Solar Assisted Electric Golf Trolley

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ABSTRACT

With more people wanting to get exercise from walking while out playing a round of golf, push carts on the golf course have become much more common. There are multiple problems with the motorized push carts that are available on the market today. The problems with these carts is that they are too heavy, inefficient and even when folded down, they are clunky and still require an almost completely empty trunk space to transport. It is because of these reasons that I propose a solar power assisted golf trolley.

The motorized pushcarts that are currently on the market fold to a volume of about 4 cubic feet, weigh upwards of 35 pounds and have an average cost of about $700.00. Majority of the carts only operate for eighteen holes before the batteries required a charge and the top of the market still only went for twenty-seven holes before needing a charge. When factoring in the cost for clubs, a golf bag, and the golf itself, seven hundred dollars for a cart is seen as a large expense for something that isn't a necessity.

In order to solve this problem, I wanted to create a new golf trolley that would excel in all of these areas and also, be a more reasonable cost to the consumer. Lithium ion batteries will be used to lessen the weight of the cart, while solar panels will be used to increase the amount of time the cart can be used without a charge. The cart will fold at two different hinge points to lessen its volume when folded. All of these modifications will be made attempting to keep the cost of the prototype at a minimum in order to pass that on to the consumer.

The frame of the cart was made from 6061 Aluminum, this was also in an effort to keep

the overall weight of the cart low, while not sacrificing any strength. The motor mount was constructed from 6061 Aluminum as well and mounted to the bottom of the cart. The cart folds once at the front wheel and also, halfway up its frame. Two 60 Watt solar panels were mounted to each side of the cart with individual controllers. These were then wired to the controller mounted in the middle of the frame and then to the motor. A variable throttle was also mounted to the aluminum handle bars to give the user greater control of the speed of the cart.

The cart performed as it was designed and achieved all goals that were set in place. The cart folded down to a volume of 2.97 cubic feet, weighs 31 pounds and was able to run consistently for 36 holes of golf and still had battery charge to spare. Even though, the end goals were achieved there are still some improvements that can be made to the prototype design that can increase the quality of this design and increase the success of this product.

PROBLEM DEFINITION & RESEARCH

PROBLEM STATEMENT & BACKGROUND

With recent events, such as collegiate golf allowing push carts, and IBISWorld.com estimating that the market size for golf is growing at a 1.2% rate annually, the market for pushcarts will only increase. Even with this prediction, there are still many issues with the motorized pushcarts that are available on the market today, and can be improved upon. Most motorized carts are expensive, heavy, bulky, inefficient, and require almost a completely empty trunk to transport.

The solution I am proposing for this would be to create a new electronic motor push golf cart that is lighter and folds down to a smaller cubic footage than any other motorized cart. Also, my solution would address the problem of inefficiency, by increasing the time or use needed between charges. This solution could use a different type of battery or a solar panel to address this. I used various websites to research current electric golf push carts on the market. The lightest electric push cart that I could find was still over 18lbs. without the battery and the smallest folded volume was 3.82 cubic feet. The longest amount of use between charges was 27 holes, which is not even two entire golf rounds. My solution would weigh less, fold up smaller and also have the ability for more rounds of golf in between charges. After visiting multiple websites to research the current market, the average price of the carts was around $700 dollars, and I am confident that my solution would be cheaper than that as well

With its introduction into college golf, more studies are being conducted on the health benefits and energy conservation of using push carts. In a Golf Digest Article, Dr. Neil Wolkodoff explains, from the results of a study that he conducted on college golfers; "People who push a cart have a lot fewer [health] issues, and a lot less potential for issues." These studies are also showing that golfers who use these carts conserve more energy throughout the round, and this study displayed that the golfers who used a pushcart shot a better score than the golfers that were carrying their bag.

RESEARCH, TECHNOLOGY & EXISTING PRODUCTS

The first type of research done for this project, was to conduct market research on existing products. The market research was conducted to identify key characteristics and targets that manufacturers were addressing, as well as to conclude which aspects this project would focus on. After researching over thirty different designs and product, both online and in retail stores, I was able to list the key characteristics that the manufacturers and customers considered important. Once the key engineering characteristics were acknowledged, averages in each were calculated in an attempt to determine project targets with units. Figure 1, shows five examples of carts currently on the market, along with target properties each manufacturer. After researching the current market, it became apparent that these five areas were the main characteristics that both manufacturers and customers were concerned with.

Market Research Sample Specifications

Sample Market Motorized Carts	*Specifications*					
	Weight (lbs)	**Folded Volume** (ft^3)	**Battery Life** (Holes)	**Price**	**Remote Controlled** (Y/N)	**Cart Pictures**
BattCaddy X3	55	6.3	27	$500	N	
Clubrunner Electric Cart	46	6.3	18	$650	N	
MotoCaddy S1	38	5.88	18	$800	N	
Spritzer RL150	36	5.01	27	$1,500	Y	
BattCaddy XR3	47	5	18	$1,100	Y	

Table 1: Market Engineering Targets & Examples

Customer Needs, Questionnaire & Weighted Importance

In order to get a first-hand account of the criteria that golfers in the area found important, a short questionnaire was given. The questionnaire was conducted at Miami View Golf Course on Saturday, November 19th, 2016. The short questionnaire was five questions long and aimed to determine a random sample of the amount of interest in motorized carts and which design aspects these golfers found to be the most important. Twenty golfers overall responded to the questionnaire, fifteen men and five women. Analysis of the questionnaire revealed multiple aspects that customers found important. As seen in Table 2 below, the amount of time that the cart can go between charges was the main concern from this surveyed group. The folded volume and weight of the cart were also of concern. The questionnaire & results can be found in Appendix B.

#	Customer Need	Response
1	Amount of Holes Between Charges	9/20
2	Folded Volume	5/20
3	Weight	5/20
4	Remote or GPS Control	1/20

Table 2: Survey Results Summary

The customer needs from this questionnaire were then combined with the market research results. The complete customer needs, as seen in Table 3 below, were then given percentage weights to determine the most important customer requirements. The amount of holes that a cart can operate in between charges was given the largest weight, because of the combined importance found from the survey and research. It is then followed by the folded volume of the cart and the ability to vary the speed of the cart.

Weighted Consumer Needs

#	Customer Need	Weight
1	Amount of Holes Between Charges	23%
2	Folded Volume	18%
3	Variable Motor Speed	15%
4	Detachable Panels & Batteries	10%
5	Weight	10%
6	Safety	8%
7	Durability	6%
8	Ability to Traverse Hills	5%
9	Doesn't Tip	5%

Table 3: Weighted Consumer Needs

PRODUCT ENGINEERING FEATURES

The combined, weighted customer needs list was then combined with the corresponding engineering requirements, in a QFD, (Quality Function Deployment) which can be found in Appendix C. The QFD allows the designer to correlate engineering features to the engineering requirements. This correlation results in the importance percentages of each requirement and feature to the objectives of the design. The needs were given specific targets and then the importance of the engineering characteristics was calculated. The engineering features are listed in Table 4 by percentage, from highest to lowest, with the number one importance being ≥ 36 holes without a battery charge. The Engineering requirements are listed in Table 5 below, with their calculated importance percentages.

Weighted Engineering Features

#	Engineering Features	Weight
1	≥ 36 Holes Without Charge	23%
2	Folded Size Under 4.5 ft^3	18%
3	Variable Motor Speed	15%
4	Batteries & Panels Detachable	10%
5	Weighs Less Than 35 lbs.	10%
6	Safe to Use	8%
7	Durable	6%
8	Climbs Hills of ≤ 12°	5%
9	Doesn't Tip	5%

Table 4: Weighted Engineering Features

Engineering Requirements

Time Between Charges (holes)	15.35%
Weight (lbs)	12.64%
Motor Torque (lb-ft)	11.74%
Folded Size (ft^3)	11.26%
Speed (ft/s)	10.45%
Frame Material	9.80%
Solar Panel Charge (Amps)	9.76%
Hill Climbing (°)	8.08%
Assembly Time (s)	6.62%
Pinch Points (Y/N)	4.30%
Total	**100.00%**

Table 5: Engineering Requirement Importance Percentages

PRODUCT OBJECTIVES/CONCLUSIONS

OBJECTIVES

Objectives for the project are a set of design parameters that are the resultant from analysis of the customer questionnaire, as well as analysis of market research. The subsequent list of top five objectives results from these analyses, with corresponding design weights and possible strategies to obtain them. Only the top five are listed here. The remaining can be found in Appendix E.

1. ***≥ 36 Holes Without Battery Charge*** ***23%***
   - **a.** Use lithium ion batteries instead of lead acid, in order to keep weight down, while still providing sufficient amp hours.
   - **b.** Incorporate regenerative energy system into design, if applicable.
   - **c.** Incorporate solar energy system into design, if applicable.
   - **d.** Keep design weight of cart down.
2. ***Folded Volume Under 4.5 ft^3*** ***18%***
   - **a.** Do not interfere with front wheel collapsing profile.
   - **b.** Make use of voids already in collapsed profile for design components.
   - **c.** If necessary, add additional hinging sections to collapse volume.
3. ***Variable Motor Speed*** ***15%***
   - **a.** Use of variable speed motor
   - **b.** Use of variable speed potentiometer throttle
   - **c.** Ensure gear ratio provides appropriate rpm range
4. ***Weight ≤ 35 lbs*** ***10%***
   - **a**. Use lithium ion batteries in design, instead of lead acid batteries
   - **b**. Incorporate only one motor into design, instead of two separate rear wheel motors.
   - **c**. Use aluminum for bracketing and components.
   - **d**. Allow for batteries and solar panels to be removable.
   - **e**. Eliminate any unnecessary components.
5. ***Batteries & Solar Panels Detachable (Charge Independently)*** ***10%***
   - **a**. Make battery mounts removable with batteries & solar panels.
   - **b**. Use of folding solar panels.
   - **c.** Wire connections for batteries to controller must be able to be quickly attached and detached.
   - **d.** Solar panel controllers must be stored in battery mount or on panels.
   - **e.** Panels must be easily attached and detached to cart frame.

DESIGN

Pre-Design Research & Data Acquisition

Before design concepts could be drafted for this product, research and testing needed to be carried out to determine the necessary components that will be implemented into the cart. The first property that needed to be determined, is the force necessary to move the cart from rest and the force required to keep the cart moving. Once this force was determined, the corresponding torque could then be calculated. This test was conducted by attaching a fish scale to the front axle and gently pulling the scale parallel to the ground until the cart began to move. The value seen on the scale when the cart began to move was then recorded. After that, the cart was pulled continuously for five seconds, while the scale was videotaped. The video was then analyzed and an estimated average scale reading was then recorded. This test was conducted thirty times and then the results averaged in order to receive the most accurate value. The average force from rest was found to be 6.72 lb_f and the force in motion was 4.1 lb_f. The table of the thirty recorded values can be found in Appendix D.

Next, research had to be conducted to determine the average course length and average course overall elevation change. Golfclubatlas.com estimates the average golf course length to be 7,250 yards with the average elevation change being close to even. Also, research was conducted on the average walking pace in order to determine a range of speed for the motor. This was found to be 3.1 mi/hr. Further research was conducted to determine any PGA standards for pushcarts, of which there were none. Both OSHA and ASME standards were also researched in order to comply with pinch points. The final research that was conducted was to determine if any possible design ideas would infringe on any existing copyrights.

Design Alternatives & Selection

When designing this motorized cart, there were several driving factors that led to the final design selection. Figure 1 displays the front wheel hinge that folds underneath the cart. In order for the motor to be mounted to the front wheel, it must fit in this area and rotate at along with the wheel on a consistent axis.

Figure 1: Front Wheen Hinge

Because of this constraint, a motor must be chosen first and then, the mounting bracket was designed.

The second driving factor was that in order to keep the folding volume of the cart as low as possible, folding solar panels would be used for the alternative energy source, instead of regeneration or other options.

Figure 2 shows an alternative design mock-up for the motor bracket. The wood in this picture was designed to be aluminum, along with different hose clamps and was designed to mount a 100 Watt motor to the cart.

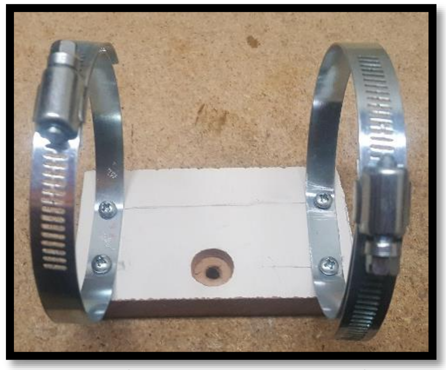

Figure 2: Alternative Motor Bracket Mock-up

Figure 3, also displays some alternative designs to a possible motor mount on the front hinge. After this type of bracket was designed in Solidworks and the motor was selected, a variation of this design was chosen.

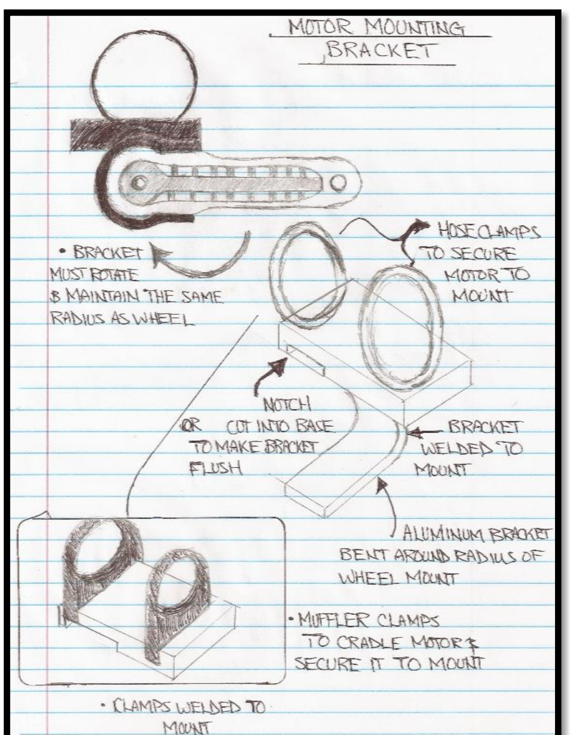

Figure 3: Alternative Motor Mount Design

The final design selection was based on a 250 Watt motor. A variation of Figure 3 was used for the final design. Because this motor had a mount welded to the bottom of it, the muffler clamps or hose clamps that were needed to secure the motor to bracket itself were no longer required. The motor would be mounted to the bracket using ¼ - 20 bolts, two in the front of the aluminum base and two in the back. This design was chosen, because the aluminum flat bar wrapped tightly around the radius of the wheel mount prohibits any movement from the motor that might result from the torque generated. The final design selection can be seen here in Figure 4. Other design alternatives for the mounting bracket, cart and alternative energy sources can be found in Appendix F.

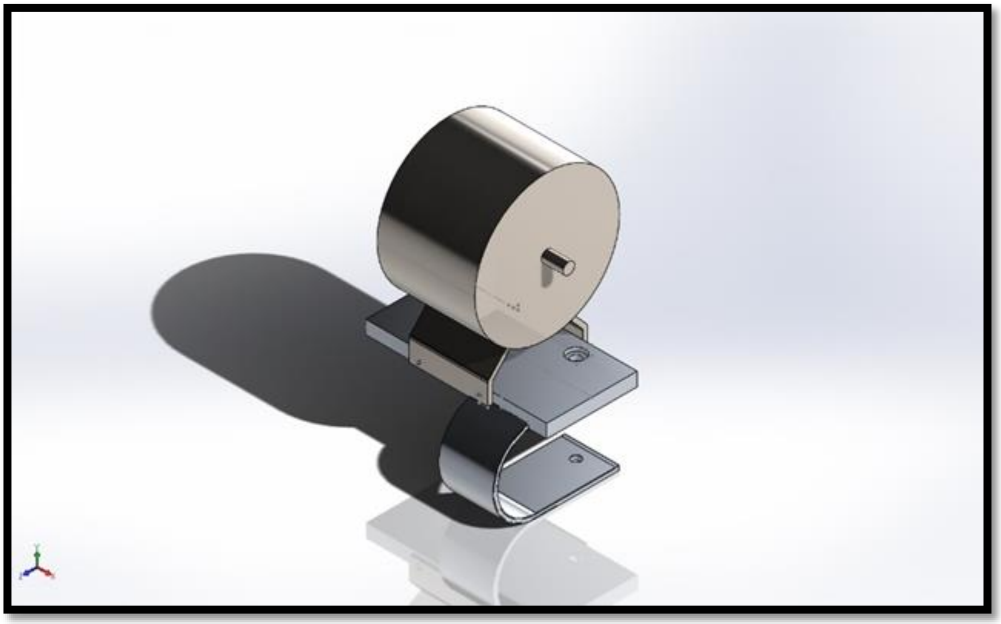

Figure 4: Final Motor Mount Design

DRAWINGS

Figure 4 displays the motor mount, fully assembled that will wrap around the wheel mount, using the U bracket, as well as being secured through the wheel mount using a 5/16 bolt. The figures below show the individual parts of the motor mount.

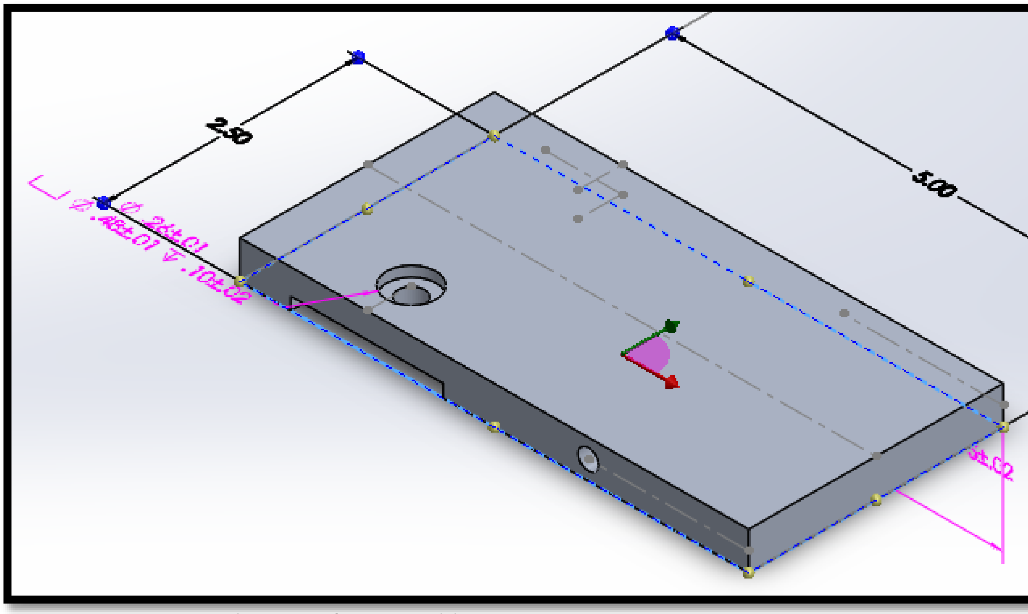

Figure 5: Motor Bracket Base for Assembly

Figure 5 shows the base for the motor bracket. The base is a ¾ in. piece of 6061 Aluminum. The 1½ in. notch was cut extruded into the bottom of the base in order for the U bracket to fit flush with the base. The Solidworks hole wizard tool was used to create the center 5/16 tap hole and is recessed below the top of the base. The hole wizard tool was also used to create the ¼ - 20 tap holes in the side of the base for the motor to be mounted.

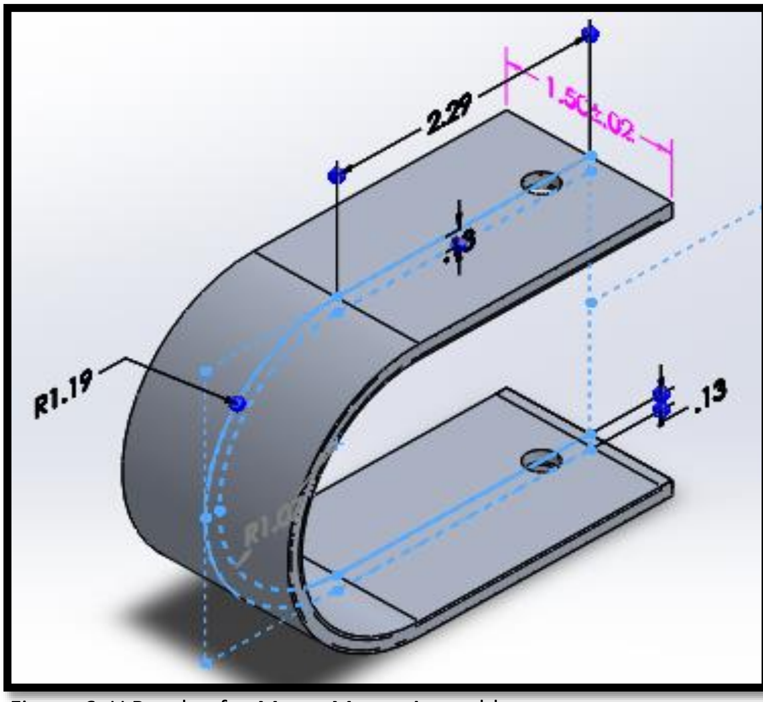

Figure 6: U Bracket for Motor Mount Assembly

Figure 6, displays the Solidworks design for the U bracket, which is used to secure the motor mount to the wheel mount of the cart. The bracket is constructed from 6061 Aluminum. The bracket was extruded to fit flush into the extruded cut in the motor mount base. Both 5/16 tap holes were cut using the hole wizard tool. The motor mount is designed so that the 5/16 bolt goes through the motor mount base, top of the U bracket into and through the wheel mount and secured to the bottom of the wheel bracket with a washer and nut. The radius of the U bracket is also designed to fit snugly over the radius of the when mount to prevent any possible movement originating from the torque of the motor.

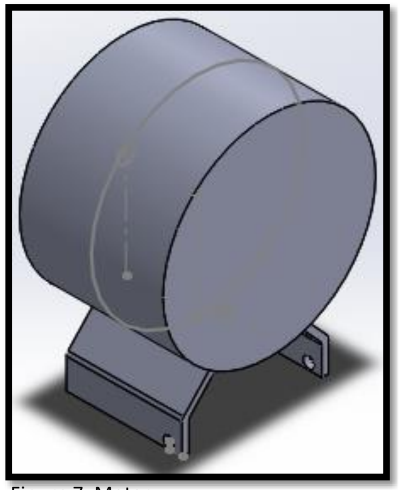

Figure 7: Motor

Figure 7 shows the motor that is connected to the motor mount base. The motor is secured to the base using ¼ - 20 bolts. The tap holes for these were cut into the motor mounting bracket using the hole wizard tool. The motor is mounted to other the front and back side of the motor mount base.

The corresponding part drawings and more design renders can be found in Appendix F.

LOADING CONDITIONS

A Finite Element Analysis was conducted on the entire motor mount. This FEA was ran in order to determine the max stress concentration and locations, as well as to determine an overall safety factor for the mount. For the analysis, two forces were applied to the motor bracket. The first force applied was gravity. The second force that was applied to the motor mount was the rated motor torque and it was applied at the motor armature. The rated torque for the motor was found to be 8 lbs-in. In order to account for any errors, an extra 1.5 lbs-in. was added to the load, to make a total of 9.5 lbs-in. applied at the end of the motor armature. The loading conditions can be seen in Figure 8, while the results from the analysis can be seen in Figures 9 and 10, below.

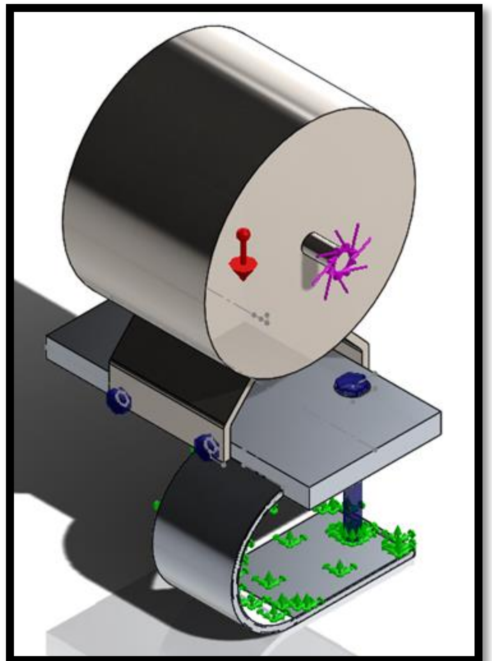

Figure 8: FEA Loading Conditions

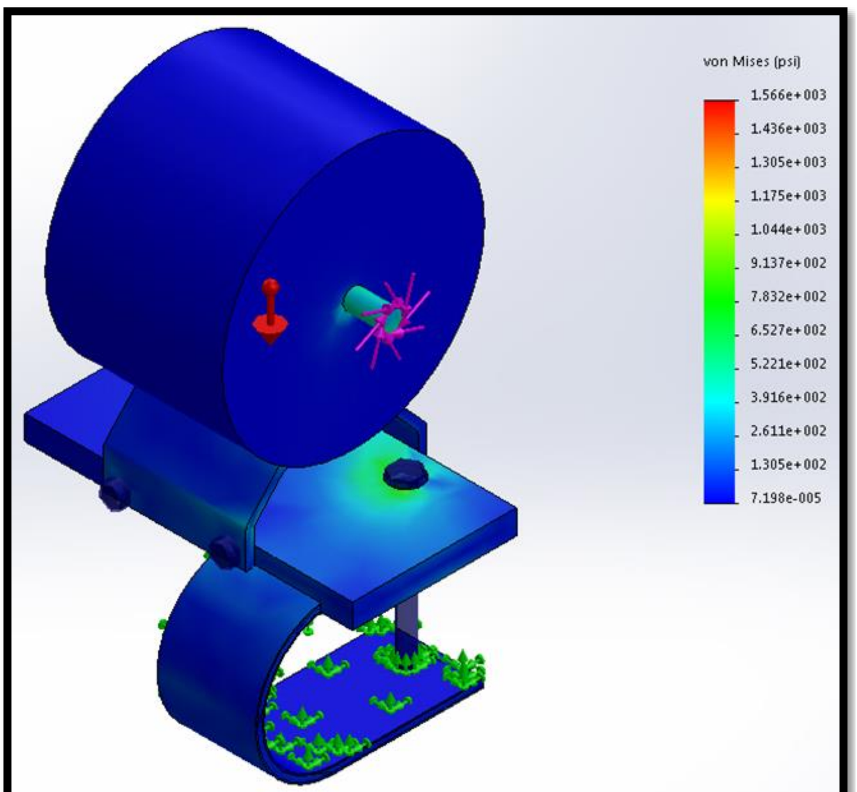

Figure 9: von Mises Stress Test Results

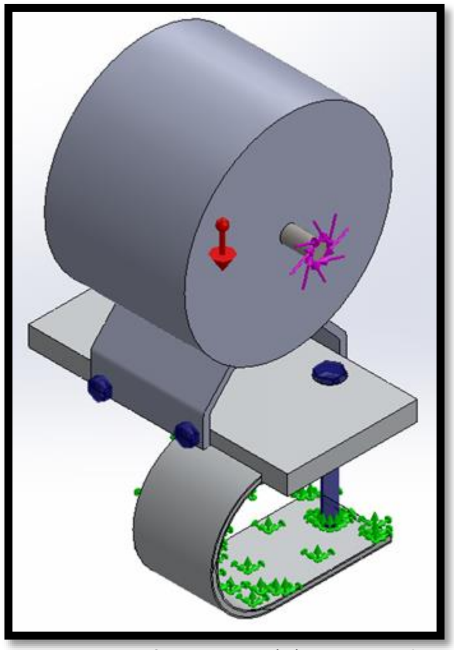

Figure 10: Safety Factor (2) Test Results

From Figure 9, it can be seen that the max stress applied to the motor bracket is 1,566 psi and it is concentrated at the recessed 5/16 bolt head and the base. This is an allowable stress for this application. Also, washers were not used in this analysis, which if they were applied to it, the concentration of this stress would be spread out and lessened.

Figure 10 displays the safety factor analysis that was applied to the von Mises Stress Analysis. A safety factor of two was applied to the assembly. If any node in the motor mount did not satisfy this safety factor, it would have shown in red on the graphic. As it can be seen in Figure 10, every part of the mount satisfied this condition. Figure 10 also shows that the inside face of the U bracket is constrained and in contact with the wheel mount. The entire report and analysis of the FEA can be found in Appendix G.

Calculations

The following are sample calculations used for design and analysis of the prototype. Tables for gear ratio calculation can be found in Appendix H.

1. *Miles per hour to feet per minute*

   (For Average Walking Pace)

$$3.1\frac{\cancel{mi}}{1\,\cancel{hr}} * \frac{5280\,ft}{1\,\cancel{mi}} * \frac{1\,\cancel{hr}}{60\,min} = 272.8\ {}^{ft}/_{min}$$

2. *Front Tire Circumference*

$$c = 2\pi r \ \rightarrow c = 2\pi\frac{1}{2}ft \ \rightarrow c = 3.14\ ft$$

3. *Goal Angular Velocity for Front Wheel*

   (For Cart Max Speed of 6 mi/hr)

$$\frac{6\,\cancel{mi}}{1\,\cancel{hr}} * \frac{5280\,\cancel{ft}}{1\,\cancel{mi}} * \frac{1\,\cancel{hr}}{60\,min} * \frac{1\,rev}{3.1416\,\cancel{ft}} = 168.1\,rpm$$

4. *Required Torque to Move Cart from Rest*

   (Front Wheel Fish Scale Test)

$$\tau = F * d \;\rightarrow\; \tau = 6.72\,lb_f * 0.01875\,ft \;\rightarrow\; \tau = 0.126\,lb_f ft$$

5. *Gear Ratio*

   (Goal: rated motor rpm/max speed rpm)

$$GR = \frac{\omega_{motor}}{\omega_{wheel}} \rightarrow GR = \frac{2650\,\cancel{rpm}}{168.1\,\cancel{rpm}} \rightarrow 15.76$$

6. *Max Solar Panel Charge/Round*

$$P = I * V \;\rightarrow 40\,Watts = I * 12\,Volts \;\rightarrow I = \frac{40\,\cancel{Watts}}{12\,\cancel{Volts}} \rightarrow I = 3.33\,Amps$$

$$I = 3.33\,Amps * \frac{4\,hr}{1\,round} = 13.32\,{}^{Amphr}/_{round} * 2\,Panels = 26.64\,{}^{Amphr}/_{round}$$

7. *Battery Drain/Round (without solar addition)*

   (Estimate @ Avg. Half Throttle)

$$\frac{7{,}250\,\cancel{yds}}{1\,round} * \frac{3\,\cancel{ft}}{1\,\cancel{yd}} * \frac{1\,\cancel{min}}{273\,\cancel{ft}} * \frac{1\,\cancel{hr}}{60\,\cancel{min}} * \frac{6.7\,Amp}{1\,\cancel{hr}} = 8.9\,{}^{Amps}/_{round}$$

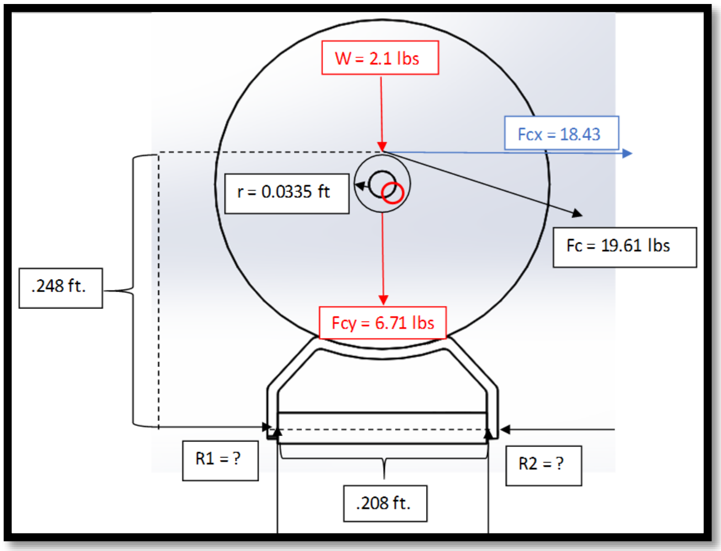

Figure: Motor Mount Plate FBD

8. *Mount Plate Forces & Reaction Forces Calculations:*

$$Rated\ Torque = 0.6638\ lb * ft \qquad Sprocket\ Radius = 0.03385\ ft$$
$$Chain\ Angle = 20°$$

$$Torque = Force * distance\ ;\ \tau = F_c * d \qquad F_c = \frac{0.6638\ lb*\not{ft}}{0.03385\ \not{ft}} \qquad F_c = 19.61\ lbs$$

$$F_{cx} = F_c * cos\emptyset\ ;\ F_{cx} = 19.61\ lbs * cos20°\ ;\ F_{cx} = 18.43\ lbs$$
$$F_{cy} = F_c * sin\emptyset\ ;\ F_{cy} = 19.61\ lbs * sin20°\ ;\ F_{cy} = 6.71\ lbs$$

$$+\uparrow \sum Fy = 0 = -2.1lb - 6.71lb + R_{1y} + R_{2y} \quad ; \quad R_{1y} + R_{2y} = 8.81lb$$
$$+\rightarrow \sum Fx = 0 = 18.43lb + R_{1x} - R_{2x} \quad ; \quad R_{1x} + R_{2x} = -18.43lb$$

$$+\circlearrowleft \sum M1 = 0 = (.208\ ft)R_{2y} - (.104ft)(2.1lb) - (.104ft)(6.71lb) - (.248ft)(18.43lb)$$
$$R_{2y} = 26.77\ lb$$

$$R_{1y} + R_{2y} = 8.81lb \quad ; \quad R_{1y} + 26.77\ lb = 8.81\ lbs \quad ; \quad R_{1y} = -17.96\ lb$$

$$+\circlearrowleft \sum Mo = 0 = (.248\ ft)R_{1x} - (.248\ ft)R_{2x} - (.104ft)(26.77lb) - (.104ft)(-17.96lb)\ ;$$
$$+\circlearrowleft \sum Mo = 0 = (.248\ ft)(-18.43 - R_{2x}) - (.248\ ft)R_{2x} - (.104ft)(26.77lb) - (.104ft)(-17.96lb)\ ;$$
$$-4.65lb * ft = 4.65lb * ft + (.248\ ft)R_{2x} - (.248\ ft)R_{2x} \quad ; \quad R_{2x} = 0\ lbs$$
$$R_{1x} + R_{2x} = -18.43lb \quad ; \quad R_{1x} + 0 = -18.43\ lbs \quad ; \quad R_{1x} = -18.43\ lbs$$

DESIGN ANALYSIS

It can be seen from the calculations of target values and FEA analysis results, that this design for the motor mounting bracket is a viable solution for attaching the motor to the cart. After constructing a mock-up from wood and attaching it to the wheel mount, it was proven that the dimensions were correct and the motor mount will rotate around the same radius as the wheel when folded in.

FACTORS OF SAFETY

For this motorized vehicle there are a few different safety factor aspects that need to be acknowledged and accounted for. The first is listed and analyzed in the above design in the Loading Conditions section of the report and is represented by Figure 10. The analysis done here was to ensure that the motor mount was designed well enough, so that it was able to withstand all stresses, torques and other forces acting upon it and still be able to fully function. As seen in Figure 10, a Safety Factor of 2 was used to run the analysis and no part of the motor was compromised.

Another safety factor to account for was the possibility of the cart tipping. Two measures were taken to ensure that this will not happen to this cart. The first was to design the cart with a low stable center of gravity to ensure that the tipping force is as high as possible. The second was to mound the handbrake and brake locking mechanism to the cart. This was done to prevent the cart from rolling, while unattended and tipping over.

The next aspect of the cart that needed to be analyzed for safety was the drive train (sprockets and chain). The factor of safety here was to mount a chain guard to the cart itself, fully covering the motor sprocket, chain and wheel sprocket. This guard prevents any pinch points that might occur from this moving apparatus, as seen in Figure 11.

Figure 11: Chain Guard

COMPONENT SELECTION

Component Selection

#	Component	Material/Product Type
1	Frame	6061 Aluminum
2	Motor	24 V 250W DC
3	Motor Mount	6061 Aluminum
4	Motor Sprocket	9 Tooth, 3/8 Bore, #25 Chain
5	Chain	#25 Chain
6	Wheel Sprocket	142 Tooth, #25 Chain
7	Solar Panels	12V 40 W
8	Solar Controllers	Max 12V 5A
9	Motor Controller	24V Variable Speed
10	Throttle	24V Variable Speed
11	Battery Housing	Waterproof Velcro Bags
12	Batteries	12V 9Ah Lithium ion
13	Fasteners	1/4-20 S Steel Bolts

Table 6: Component Selection Reference

Component selection for the design of this prototype followed the design parameters that were set from the earlier research, calculations and analysis. 6061 Aluminum was used for the frame, as well as the motor mount in order to keep the weight of the cart low, while still not sacrificing strength. Two 12 volt, 9 amp hour, lithium ion batteries were used for the power source. Lithium ion was chosen over lead acid, to again reduce weight and for more efficiency. Comparable lead acid batteries of 12 volt, 7 amp hour are double the weight of the lithium ion batteries. The reason that two 12 volt batteries were chosen, instead of one 24 volt battery was so that each battery would be charged by its own corresponding solar panel. The solar panels are light weight and foldable. Each has its own solar controller that is connected in series with the battery. This allows for the solar panel and battery subsystem to be completely removed from the cart and can be charged independently. The batteries can also be charged by a 12 volt DC trickle charger as well. The batteries were chosen to be housed in waterproof bags, secured by Velcro and a strap to provide weatherization, as well as allowing for easy removal in order to charge the batteries independently, if desired. The motor controller was selected in correspondence with the specifications of the motor, as well as the 24 volt variable speed throttle. This throttle allows the user to set their own desired pace very easily. The motor was chosen in sync with the design parameters and sprockets were then chosen to fit the motor armature, as well as gear ratio. The #25 chain was chosen in accordance with the requirements of the sprockets. Finally, Stainless Steel ¼-20 bolts were used to provide strong connections where needed.

BILL OF MATERIALS

The Bill of Materials (BOS) is the list of materials, products and items that were used in the construction of this prototype. It provides the description of the item, vendor, part number, price, quantity and total cost for analysis of the project. The BOM for this project can be seen below as Table 7.

Bill of Materials

List #	*Part*	*Qty*	*Cost/Part*	*Total Cost*	*Part Picture*
1	Sun Mountain Speed Cart V1	1	$35.00	$35.00	
2	StarkPower Deep Cycle 12V9-EP Lithium Ion Battery	2	$79.99	$159.98	
3	Koch 7425100 Roller Chain, #25, 10 Feet	1	$22.59	$22.59	
4	47 Tooth Rear Sprocket - 4 Bolt Pattern Part Number: 119-229	1	$9.99	$9.99	
5	24 Volt 250 Watt MY1016 Electric Motor with 10 Tooth #25 Chain Sprocket	1	$39.99	$39.99	
6	HB2430-TYD6-FS Razor 6-Wire Throttle & Controller Bundle	1	$37.99	$37.99	
7	24 Volt 1.5 Amp 3-Prong Battery Charger	1	$19.99	$19.99	
8	20A Reset Switch Part Number: 119-228	1	$4.99	$4.99	
9	3-Wire Charger Port Part Number: 119-223	1	$4.49	$4.49	
10	Handlebar Grips Part Number: 119-147	1	$7.99	$7.99	
11	Suaoki 40W Portable Sunpower Mono-crystalline Solar Panel	2	$134.99	$269.98	
12	Instapark INCC1205 12V / 5A Waterproof PWM Solar Charge Controller	2	$17.95	$35.90	

13	On/Off Switch with Light Indicator Part Number: 119-217	1	$5.49	$5.49	
14	Chain Guard Part Number: 119-171	1	$5.99	$5.99	
15	Everbilt 2 in. x 36 in. 6061 Aluminum Flat Bar with 1/8 in. Thick	1	$10.21	$10.21	
16	Midwest Steel Supply 6061 Aluminum Flat Bar (.75 x 2.5 x 5) in.	1	$9.67	$9.67	
17	1-Gang Deep Extra Duty Non-Metallic While-In-Use Weatherproof Horizontal/Vertical Receptacle Cover, Clear	1	$14.93	$14.93	
18	Southwire 25 ft. 16 Red Stranded CU Primary Wire	1	$5.20	$5.20	
19	1 in. EMT Conduit	1	$6.89	$6.89	
20	Everbilt 1/4 in.-20 x 1/2 in. One-Way Round-Head Machine Screws (2-Pack)	4	$1.18	$4.72	
21	Everbilt 5/16 in. x 12 in. Stainless Steel Threaded Rod	1	$5.78	$5.78	
22	Everbilt 5/8 in. Zinc-Plated Cut Washer	2	$0.33	$0.66	
23	Everbilt 5/16 in. Stainless-Steel Hex Nut	2	$0.32	$0.64	
24	Everbilt 1/4 in.-20 tpi Zinc-Plated Nylon Lock Nut (2-Piece per Pack)	2	$1.18	$2.36	
25	Everbilt 1/4 in. Zinc-Plated Flat Washer (25-Piece per Bag)	1	$2.46	$2.46	
26	VELCRO Brand 4 in. x 2 in. Industrial Strength Extreme Strip, Black	1	$4.17	$4.17	
27	Tyco Electronics 0.250 Series 16-14 AWG 10/Clam Female Disconnect Fully Insulated Nylon	1	$3.18	$3.18	
28	PACKiT Freezable Mini Lunch Bag, Black (PKT-MC-BLA)	2	$3.50	$7.00	
Total				***$738.23***	

Table 7: Bill of Materials (BOM)

FABRICATION & ASSEMBLY

FABRICATION & MODIFICATIONS

The first part of the fabrication for this prototype, was machining, drilling and tapping the motor mount base, as seen in Figure 12.

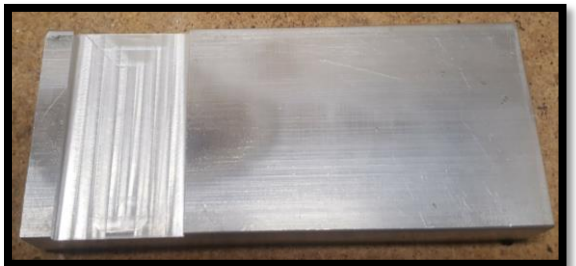

Figure 12: Motor Mount Base Fabrication

The 1.5 in. notch was milled 1/8 in. deep. This allows for the U bracket of the mount to sit flush with the bottom of the base. Next, the single 5/16 in. hole was drilled and tapped though the notch and the top of the base, to provide a means of securing the U bracket, base and wheel mount. The last step was to drill and tap the four ¼ - 20 holes in the side of the base for the motor to be mounted.

The U bracket was fabricated next for the mount. The U bracket began as a flat piece of 6061 Aluminum flat bar stock and was cold worked to get the shape necessary as seen in Figure 13. A pipe with the same radius as the wheel mount was placed in the vice along with the aluminum. The Aluminum was then bent around the radius of the pipe and various other clamps were used to keep the radius as tight as possible. When the radius became close to that of the pipe, any imperfections and gaps were hammered out until it became flush. The Bracket was then drilled and tapped with the 5/16 in. tap. Once this was complete, the parts were painted, and ready to be assembled.

Figure 13: U Bracket Fabrication

ASSEMBLY

The motor mount was then assembled using the 5/16 bolt, four ¼-20 bolts, nuts and washers and attached to the wheel mount, as seen in Figure 14.

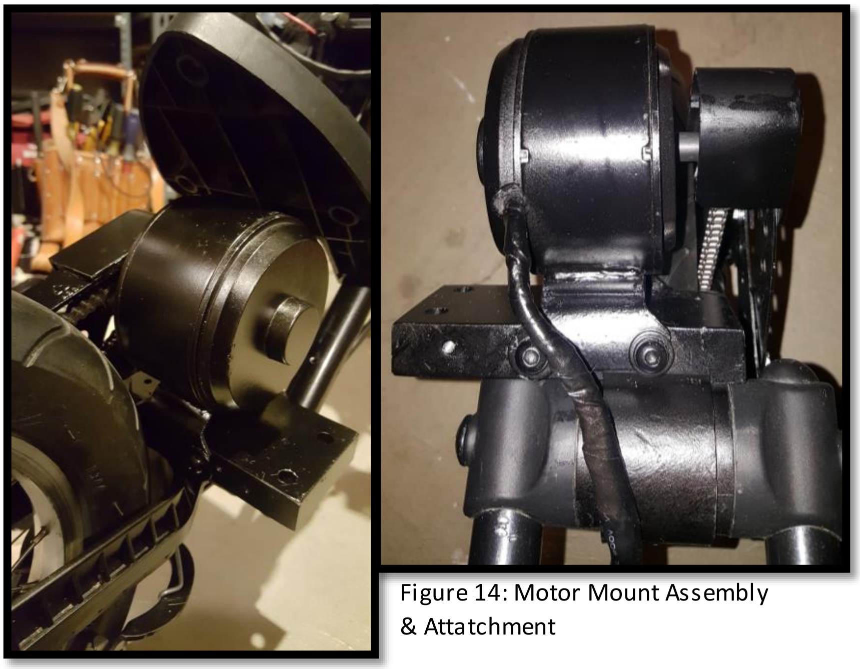

Figure 14: Motor Mount Assembly & Attatchment

Next, the sprockets were both mounted to the motor, as well as the wheel. The motor sprocket was attached using a keyseat, while the wheel sprocket was mounted using S Steel recessed bolts. The chain was then installed and the wheel mounted to the wheel mount using its axle and nuts. Once everything was in place and aligned, the chain guard was installed. All of this seen in Figure 15.

Figure 15: Wheel, Sprocket, Chain & Guard

The next step in this assembly process was to determine the wiring for all of the electrical components. The final wiring diagram can be seen below in Figure 16. All components flow into the motor controller, besides the solar panels (not included in diagram), which are individually wired in series to each battery.

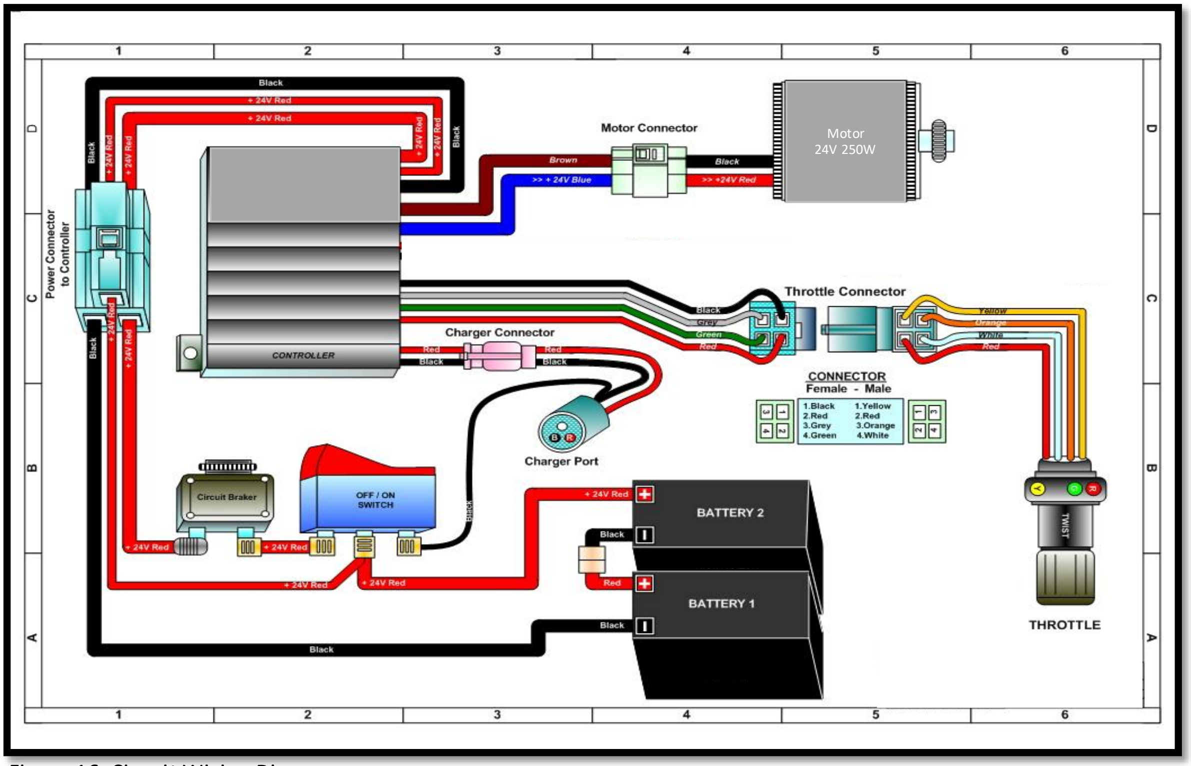

Figure 16: Circuit Wiring Diagram

The next step, was to assemble the circuit box that would house the motor controller, wiring, power switch, charging port and circuit breaker. First, holes needed to be drilled in the side of the box to mount the switch, charge port and breaker. The box was then painted and components mounted. Which can be seen in Figure 17.

Figure 17: Mounted Box Components

Next, the controller was mounted inside the circuit box, and the box was then mounted onto the frame of the cart using four 1/4 -20 screws. This can be seen in Figure 18, below.

Figure 18: Mounted Contoller

After this was completed, the handlebars were mounted to the top of the cart using 1/4 -20 bolts. The variable speed throttle was then mounted, and the grips after that, as seen in Figure 19.

Figure 19: Mounted Handlebars & Throttle

The final step for the assembly, was to mount the solar panels & batteries to the cart and complete the wiring connections. The batteries and bags were mounted to each side of the cart using the bag strap and Velcro. The solar Panels were then mounted to each side using, two carabiners per panel, one at the handle bars and the other at the bottom bag rest. They are then secured with Velcro underneath the handlebars. The solar controllers were then wired to each panel and then to the batteries, where they are housed. Once this was complete the rest of the wiring connections were made and the assembly was complete. Figure 20 below, displays the cart with one of the panels mounted, and the completed cart in Figure 21.

Figure 20: Mounted Panel

Figure 21: Completed Cart

PROJECT MANAGEMENT

BUDGET (PROPOSED/ACTUAL)

The entire budget for this project, was self-funded, so the ceiling cost for the project was set at $1,200.00. The percent cost estimates were then distributed to each subsystem and then the dollar amounted calculated from these estimates.

The original proposed budget (seen in Table 8), was constructed at the beginning of the project and provides a researched estimate cost for each subsystem of the prototype, as well as a total cost. The cost of labor was omitted from these projections. Although, $1,200.00 was set aside for the project, there was still a goal to keep costs at a minimum, as long as overall performance and safety were not compromised.

The actual cost of the prototype and its corresponding subsystems can be found in Table 8. This table reflects the actual dollar amount spent on each subsystem, along with percentages and the final total cost of the prototype.

Budget** - Proposed* ***$1,200.00

Subsystem	*Budget Percentage*	*Budget Dollar Amount*
Frame & Modifications (+ Motor Mount)	20%	$240.00
Motor & Drivetrain	15%	$180.00
Batteries	25%	$300.00
Solar Panels & Controllers	30%	$360.00
Controller (+Throttle)	10%	$120.00
Total	***100%***	***$1,200.00***

Table 8: Proposed Budget

Budget** - Actual* ***$738.23

Subsystem	*Budget Percentage*	*Budget Dollar Amount*
Frame & Modifications (+ Motor Mount)	16.05%	$118.47
Motor & Drivetrain	9.83%	$72.57
Batteries	21.67%	$159.98
Solar Panels & Controllers	41.43%	$305.88
Controller (+Throttle)	11.02%	$81.33
Total	***100%***	***$738.23***

Table 9: Actual Budget

As it can be seen from the two tables, the actual cost of the prototype was $738.23, which is much lower than the proposed cost. This actual total cost of $738.23 is a justifiable cost for this prototype and even a little higher would have been acceptable. The actual manufacturing cost of this cart would lower than this because, the manufacturing materials would be bought in bulk or constructed onsite and not from retail stores and websites. Overall, the cost of this project was well within the acceptable range.

SCHEDULE (PROPOSED/ACTUAL)

The time frame, proposed schedule and actual schedule can be seen in Table 10 below. This graph shows the initial proposed schedule that was constructed during the first few weeks of the project, as well as the actual schedule that took place over the course of the project.

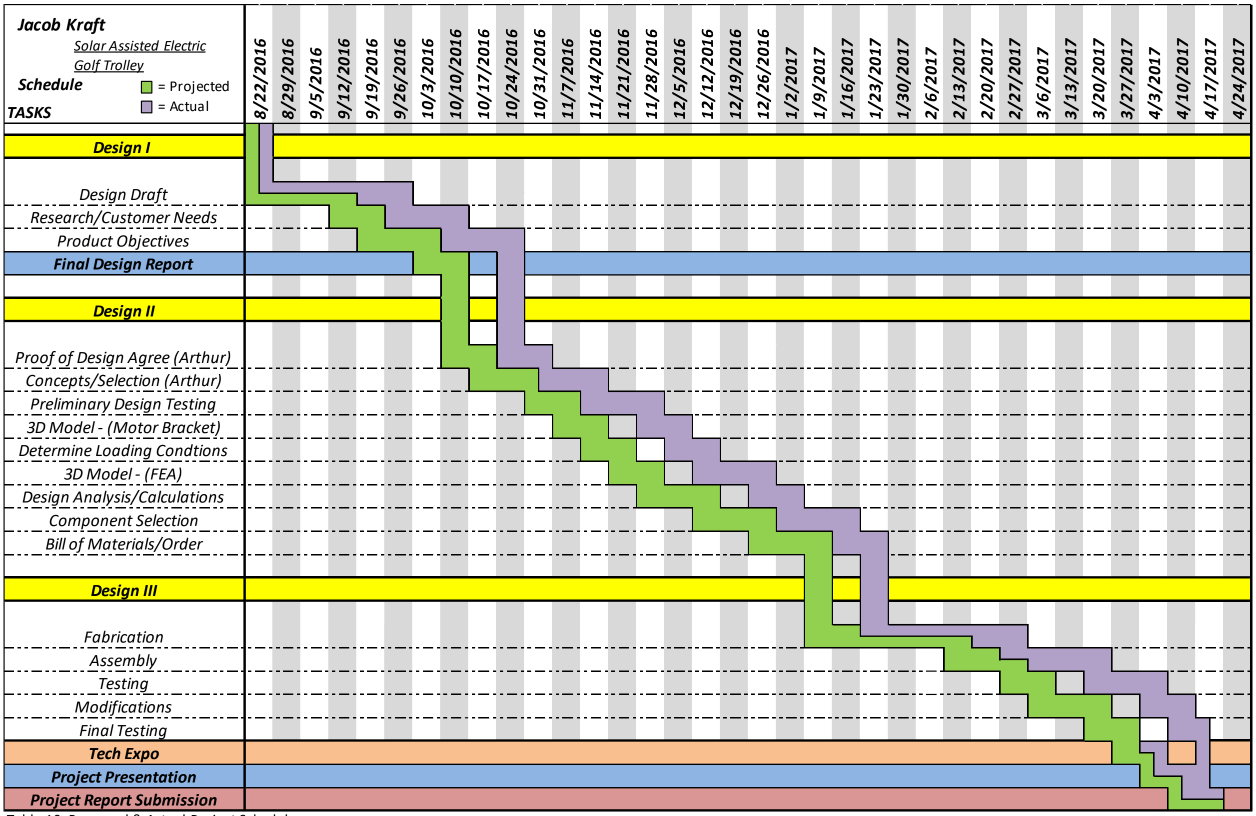

Table 10: Proposed & Actual Project Schedule

The timespan for this project took place from the beginning of the first semester of senior year (August 22nd, 2016), until the end of the second semester (April 4th, 2017). The graph is broken weekly with each column representing one week and the date of the first day of that week as the column heading. The left represents project progression, using significant steps throughout the products design. Design I, II and III, are the senior design courses in the MET curriculum. Design I and II, each were half of the first semester, while Design III covered the entire second semester. The green path on this graph represents the projected schedule and completion dates. This was constructed during the first few weeks of the project and was the ideal schedule goal and path to completion. The purple path represents the actual length of time each section of the project took, as well as the start and completion dates. It can be seen that the actual path doesn't follow the proposed schedule throughout the project, which can be expected with any project. There were some unforeseen setbacks that put the actual time schedule a little behind the proposed.

PRODUCT TESTING & RESULTS

FIELD TESTING

This prototype was tested in a few different ways, aiming to validate three main criteria. The first test that took place was done in order to test this designs number one objective. This was to test if the cart can carry a golf bag for thirty-six holes of golf, without needing to be plugged into an outlet charger. The secondary goal of this test was to identify and address any issues that the cart might have during extended operation. This testing took place on Saturday, April 8th, and Sunday, April 9th at Miamiview Golf Club. The testing was done on two separate dates in order to simulate real life conditions, by not playing thirty-six holes consecutively. Before the first round the batteries were charged to full capacity by using the outlet charger.

The second test that took place for this product was aimed to establish the effectiveness of the solar panels on the battery's state of charge. This test was carried out by first, elevating the front driving wheel of the cart off of the ground and then opening the throttle completely and fixating there so that motor was running at full rpm (seen in Figure 22). The batteries were charged to full capacity before the test and open circuit voltage checked. The test was then ran for two iterations of two hours. The first test used the solar panels, while the second did not. In between the tests the batteries were charged to full capacity and checked again to endure both iterations started with the same charge. Once the second test had concluded, both test ending voltages were recorded, referenced to the state of charge and open circuit voltage reference chart corresponding to these batteries, and compared.

Figure 22: Battery Charge Testing

In order to establish that the cart did indeed meet the project objective for the folded volume of the cart, the cart was measured while folded and its volume calculated. Figure 23 displays the cart in its folded state.

Figure 23: Folded Cart

The last test that took place was to ensure that the prototype was below or met the weight objective for the design. This was done by simply placing the cart on a scale, weighing it, recording the value and comparing the results.

RESULTS/CONCLUSION

The Solar Assisted Electric Golf Trolley performed as expected and either achieved or surpassed the main objectives set for the project. The cart runs smoothly and is easy to maneuver and is able to easily handle the extra weight from the golf bag. The results from the first test of playing thirty-six holes of golf were positive. The cart was able to achieve number one objective from the design of playing thirty-six holes of golf with a golf bag, without require a plug in charge. The cart also, operated those holes with little to no operational issues. The only issue that became apparent during the test, was that the chain guard would sometimes vibrate and contact the chain slightly, over rough terrain. This issue was easily fixed after this by adding another support to the guard, which supported it better.

The results from the battery state of charge test were positive as well. At the conclusion of this test, where the motor had run for two consecutive hours at full rpm, the open circuit voltage was measured and recorded for both trials. This can be seen in Figure 24, below.

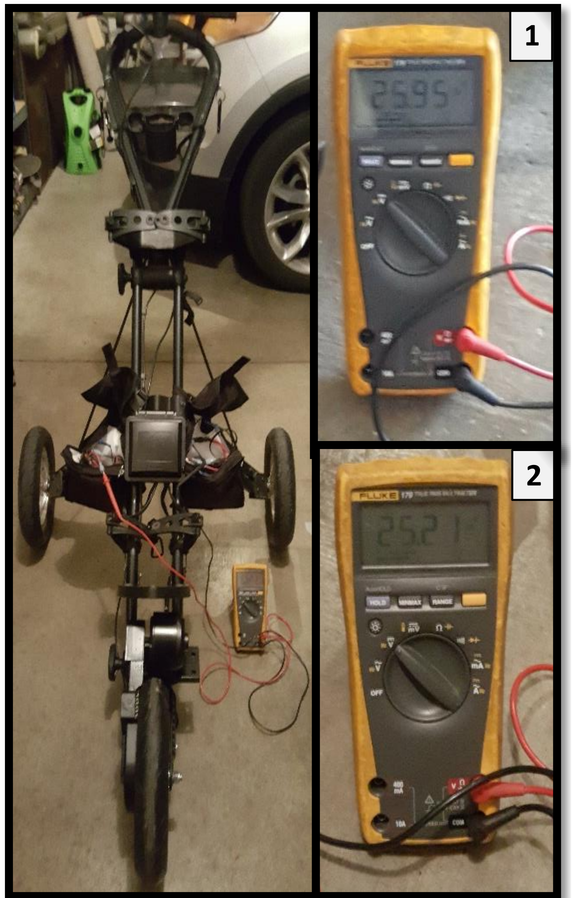

Figure 24: Battery Charge Test Results

Before each iteration of the test was ran, the batteries were charged to full capacity and tested to ensure they began at the same voltage. The fully charges open circuit voltage of the batteries was 25.98 volts. In the above Figure, the first voltmeter reading of 25.95 volts, is the result from the first iteration, when solar panels were used. The second reading of 25.21 volts, is the result of the second iteration, when the panels were not used. These two values were then translated into corresponding values for battery state of charge using the chart rated for these batteries (Appendix A). The percent charge of the batteries after the first iteration was only .3 volts less than full charge, which is almost 100% charged. The percent charge from the second iteration of around 62% charged.

For the last tests that took place, the results of the cart achieved the design objectives as well. Once the cart was measured in its folded state, the volume was calculated. The objective for this parameter was to be below four and a half cubic feet and the calculations returned a value of 2.97 cubic feet. Also, the target weight for the cart design was set to be at 35 lbs. or less. The cart was weighed five times to account for any fluctuation and the weight of the cart was recorded at 31 lbs. A summary table of results can be found in Appendix A.

The performance of the cart was well above satisfactory. The cart met all of the design expectations and objectives and even surpassed some. Some of the results were to be expected, while some were not. The result that was most surprising was that from the first iteration of the second test. I was surprised to see that the solar panels were able to keep the batteries at almost 100% charge after the motor had been running at full rpm for two hours.

Overall I believe that the performance of the cart exceeded the design criteria and with a few alterations, could be a successful market product.

PLAN TO FINISH

There is one modification that I would like to make to the cart, in order for it to be complete. In order for the user to have the ability to easily attach and detach the panels from the cart, the panels are mounted with clips and Velcro. I would still like to keep the operation of attaching and detaching the panels, simple, but I would also like to design a small mount for them. The mount would be small and nonintrusive, but would be sturdy enough to allow the user to position the panels instead of just letting them rest over the bad and cart. To maintain ease of use for the panel attaching, there would be only one attachment for the mount and it would also have the ability to fold in, when not in use.

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APPENDIX A – RESULTS SUMMARY

Battery Reference Chart

Percent Charge	Open Circuit Voltage
100%	25.98
90%	25.76
80%	25.54
70%	25.32
60%	25.18
50%	24.96
40%	24.54
30%	24.32
20%	23.9

Results

Objective/Test	Mesurement Units	Original Value	Target	Result
≥ 36 Holes Without Battery Charge	Holes		36	36
Folded Volume Under 4.5 ft^3	ft^3	2.8	4.5	2.97
Variable Motor Speed	(Y/N)		Y	Y
Weight ≤ 35 lbs	lbs	17.6	35	31
Batteries & Solar Panels Detachable	(Y/N)		Y	Y
2 Hour Open Throttle Test	% Charge		80	99

APPENDIX B – SURVEY RESULTS

Golfer Questionnaire

Results

Taken: Sat. Nov. 19th, 2016

20 Total People Questioned

15 Men

5 Women

1.) How many clubs to do carry in your bag?

- 12 : 0
- 13 : 2
- 14 : 13
- >14 : 3

2 Didn't Know

2.) Do you leave you clubs in your car after every round or do you store them in your house?

- Car : 16
- House : 4

3.) Have you ever thought about buying an electric powered push cart?

- Yes :
- No : 4

4.) Which of these 4 aspects would be most important to you if you were looking to buy one?

- Amount of rounds before charge : 9
- Size of Folded Cart : 5
- Follows you (No Input Needed) : 1
- Weight of Cart : 5

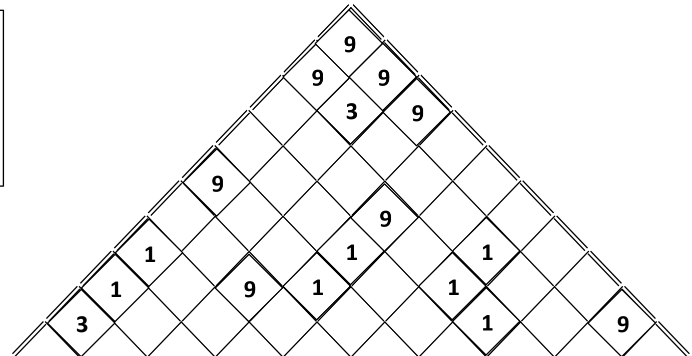
5.) Are there any features that you think would compliment a motorized pushcart?

USB Port For Charging Electronics

Seat

APPENDIX C - QFD

Quality **F**unction **D**eployment
for
The Solar Assisted Electric Golf Trolley



	Customer Requirements	Importance wt.	Weight (lbs)	Speed (ft/s)	Time Between Charges (holes)	Assembly Time (s)	Solar Panel Charge (Amps)	Frame Material	Pinch Points (Y/N)	Folded Size (ft^3)	Hill Climbing (°)	Motor Torque (lb-ft)	Customer Satisfaction Rating (0.00 - 1.00)
			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**A**
1	Variable Motor Speed	0.15	1	9	3		1	1			3	9	0.9
2	≥ 36 Holes Without Charge	0.23	3	3	9		9	1			1	3	1
3	Folded Size Under 4.5 ft^3	0.18	1			3		1	1	9			1
4	Batteries & Panels Detachable	0.10	3		9	9		1	1	9			0.80
5	Climbs Hills of ≤ 12°	0.05	3	3	3		1	1			9	9	0.6
6	Safe to Use	0.08	3	3				1	9		3	3	0.7
7	Weighs Less Than 35 lbs.	0.10	9			1		9		1			0.9
8	Doesn't Tip	0.05	3					1			9		0.8
9	Durable	0.06	3					9			1		0.7
	Total Importance	**1.00**	**2.94**	**2.43**	**3.57**	**1.54**	**2.27**	**2.28**	**1**	**2.62**	**1.88**	**2.73**	**23.3**
	Engineering Requirement %		12.64%	10.45%	15.35%	6.62%	9.76%	9.80%	4.30%	11.26%	8.08%	11.74%	

Engineering Requirements (units)

APPENDIX D – FORCE TESTING RESULTS

Fish Scale Testing Results

Iteration #	Force to Move Cart from Rest (lb_f)	Estimated Avg. of Force while Pushing for 5 sec. (lb_f)
1	5.5	3
2	7	3.5
3	6.5	3.5
4	7.5	3
5	8	4
6	6.5	3.5
7	7	4
8	7	5
9	7.5	4.5
10	8	5.5
11	6	4
12	7.5	4.5
13	6	3
14	6	3.5
15	7.5	5
16	7	5.5
17	6	4
18	7	4.5
19	8	4.5
20	7	5
21	5.5	4
22	6	3.5
23	7.5	4.5
24	5	3
25	6.5	4
26	6	4
27	5.5	4.5
28	7	5
29	6	2.5
30	8	5
Average	**6.72**	**4.1**

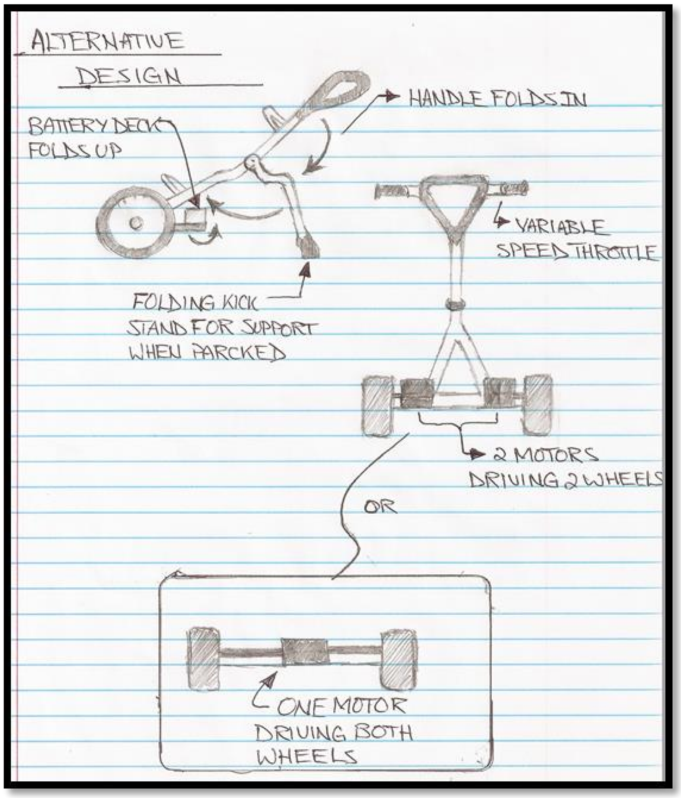
APPENDIX E - OBJECTIVES

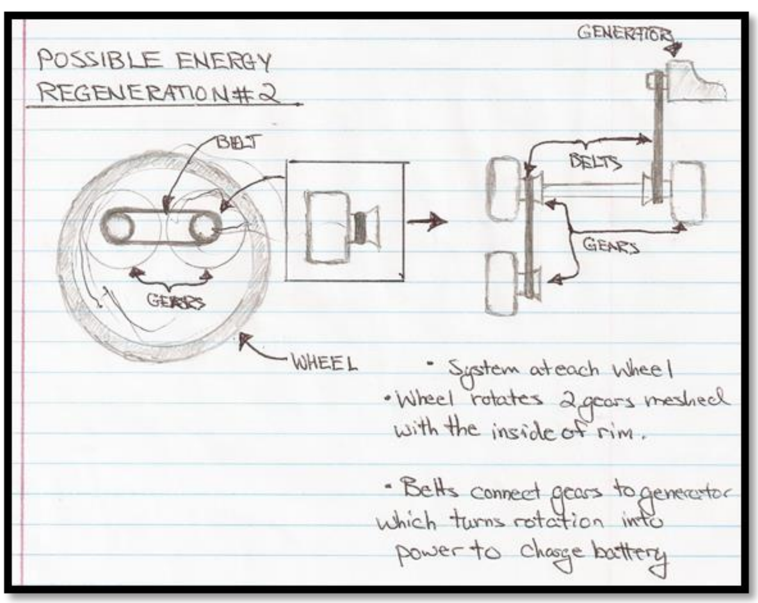
OBJECTIVES

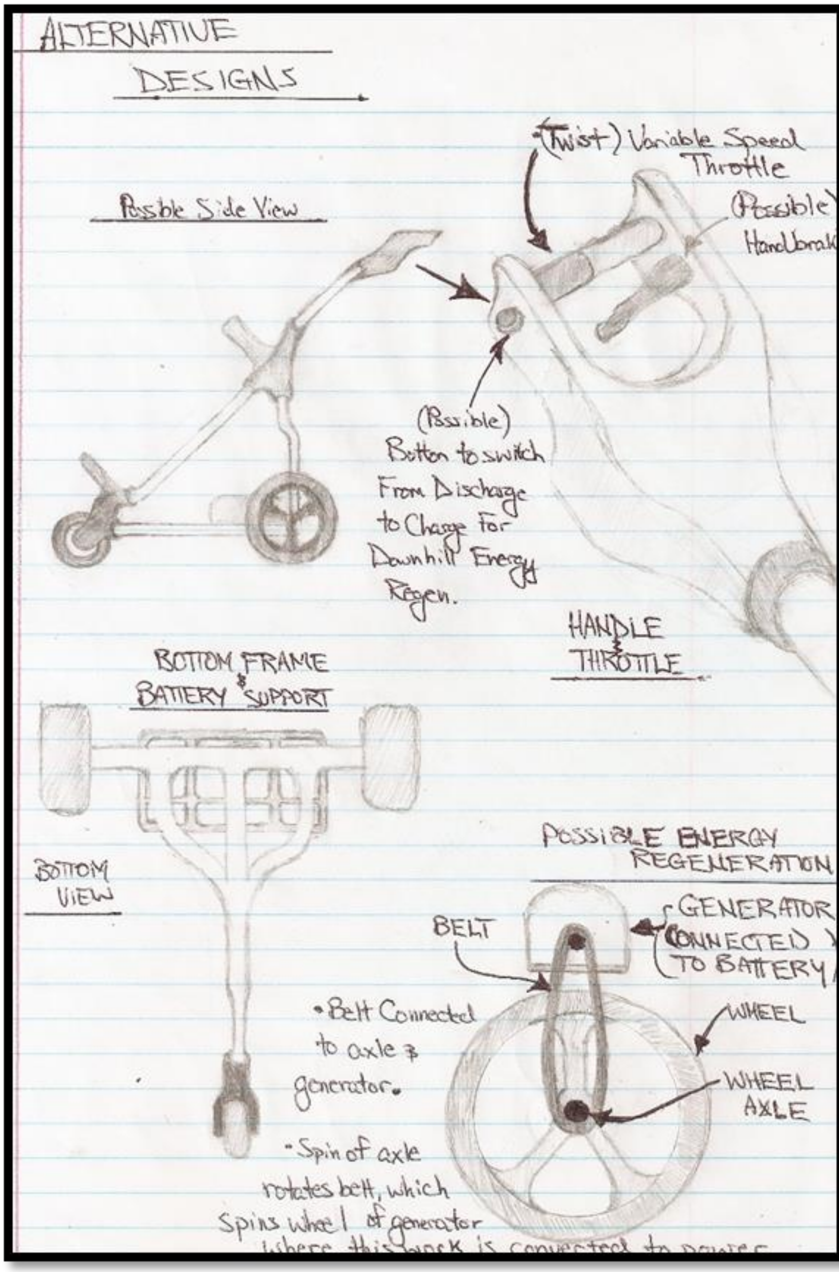
Objectives for the project are a set of design parameters that are the resultant from analysis of the customer questionnaire, as well as analysis of market research. The subsequent list of top five objectives results from these analyses, with corresponding design weights and possible strategies to obtain them.

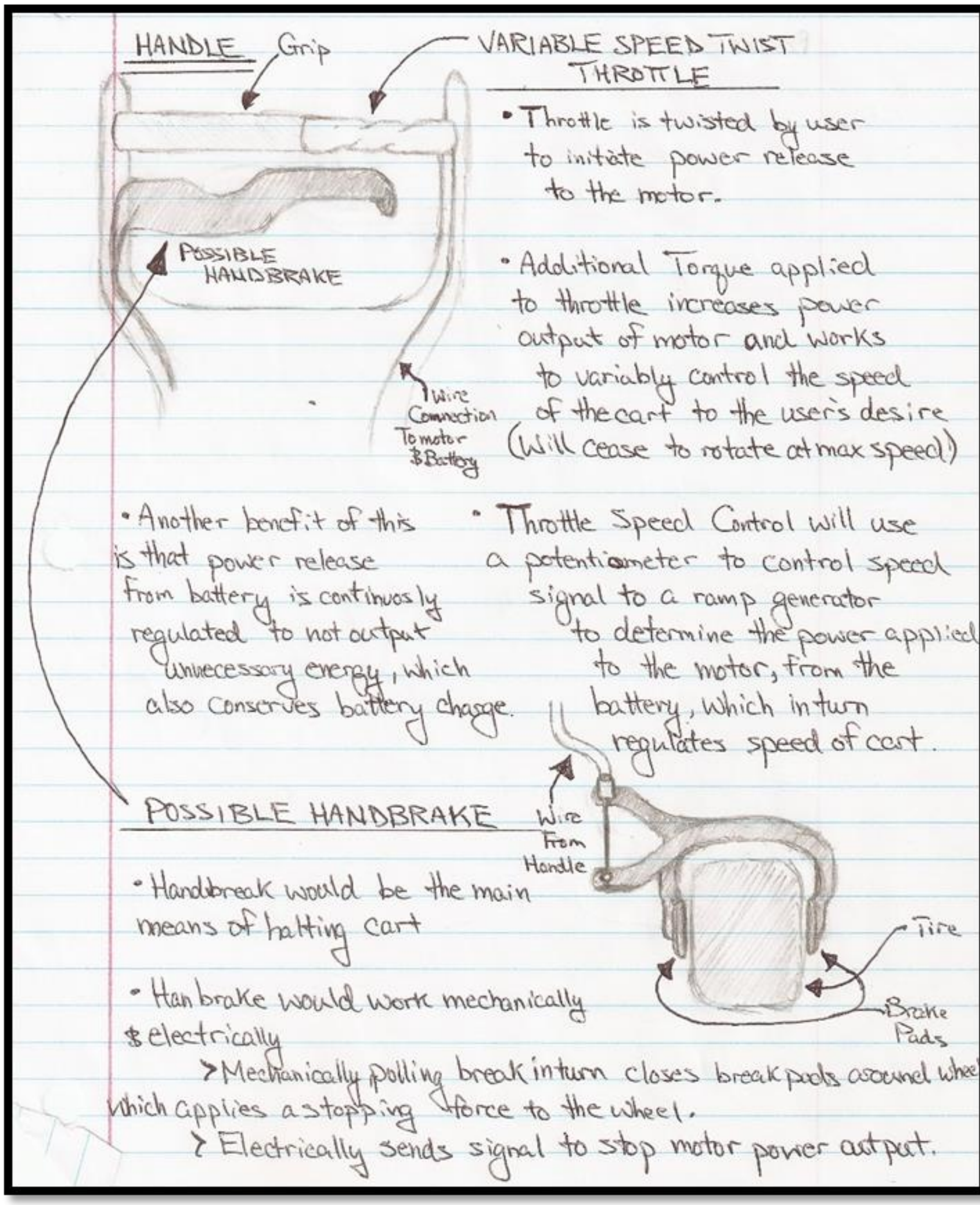
6. ***Safe to Use*** — ***8%***
    - **a.** No pinch points
    - **b.** Design cart for stability
7. ***Durable*** — ***6%***
    - **a.** Use corrosion resistant material and coating
    - **b.** Securely house motor
    - **c.** Cover solar panels
8. ***Able to Climb Hills ≤ 12°*** — ***5%***
    - **a**. Design cart with enough torque to climb hills
    - **b**. Design cart for stability on slopes
9. ***Doesn't Tip*** — ***5%***
    - **a**. Design cart for stability
    - **b**. Ensure center of gravity is centered and low

APPENDIX F – ALTERNATIVE DESIGNS & PART DRAWINGS






ALTERNATIVE
DESIGNS
(Twist) Variable Speed
Throttle
Possible Side View
(Possible)
Handbrak
(Possible)
Button to switch
From Discharge
to Charge For
Downhill Energy
Regen.
HANDLE
&
THROTTLE
BOTTOM FRAME
&
BATTERY SUPPORT
POSSIBLE ENERGY
REGENERATION
BOTTOM
VIEW
BELT
GENERATOR
CONNECTED
TO BATTERY
• Belt Connected
to axle &
generator.
WHEEL
WHEEL
AXLE
• Spin of axle
rotates belt, which
spins wheel of generator



HANDLE Grip

VARIABLE SPEED TWIST THROTTLE

• Throttle is twisted by user to initiate power release to the motor.

POSSIBLE HANDBRAKE

• Additional Torque applied to throttle increases power output of motor and works to variably control the speed of the cart to the user's desire (Will cease to rotate at max speed)

Wire Connection To motor & Battery

• Another benefit of this is that power release from battery is continuosly regulated to not output unnecessary energy, which also conserves battery charge.

• Throttle Speed Control will use a potentiometer to control speed signal to a ramp generator to determine the power applied to the motor, from the battery, which in turn regulates speed of cart.

POSSIBLE HANDBRAKE

Wire From Handle

• Handbreak would be the main means of halting cart

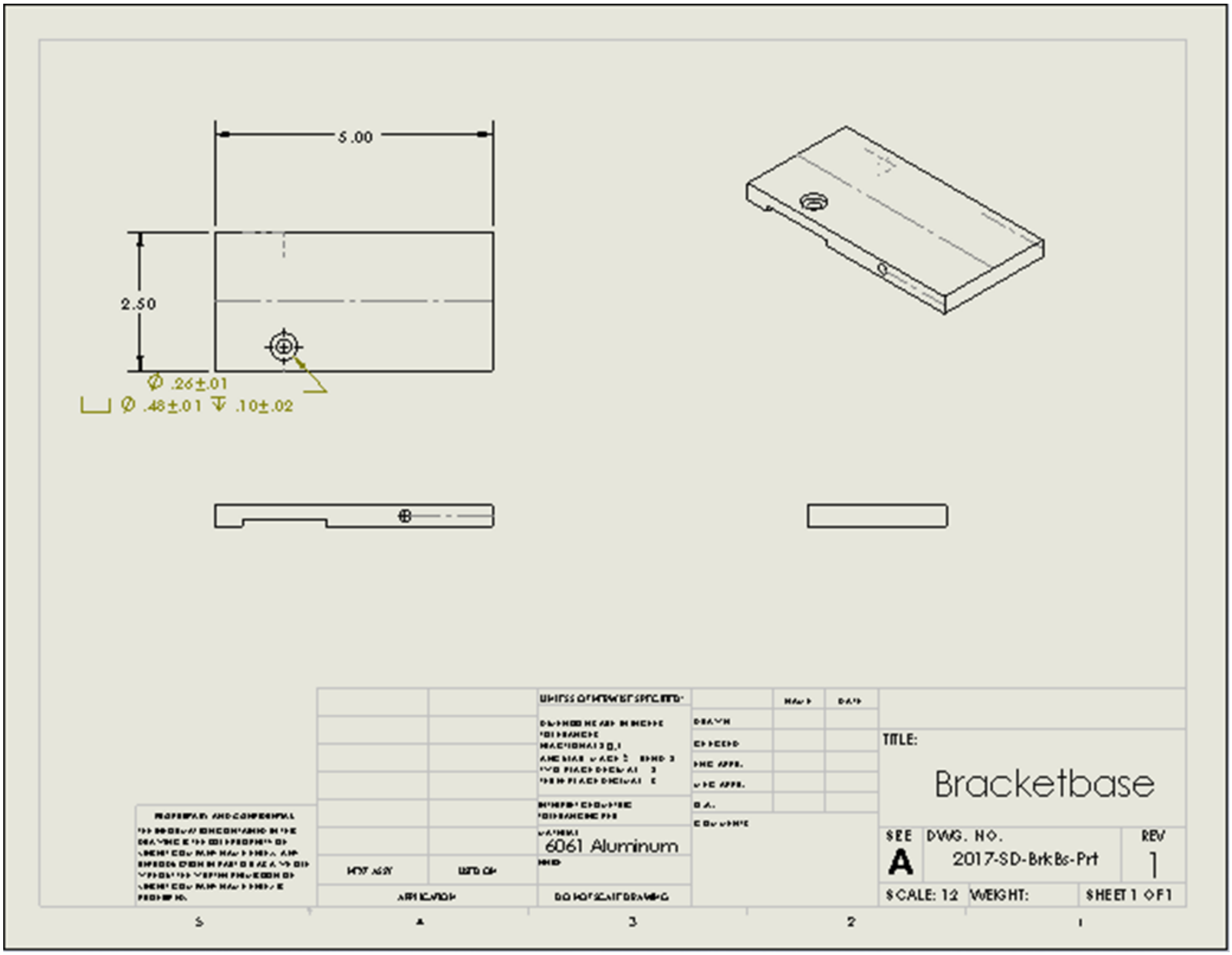
• Han brake would work mechanically & electrically

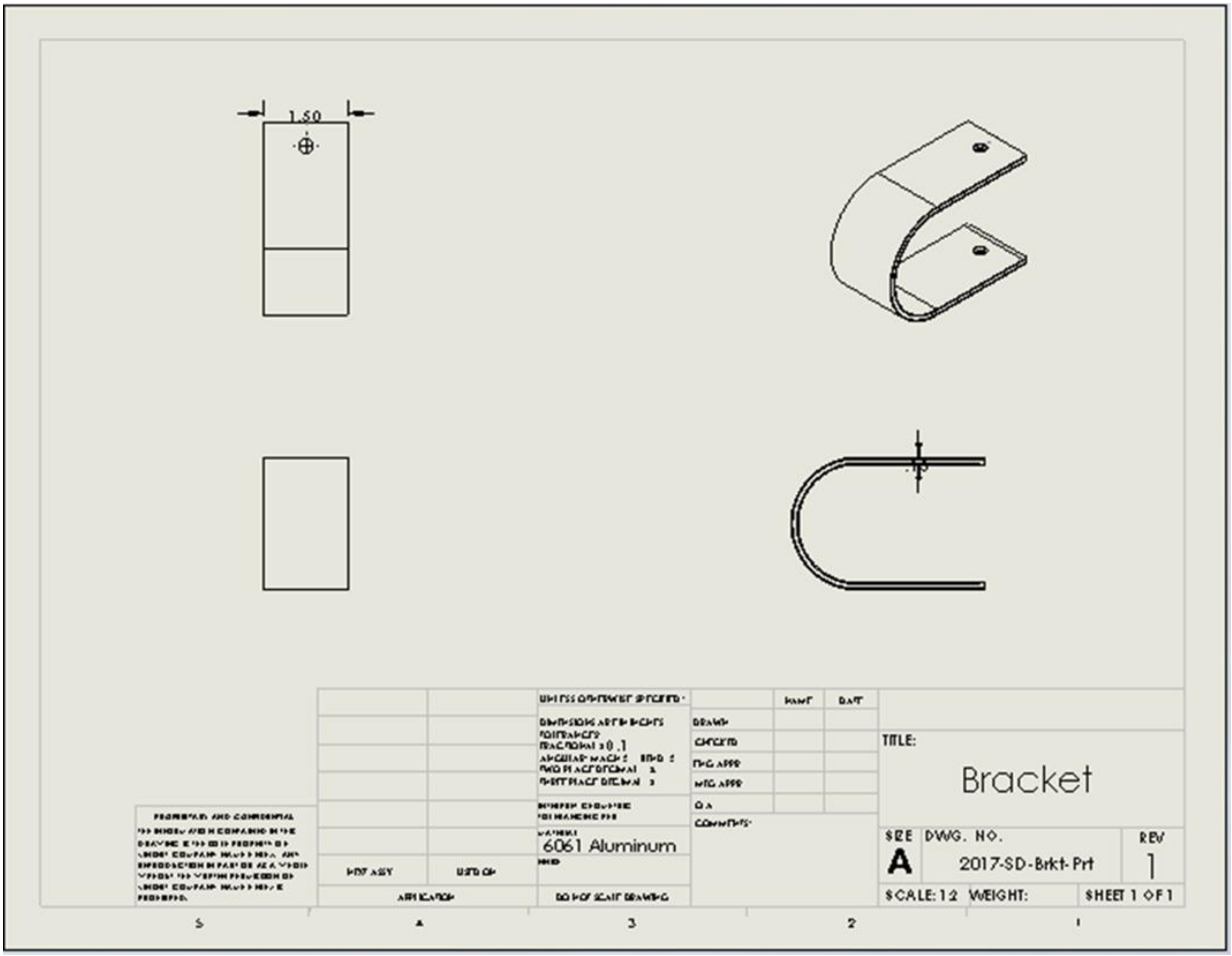
Tire

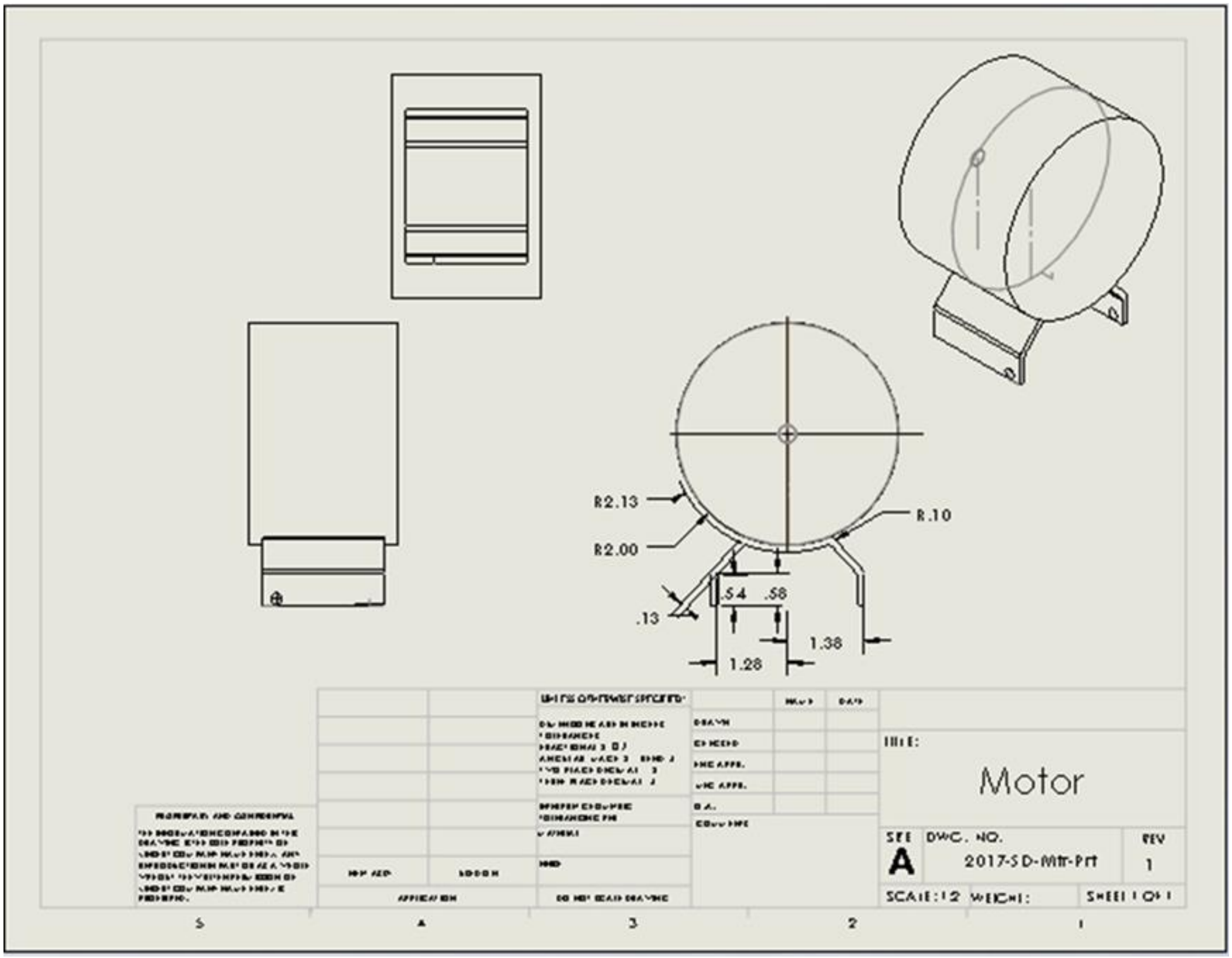
Brake Pads

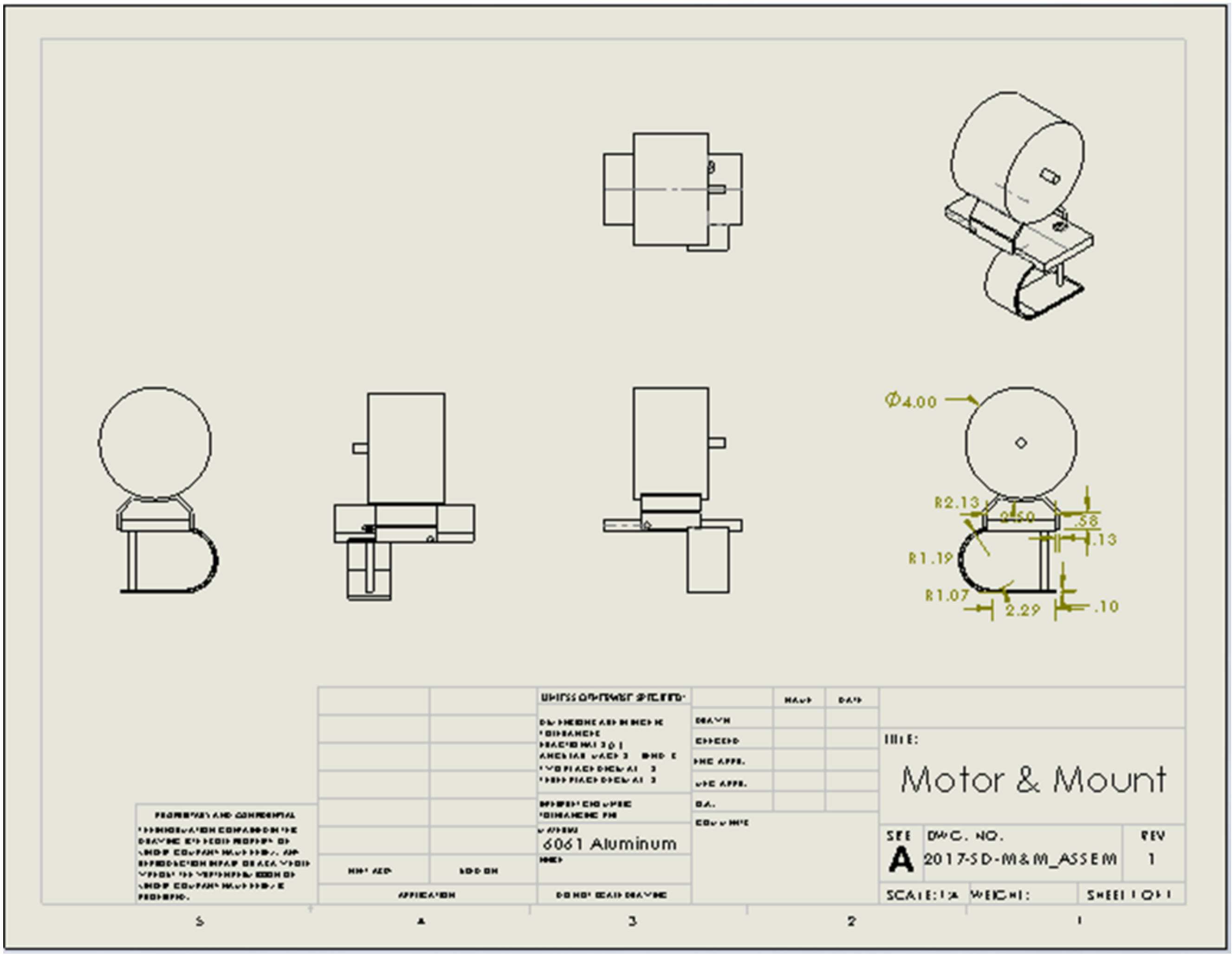
> Mechanically polling break in turn closes break pads around wheel which applies a stopping force to the wheel.

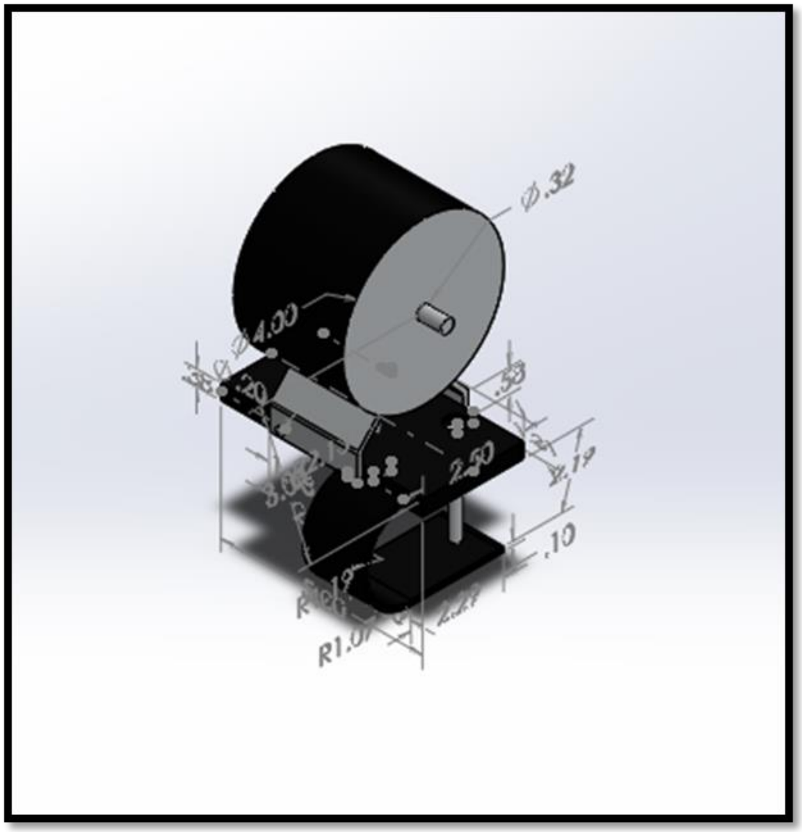
> Electrically sends signal to stop motor power output.


5.00
2.50
Ø .26±.01
⌴ Ø .48±.01 ↧ .10±.02
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
MATERIAL
6061 Aluminum
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Bracketbase
SIZE
A
DWG. NO.
2017-SD-BrkBs-Prt
REV
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

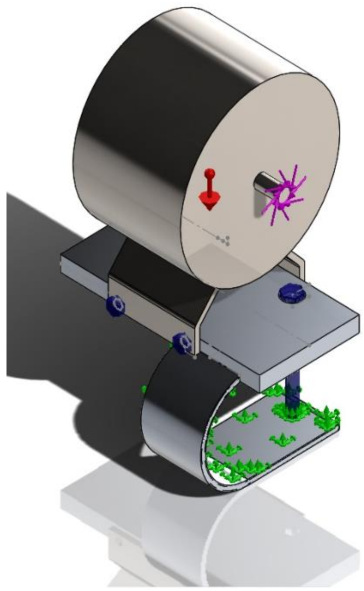

1.50
6061 Aluminum
TITLE:
Bracket
SIZE
A
DWG. NO.
2017-SD-Brkt-Prt
REV
1
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


R2.13
R2.00
R.10
.13
.54
.58
1.38
1.28
TITLE:
Motor
SIZE
A
DWG. NO.
2017-SD-Mtr-Prt
REV
1
SCALE:1:2
WEIGHT:
SHEET 1 OF 1


Ø4.00
R2.13
2.50
.58
.13
R1.19
R1.07
2.29
.10
UNLESS OTHERWISE SPECIFIED:
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Motor & Mount
6061 Aluminum
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
2017-SD-M&M_ASSEM
REV
1
WEIGHT:
SHEET 1 OF 1

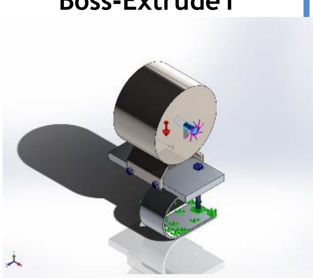

Ø.32
Ø4.00
.20
.53
2.50
2.19
.10
R1.07

APPENDIX G – FEA ANALYSIS & REPORT

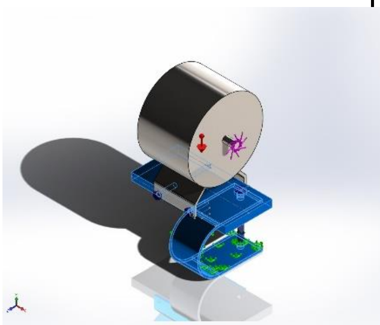
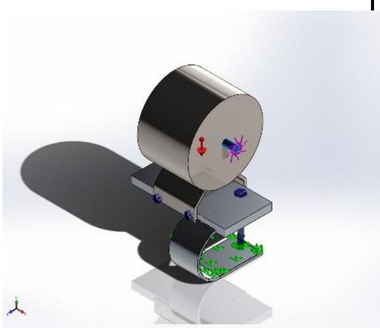
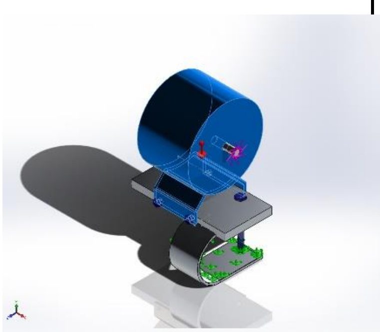


Model name: FEA
Current Configuration: Default

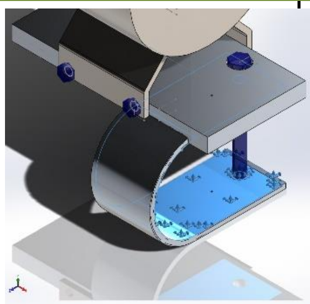
Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Tap Drill for 5/16-18 Tap1[2]	Solid Body	Mass:0.0532139 kg Volume:1.97089e-005 m^3 Density:2700 kg/m^3 Weight:0.521497 N	\\clusterfsnew.ceas1.uc.edu\students\kraftjt\desktop\New folder\Bracket.SLDPRT Apr 19 14:54:58 2017
Tap Drill for 1/4-20 Tap4	Solid Body	Mass:0.182256 kg Volume:6.75021e-005 m^3 Density:2700 kg/m^3 Weight:1.7861 N	\\clusterfsnew.ceas1.uc.edu\students\kraftjt\desktop\New folder\Bracketbase.SLDPRT Apr 19 15:08:34 2017
Boss-Extrude1 	Solid Body	Mass:0.0124972 kg Volume:1.5569e-006 m^3 Density:8027 kg/m^3 Weight:0.122473 N	\\clusterfsnew.ceas1.uc.edu\students\kraftjt\desktop\New folder\motor arm.SLDPRT Apr 19 12:38:11 2017

Material Properties

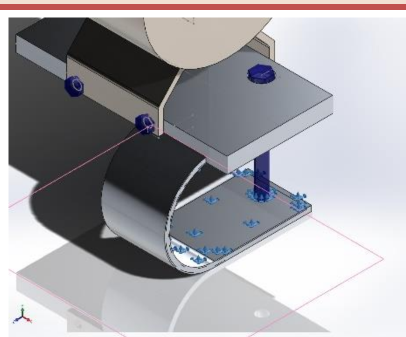
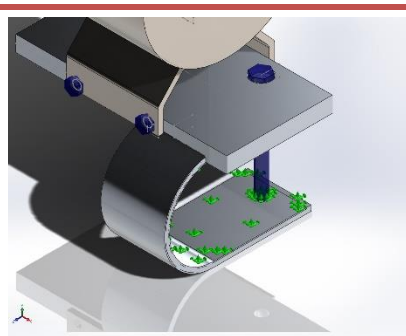
Model Reference	Properties	Components
	Name: 6061-T6 (SS) Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 2.75e+008 N/m^2 Tensile strength: 3.1e+008 N/m^2 Elastic modulus: 6.9e+010 N/m^2 Poisson's ratio: 0.33 Mass density: 2700 kg/m^3 Shear modulus: 2.6e+010 N/m^2 Thermal expansion coefficient: 2.4e-005 /Kelvin	SolidBody 1(Tap Drill for 5/16-18 Tap1[2])(Bracket-1), SolidBody 2(Tap Drill for 5/16-18 Tap1[1])(Bracket-1), SolidBody 1(Tap Drill for 1/4-20 Tap4)(Bracketbase-1)
Curve Data:N/A		
	Name: AISI Type 316L stainless steel Model type: Linear Elastic Isotropic Default failure criterion: Unknown Yield strength: 1.7e+008 N/m^2 Tensile strength: 4.85e+008 N/m^2 Elastic modulus: 2e+011 N/m^2 Poisson's ratio: 0.265 Mass density: 8027 kg/m^3 Shear modulus: 8.2e+010 N/m^2 Thermal expansion coefficient: 1.7e-005 /Kelvin	SolidBody 1(Boss-Extrude1)(motor arm-1)
Curve Data:N/A		
	Name: Alloy Steel Model type: Linear Elastic Isotropic Default failure criterion: Max von Mises Stress Yield strength: 6.20422e+008 N/m^2 Tensile strength: 7.23826e+008 N/m^2 Elastic modulus: 2.1e+011 N/m^2 Poisson's ratio: 0.28 Mass density: 7700 kg/m^3 Shear modulus: 7.9e+010 N/m^2 Thermal expansion coefficient: 1.3e-005 /Kelvin	SolidBody 1(Tap Drill for 1/4-20 Tap2)(motor-1)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 3 face(s) **Type:** Fixed Geometry

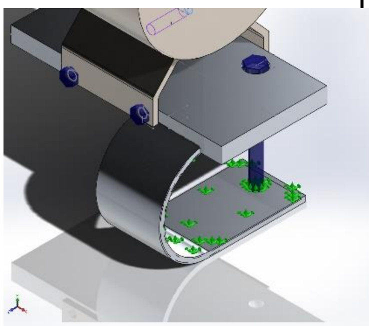
Resultant Forces

Components	X	Y	Z
Reaction force(N)	1.84774e-006	53.6764	-15.2713
Reaction Moment(N.m)	0	0	0

Load name	Load Image	Load Details
Gravity-1		**Reference:** Top Plane **Values:** 0 0 -386.22 **Units:** English (IPS)
Torque-1		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply torque **Value:** -1.524 lbf.in

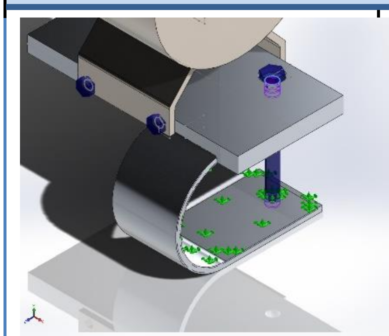
Connector Definitions

Pin/Bolt/Bearing Connector

Model Reference	Connector Details	Strength Details
 Counterbore Screw-2	**Entities:** 1 edge(s), 2 face(s) **Type:** Bolt(Head/Nut diameter)(Counterbore screw) **Head diameter:** 0.3015 in **Nominal shank diameter:** 0.201 **Preload (Torque):** 0 **Young's modulus:** 2.1e+011 **Poisson's ratio:** 0.28 **Preload units:** lbf.in	No Data

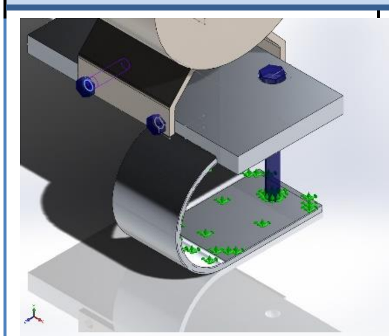
Connector Forces

Type	X-Component	Y-Component	Z-Component
Axial Force (N)	0	0	-6.3027
Shear Force (N)	2.7833	-11.505	0
Bending moment (N.m)	0.077613	0.020121	0

Model Reference	Connector Details	Strength Details
 Counterbore Screw-3	**Entities:** 1 edge(s), 5 face(s) **Type:** Bolt(Head/Nut diameter)(Counterbore screw) **Head diameter:** 0.3855 in **Nominal shank diameter:** 0.257 **Preload (Torque):** 0 **Young's modulus:** 2.1e+011 **Poisson's ratio:** 0.28 **Preload units:** N.m	No Data

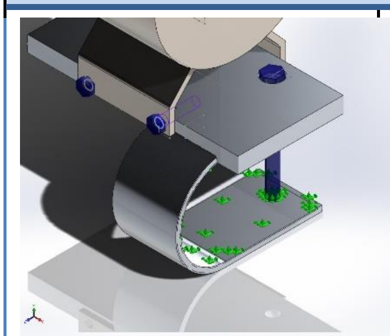
Connector Forces

Type	X-Component	Y-Component	Z-Component
Axial Force (N)	-0	-0.096023	-0
Shear Force (N)	0.014316	0	-0.039028
Bending moment (N.m)	0.00087258	0	0.00036769

Model Reference	Connector Details	Strength Details
 Counterbore Screw-4	**Entities:** 1 edge(s), 2 face(s) **Type:** Bolt(Head/Nut diameter)(Counterbore screw) **Head diameter:** 0.3015 in **Nominal shank diameter:** 0.201 **Preload (Torque):** 0 **Young's modulus:** 2.1e+011 **Poisson's ratio:** 0.28 **Preload units:** lbf.in	No Data

Connector Forces

Type	X-Component	Y-Component	Z-Component	
Axial Force (N)	0	0	0.012581	
Shear Force (N)	0.00097766	-0.0011864	0	
Bending moment (N.m)	-1.7066e-005	-1.4574e-005	0	



Counterbore Screw-5

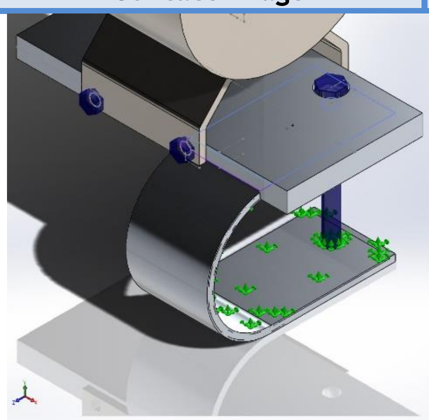
Entities:	1 edge(s), 2 face(s)
Type:	Bolt(Head/Nut diameter)(Counterbore screw)
Head diameter:	0.3015 in
Nominal shank diameter:	0.201
Preload (Torque):	0
Young's modulus:	2.1e+011
Poisson's ratio:	0.28
Preload units:	lbf.in

No Data

Connector Forces

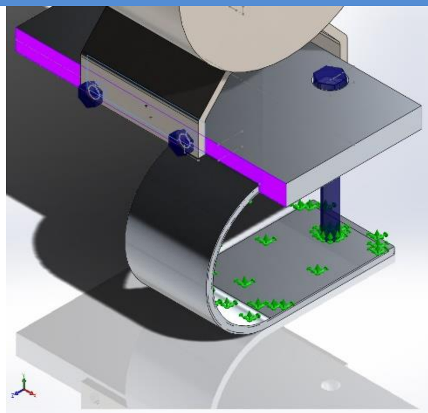
Type	X-Component	Y-Component	Z-Component	
Axial Force (N)	0	0	0.060287	
Shear Force (N)	0.0028941	-0.0048243	0	
Bending moment (N.m)	-1.5138e-005	-1.6761e-005	0	

Contact Information

Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface

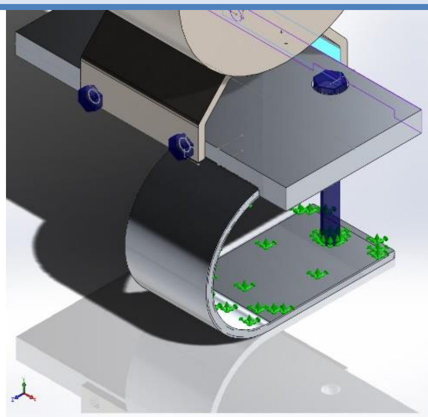
Contact/Friction force

Components	X	Y	Z	
Contact Force(N)	-3.1137	1.2901E-014	-0.48847	

Contact	Contact Image	Contact Properties
Contact Set-2		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface

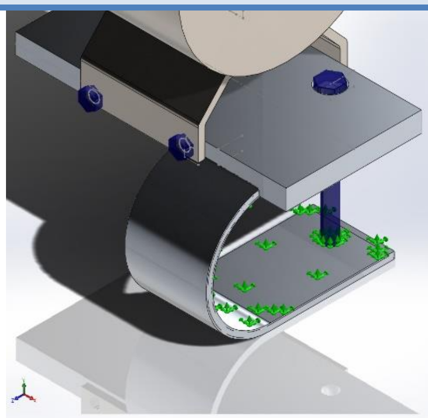
Contact/Friction force

Components	X	Y	Z
Contact Force(N)	0.41805	0.28876	4.1876E-015

Contact	Contact Image	Contact Properties
Contact Set-3		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface

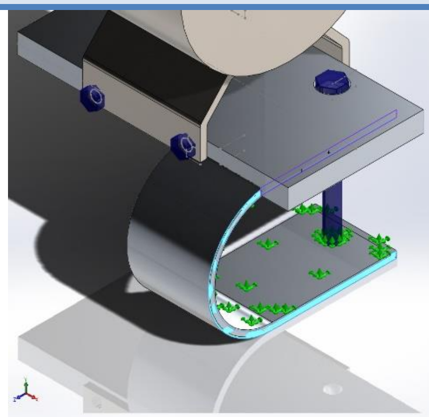
Contact/Friction force

Components	X	Y	Z
Contact Force(N)	-8.2477	0	-7.8965E-015

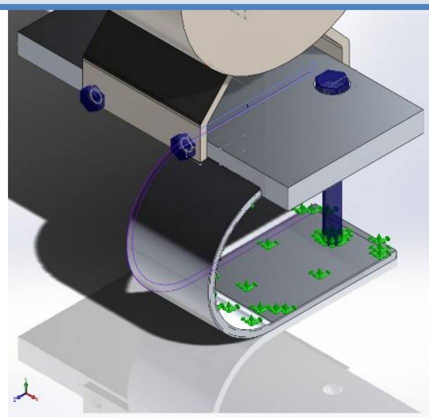
Contact	Contact Image	Contact Properties
Contact Set-4		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface

Contact/Friction force

Components	X	Y	Z
Contact Force(N)	-4.9873E-018	-1.9063E-014	8.9373E-015

Contact	Contact Image	Contact Properties
Contact Set-5		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface
Contact/Friction force		

Components	X	Y	Z
Contact Force(N)	2.8866E-015	0	0

Contact	Contact Image	Contact Properties
Contact Set-6		**Type:** No Penetration contact pair **Entites:** 2 face(s) **Advanced:** Surface to surface
Contact/Friction force		

Components	X	Y	Z
Contact Force(N)	6.9056E-014	-1.4024	-0.028334

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.598486 in
Tolerance	0.0299243 in

Mesh Quality	High
Remesh failed parts with incompatible mesh	On

Mesh information - Details

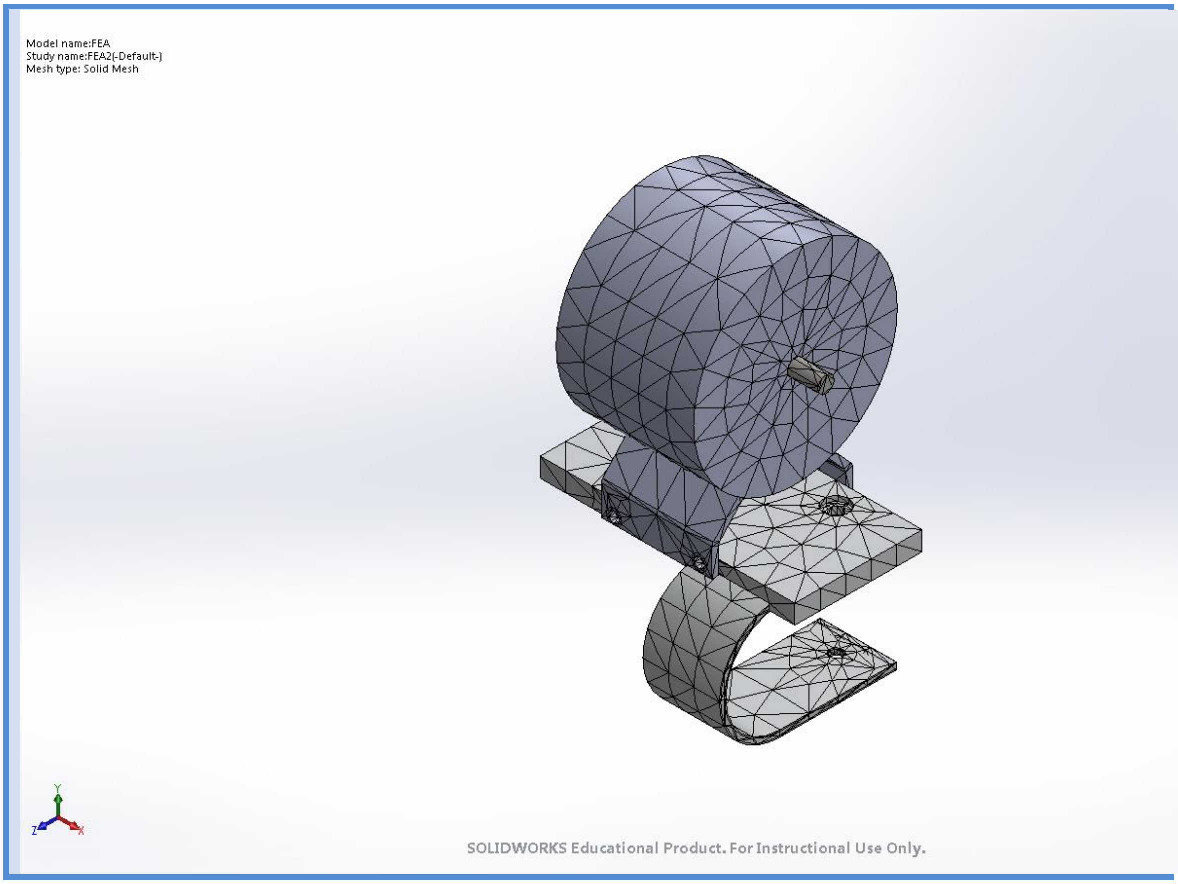
Total Nodes	9140
Total Elements	4895
Maximum Aspect Ratio	36.761
% of elements with Aspect Ratio < 3	62.6
% of elements with Aspect Ratio > 10	2.29
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	803-0103

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.598486 in
Tolerance	0.0299243 in
Mesh Quality	High
Remesh failed parts with incompatible mesh	On

Mesh information - Details

Total Nodes	9140
Total Elements	4895
Maximum Aspect Ratio	36.761
% of elements with Aspect Ratio < 3	62.6
% of elements with Aspect Ratio > 10	2.29
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	803-0103



Resultant Forces

Reaction forces

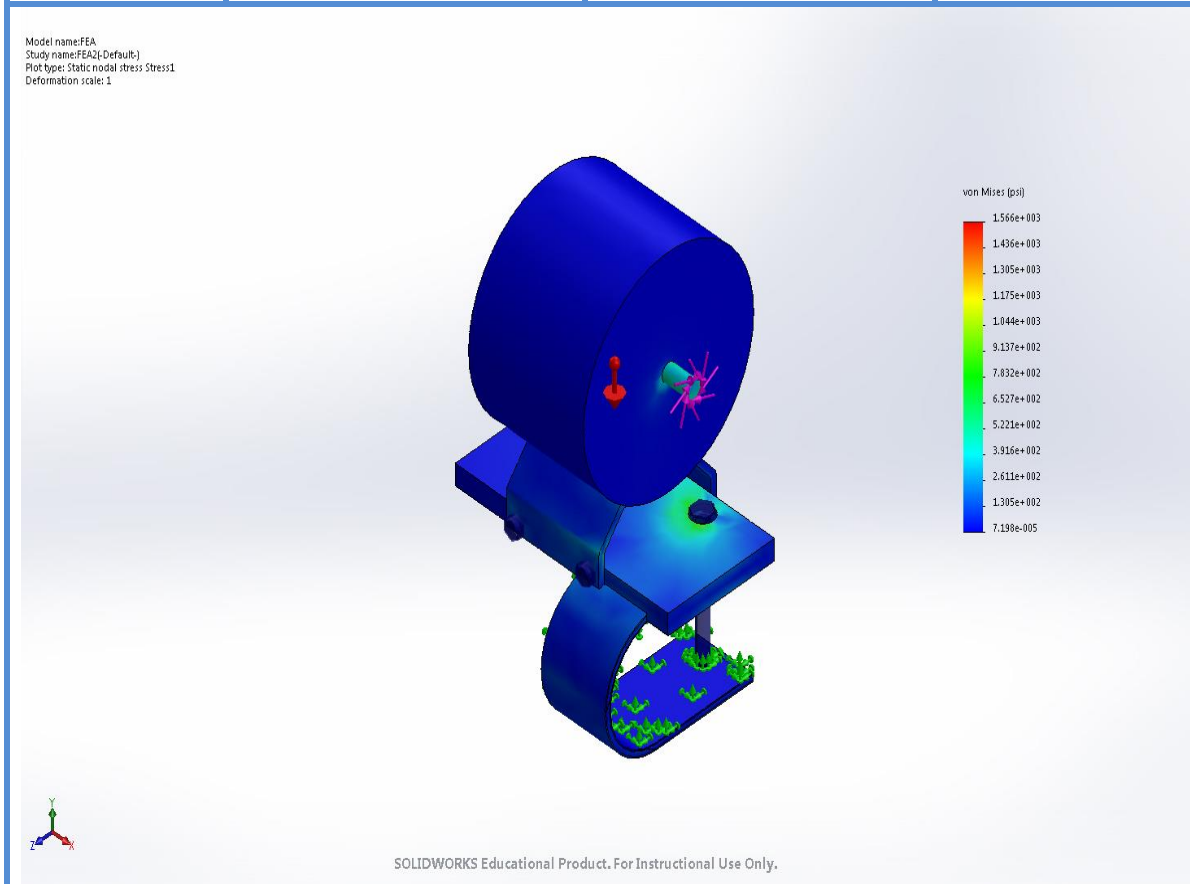
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	1.84774e-006	53.6764	-15.2713	55.8066

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Study Results

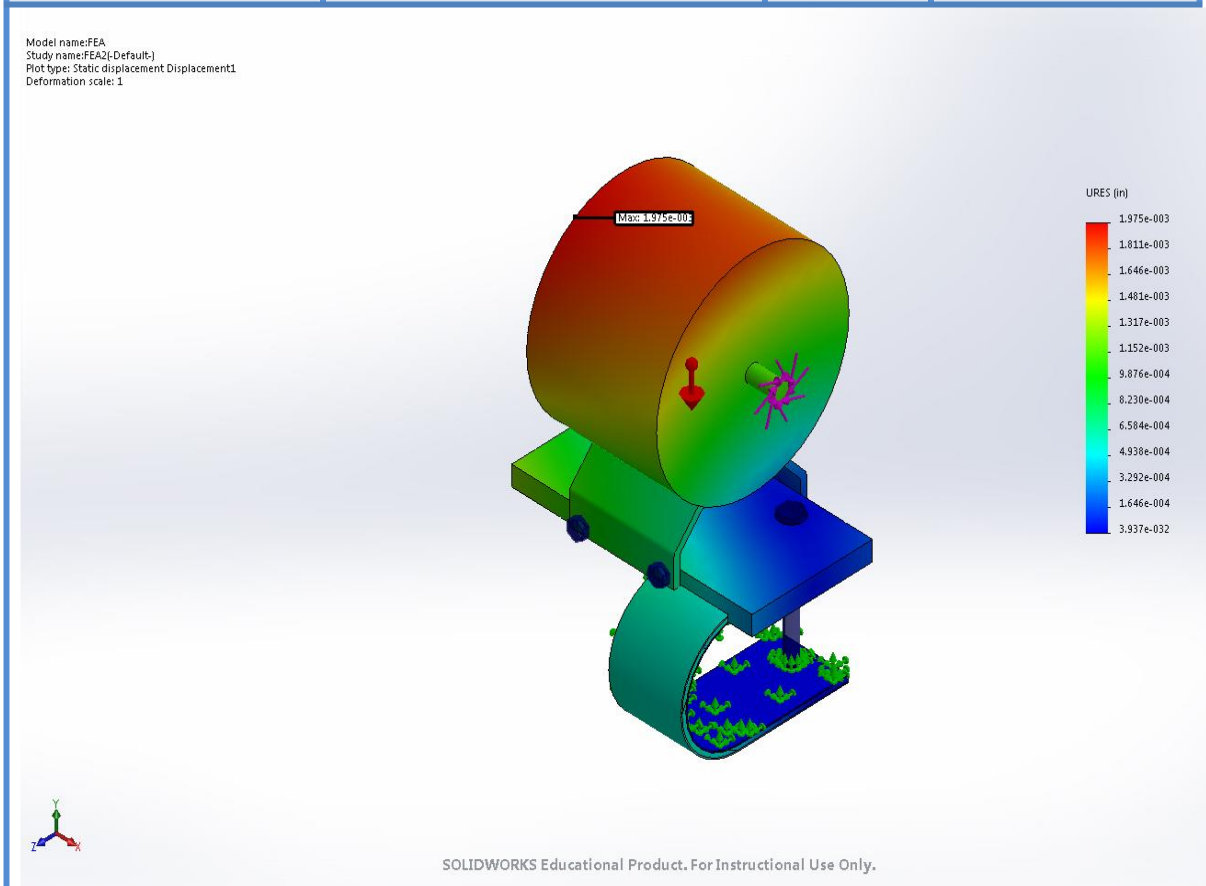
Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.19783e-005 psi Node: 574	1566.41 psi Node: 3614



FEA-FEA2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 in Node: 1	0.00197525 in Node: 4460

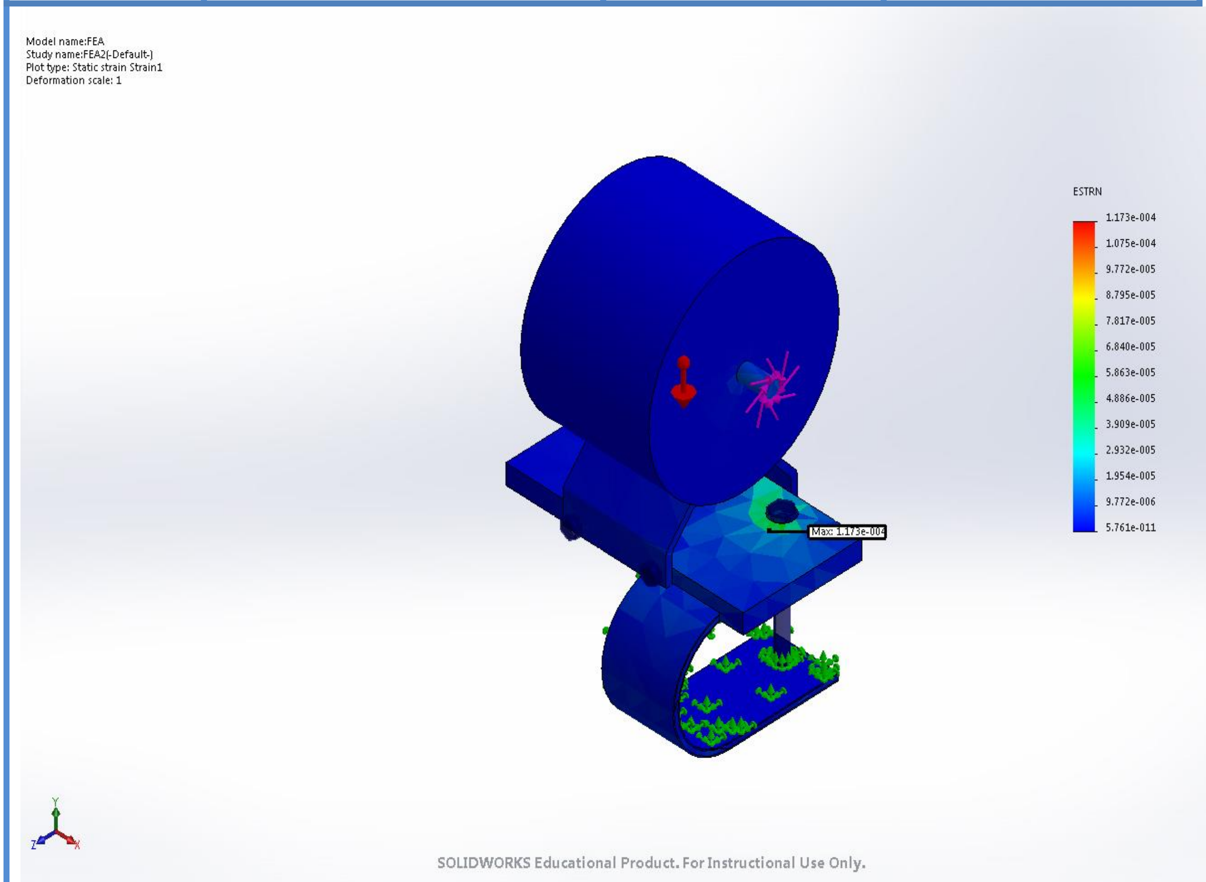
Name	Type	Min	Max



FEA-FEA2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	5.76058e-011 Element: 307	0.000117262 Element: 1731

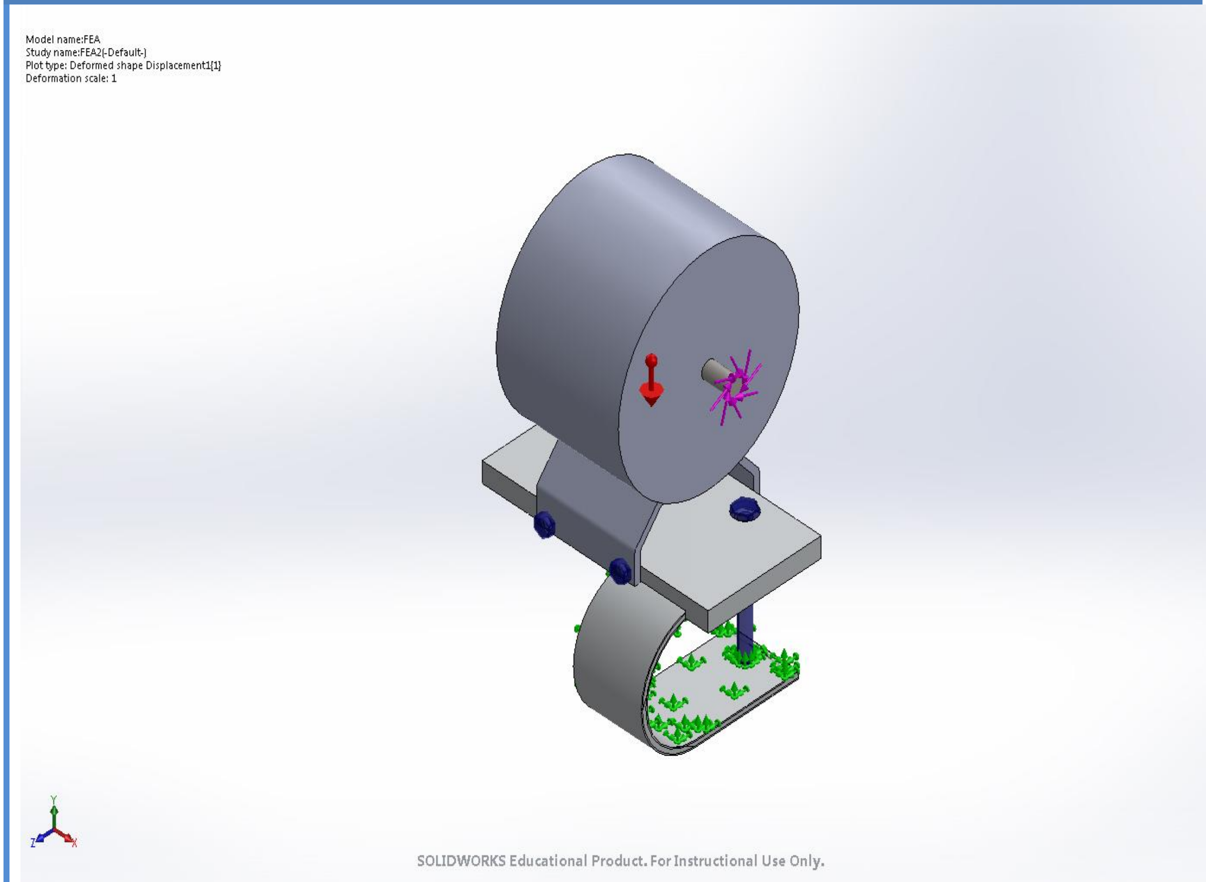
Name	Type	Min	Max



FEA-FEA2-Strain-Strain1

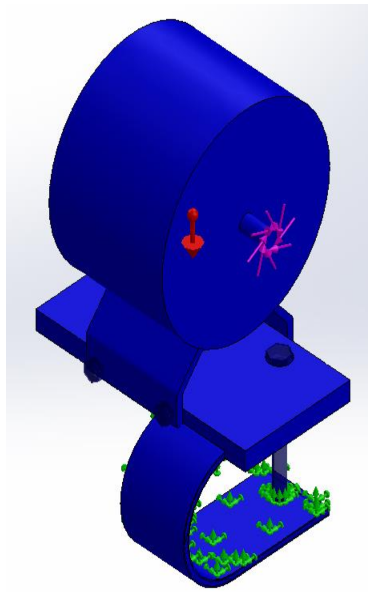
Name	Type
Displacement1{1}	Deformed shape

Name	Type



FEA-FEA2-Displacement-Displacement1{1}

Name	Type	Min	Max
Factor of Safety1	Max von Mises Stress	2 Node: 1	2 Node: 1

Name	Type	Min	Max
 FEA-FEA2-Factor of Safety-Factor of Safety1			

Name	Type
Displacement2	Deformed shape

APPENDIX H – CALCULATION TABLES

Motor Torque (lb_f - ft)	Motor Angular Velocity (rpm)	Gear Ratio	Wheel Angular Velocity (rpm)	Wheel rpm (Target)	Wheel Torque (lb_f - ft)	Wheel Radius (ft)	Wheel Crcumference (ft)	Wheel Linear Speed (ft/min)	Wheel Linear Speed (Target)
0.6638	2650	14	189.2857	168.1	9.2932	0.5	3.1416	594.6600	528
0.6638	2650	14.2	186.6197	168.1	9.42596	0.5	3.1416	586.2845	528
0.6638	2650	14.4	184.0278	168.1	9.55872	0.5	3.1416	578.1417	528
0.6638	2650	14.6	181.5068	168.1	9.69148	0.5	3.1416	570.2219	528
0.6638	2650	14.8	179.0541	168.1	9.82424	0.5	3.1416	562.5162	528
0.6638	2650	15	176.6667	168.1	9.957	0.5	3.1416	555.0160	528
0.6638	2650	15.25	173.7705	168.1	10.12295	0.5	3.1416	545.9174	528
0.6638	2650	15.5	170.9677	168.1	10.2889	0.5	3.1416	537.1123	528
0.6638	2650	15.6	169.8718	168.1	10.35528	0.5	3.1416	533.6692	528
0.6638	2650	15.7	168.7898	168.1	10.42166	0.5	3.1416	530.2701	528
0.6638	2650	15.8	167.7215	168.1	10.48804	0.5	3.1416	526.9139	528
0.6638	2650	15.9	166.6667	168.1	10.55442	0.5	3.1416	523.6000	528
0.6638	2650	16	165.6250	168.1	10.6208	0.5	3.1416	520.3275	528
0.6638	2650	16.1	164.5963	168.1	10.68718	0.5	3.1416	517.0957	528
0.6638	2650	16.2	163.5802	168.1	10.75356	0.5	3.1416	513.9037	528
0.6638	2650	16.3	162.5767	168.1	10.81994	0.5	3.1416	510.7509	528
0.6638	2650	16.4	161.5854	168.1	10.88632	0.5	3.1416	507.6366	528
0.6638	2650	16.5	160.6061	168.1	10.9527	0.5	3.1416	504.5600	528
0.6638	2650	16.75	158.2090	168.1	11.11865	0.5	3.1416	497.0293	528
0.6638	2650	17	155.8824	168.1	11.2846	0.5	3.1416	489.7200	528
0.6638	2650	17.2	154.0698	168.1	11.41736	0.5	3.1416	484.0256	528
0.6638	2650	17.4	152.2989	168.1	11.55012	0.5	3.1416	478.4621	528
0.6638	2650	17.6	150.5682	168.1	11.68288	0.5	3.1416	473.0250	528

Gear **1** Teeth	Ratio	Gear **2** Teeth
9	11.11111	100
9	12.77778	115
9	13.33333	120
9	13.88889	125
9	14.44444	130
9	15	135
9	15.11111	136
9	15.22222	137
9	15.33333	138
9	15.44444	139
9	15.55556	140
9	15.66667	141
9	15.77778	142
9	15.88889	143
9	16	144
9	16.11111	145
9	16.66667	150
9	17.22222	155
9	17.77778	160
9	18.33333	165
9	18.88889	170
9	19.44444	175
9	20	180