APPENDIX D A36 PROPERTIES

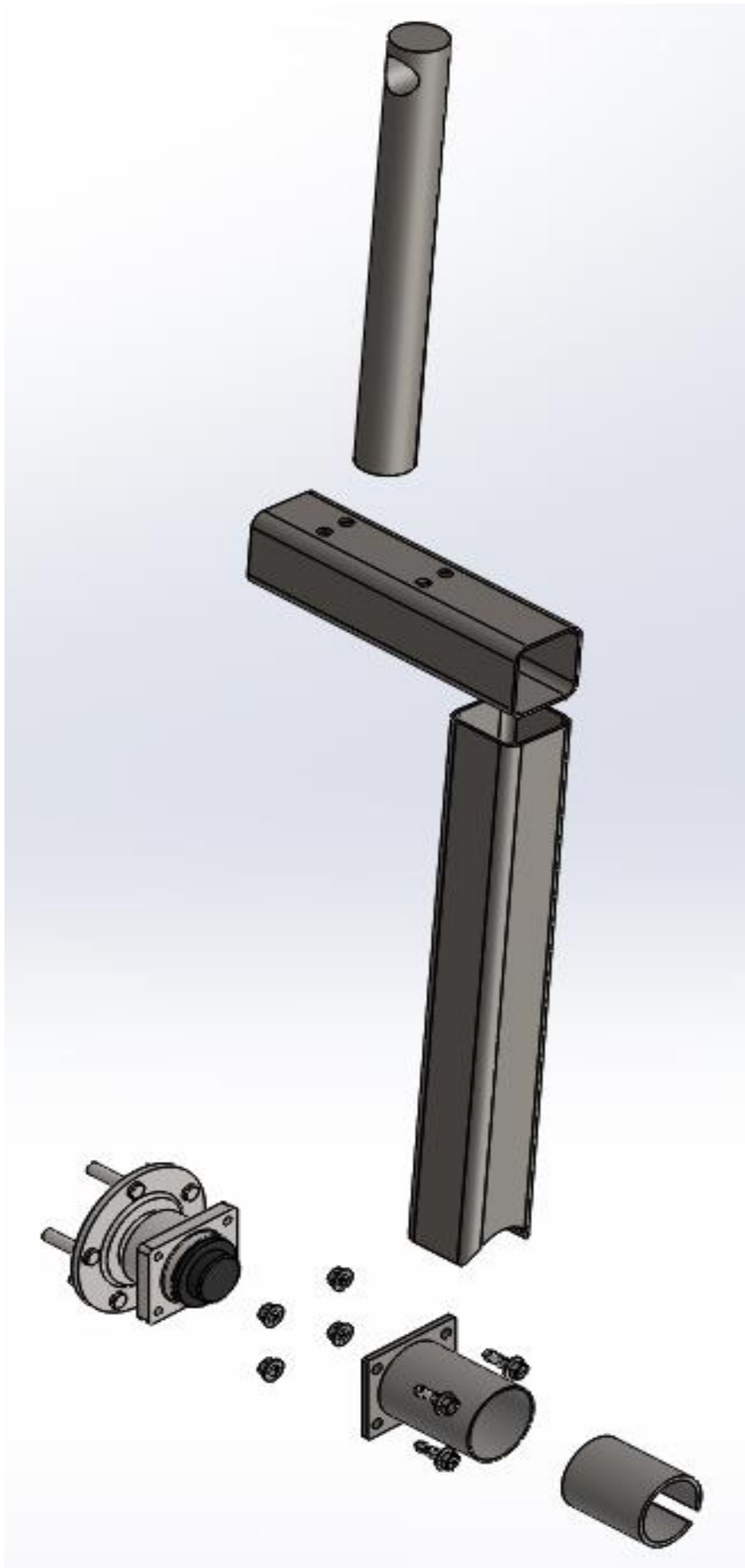
Physical Properties	Metric	English	Comments
Density	7.85 g/cc	0.284 lb/in³	Typical of ASTM Steel

Mechanical Properties	Metric	English	Comments
Tensile Strength, Ultimate	400 - 550 MPa	58000 - 79800 psi	
Tensile Strength, Yield	250 MPa	36300 psi	
Elongation at Break	20 %	20 %	in 200 mm
	23 %	23 %	In 50 mm.
Modulus of Elasticity	200 GPa	29000 ksi	
Bulk Modulus	160 GPa	23200 ksi	Typical for steel
Poissons Ratio	0.26	0.26	
Shear Modulus	79.3 GPa	11500 ksi	

Component Elements Properties	Metric	English	Comments
Carbon, C	0.25 - 0.29 %	0.25 - 0.29 %	
Copper, Cu	0.20 %	0.20 %	
Iron, Fe	98 %	98 %	
Manganese, Mn	1.03 %	1.03 %	
Phosphorous, P	<= 0.040 %	<= 0.040 %	
Silicon, Si	0.28 %	0.28 %	
Sulfur, S	<=0.050 %	<=0.050 %	

Some of the values displayed abovemay have been converted from their original units and/or rounded in order todisplay the information in a consistent format. Users requiring more precisedata for scientific or engineering calculations can click on the property valueto see the original value as well as raw conversions to equivalent units. Weadvise that you only use the original value or one of its raw conversions inyour calculations to minimize rounding error.

APPENDIX E SUSPENSION/STEERING: EXPLODED VIEW



APPENDIX F ASSEMBLY DRAWING