Electric Motor Assisted Caster Cart

Senior Design 2020-21
Miami University

ENT 498

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Statement of Purpose

To take a pre-existing cart product provided by Hamilton Caster and retrofit it with as many off the shelf parts as possible, in order to prototype an electric motor assisted cart. This project will serve as a functional prototype, while attempting to source parts for the eventual final design. Our group came to this project after Hamilton Caster was looking for volunteers to take on this project. Seeing the integration of mechanical and electrical functions and features, this project seemed to fit our group in how we wanted to pursue our senior project.

Scope & Methodology

Scope

Hamilton Caster is pursuing a motorized cart for their product line. The primary goal is to be able to take an existing cart, and provide a bolt-on solution that turns it into an electrically driven cart.

Requirements

- Transport max load of 4000 lbs
- Transport at a maximum speed of 3 miles per hour
- Capable of climbing a 3 degree uphill slope
- Travel 10 miles between charges of batteries
- Retrofittable kit
- Using existing product offerings from Hamilton Caster
- Off the shelf parts - minimize custom fabrication

We were instructed to use components that are readily available from vendors so that unique components would not be required to manufacture this cart. This helps with keeping the cost of the cart down as well as having components that are possibly off of the shelf or at least have short lead times to acquire. The bolt-on solution would allow Hamilton Caster customers to buy a kit and install it onto their cart, allowing them to attain a powered cart at a much lower price. This will enable Hamilton Caster to service a wider range of their customer base and possibly gain new customers.

Methodology

Once we received our requirements from Hamilton Caster, we started developing a work breakdown structure (WBS) to lay out what we would need to complete the project. We used this time creating the WBS to think through which systems would need to be designed and selected before subsequent systems. This allowed us to prioritize the most important parts of the project first, such as the drive system including the motor and battery selection.

Work Breakdown Structure (WBS)

1. Receive major components
    a. Receive cart (supplied by Hamilton Caster)
        i. Cart Body
        ii. Swivel Casters
        iii. Handle
    b. Receive front rigid casters (supplied by Hamilton Caster)
2. Begin brainstorming
    a. Consider design requirements
    b. Drive system
        i. Determine method of driving cart (single motor or dual motors)
    c. Control system
        i. Determine method of control for steering, forward and reverse movement, and speed
    d. Breaking system
        i. Method of emergency break for securing carts
        ii. Method of breaking to securely remain stationary
3. Design Phase
    a. Do engineering calculations
        i. Get desired torque, rpm, amp/hour rating
        ii. Use given limits from Hamilton Caster
    b. Using design calculations, begin part selection
        i. Select Motor(s)
            1. Select appropriate battery to support motor(s)
                a. Determine drive method of casters from motor
                    i. Keyed shaft
                    ii. Keyless locking coupler
                    iii. Collared shaft bolted to wheel hub
                b. Number of batteries
                c. Select charger for battery
        ii. Select Brakes
            1. Brakes for slowing down/estop
            2. Brakes for stationary load security
        iii. Select PLC/Controller (Arduino) for control of cart.
        iv. Determine layout for controls (estop, speed selector, power switch, battery level indicator)
    c. Design preferred mechanical pieces
        i. Use Inventor software to model design and make necessary changes as needed before having parts produced

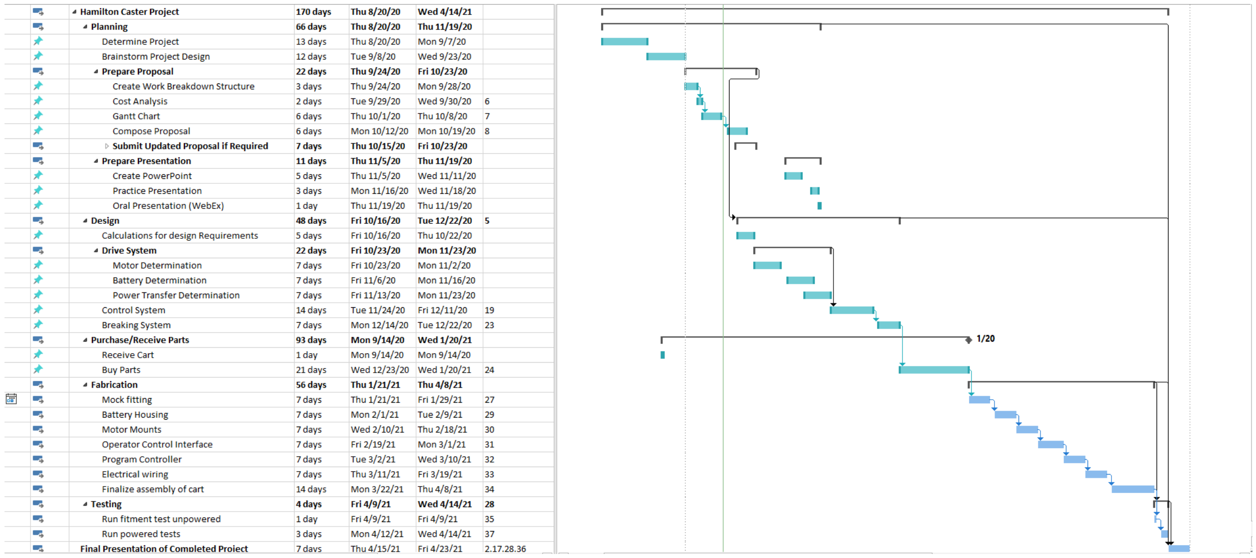
1. Components needing fabrication
2. Assemblies or sub-assemblies needing fit proven

4. Purchase/Receive
   a. Gearmotors or motors and separate gearbox
   b. Batteries
   c. Charging System
   d. Components for driven wheels
      i. Bearings
      ii. Shafts and keys
      iii. Couplers
   e. Control system components
      i. PLC/ Controller (Arduino)
      ii. Operator controls (Speed Selector, Estop, Start Switch)
      iii. Battery life display
   f. Fabricated components

5. Fabrication
   a. Battery tray or battery housing
   b. Driven caster brackets
   c. Operator display housing
   d. Any welding or fabrication that needs to be executed by the team

6. Assembly
   a. Program Controller (PLC or Arduino)
   b. Fasten driven caster assembly to cart
   c. Place batteries in tray/housing
   d. Wire all systems together on cart

7. Testing
   a. Run powered cart and troubleshoot any problems/issues that are encountered
      i. Correct any problems/issues
      ii. Verify safety features are functional
      iii. Verify design and implementation meet requirements.
      iv. Redesign if major problems/shortcomings encountered.
      v. Repeat testing as required.
   b. Once the testing is completed we can then start working on retrofit kits for Hamilton caster with the design we have completed and finished



Hamilton Caster Project	**170 days**	**Thu 8/20/20**	**Wed 4/14/21**	
Planning	**66 days**	**Thu 8/20/20**	**Thu 11/19/20**	
Determine Project	13 days	Thu 8/20/20	Mon 9/7/20	
Brainstorm Project Design	12 days	Tue 9/8/20	Wed 9/23/20	
Prepare Proposal	**22 days**	**Thu 9/24/20**	**Fri 10/23/20**	
Create Work Breakdown Structure	3 days	Thu 9/24/20	Mon 9/28/20	
Cost Analysis	2 days	Tue 9/29/20	Wed 9/30/20	6
Gantt Chart	6 days	Thu 10/1/20	Thu 10/8/20	7
Compose Proposal	6 days	Mon 10/12/20	Mon 10/19/20	8
Submit Updated Proposal if Required	**7 days**	**Thu 10/15/20**	**Fri 10/23/20**	
Prepare Presentation	**11 days**	**Thu 11/5/20**	**Thu 11/19/20**	
Create PowerPoint	5 days	Thu 11/5/20	Wed 11/11/20	
Practice Presentation	3 days	Mon 11/16/20	Wed 11/18/20	
Oral Presentation (WebEx)	1 day	Thu 11/19/20	Thu 11/19/20	
Design	**48 days**	**Fri 10/16/20**	**Tue 12/22/20**	5
Calculations for design Requirements	5 days	Fri 10/16/20	Thu 10/22/20	
Drive System	**22 days**	**Fri 10/23/20**	**Mon 11/23/20**	
Motor Determination	7 days	Fri 10/23/20	Mon 11/2/20	
Battery Determination	7 days	Fri 11/6/20	Mon 11/16/20	
Power Transfer Determination	7 days	Fri 11/13/20	Mon 11/23/20	
Control System	14 days	Tue 11/24/20	Fri 12/11/20	19
Breaking System	7 days	Mon 12/14/20	Tue 12/22/20	23
Purchase/Receive Parts	**93 days**	**Mon 9/14/20**	**Wed 1/20/21**	
Receive Cart	1 day	Mon 9/14/20	Mon 9/14/20	
Buy Parts	21 days	Wed 12/23/20	Wed 1/20/21	24
Fabrication	**56 days**	**Thu 1/21/21**	**Thu 4/8/21**	
Mock fitting	7 days	Thu 1/21/21	Fri 1/29/21	27
Battery Housing	7 days	Mon 2/1/21	Tue 2/9/21	29
Motor Mounts	7 days	Wed 2/10/21	Thu 2/18/21	30
Operator Control Interface	7 days	Fri 2/19/21	Mon 3/1/21	31
Program Controller	7 days	Tue 3/2/21	Wed 3/10/21	32
Electrical wiring	7 days	Thu 3/11/21	Fri 3/19/21	33
Finalize assembly of cart	14 days	Mon 3/22/21	Thu 4/8/21	34
Testing	**4 days**	**Fri 4/9/21**	**Wed 4/14/21**	28
Run fitment test unpowered	1 day	Fri 4/9/21	Fri 4/9/21	35
Run powered tests	3 days	Mon 4/12/21	Wed 4/14/21	37
Final Presentation of Completed Project	7 days	Thu 4/15/21	Fri 4/23/21	2.17.28.36

Figure1: Gantt chart Project Timeline

Cost Analysis

After discussing our timeline making the best estimations that we could while padding these deadlines for unexpected delays, we put together a cost estimation. We used preliminary findings from our brainstorming sessions to get the best idea of what each of our parts would cost before we were able to specifically specify them.

1. Hamilton Caster Cart (Supplied by Hamilton Caster)
2. Electrical motors/ 90 degree gearbox (BA3624-XXXX-G24-R, BA3624-XXXX-G24-L, for both wheels)......................$1000
3. Batteries for Cart (2 110 AH)...$550
4. Programmable logic controller and wiring………………....$300
5. Safety devices and sensors……………………………....$250
6. Steel for fabrication……………………………………...$200
7. Bearings and Miscellaneous Hardware…………………..$200
8. <u>Final Cost</u>……………………………...........................$2500

The following is our final project budget (Figure 2). We had overshot our original cost analysis by $314.75 due to a number of miscellaneous supplies that we did not anticipate in our initial planning. We felt that this budget oversight was well contained considering the nature of our project being the first of its kind. In prototyping and R&D projects such as these it should be expected that the original budget can be created before fully understanding the depth of the project.

Fleck Grant:								
$2,500.00								
ITEM#	PART NAME	COST/UNIT	QTY	SHIPPING	TOTAL:	Paid By:	Ordered?	Delivered?
1	Apex APX12-200 12V 200AH Sealed AGM Battery	$264.99	4	$343.64	$1,403.60	FLECK	Yes	Yes
2	Sample DR600 Gear-Motor, Right Hand w/ Electromechanical Brake	$315.00	2	$50.00	$680.00	FLECK	Yes	Yes
3	Bearing Holder-Driver Side	$0.00	2	$0.00	$0.00	HAMILTON CAS	Yes	Yes
4	Bearing Holder-Idler Side	$0.00	2	$0.00	$0.00	HAMILTON CAS	Yes	Yes
5	Bearing Block Nut-Threaded Body	$0.00	6	$0.00	$0.00	HAMILTON CAS	Yes	Yes
6	1/2-20 Large Hex Nut	$0.00	10	$0.00	$0.00	HAMILTON CAS	Yes	Yes
7	DEVMO Joystick Modules (5 per pack)	$11.99	1	$9.99	$21.98	TEAM	Yes	Yes
8	Cytron SmartDriveDuo60-60A	$149.90	1	$0.00	$149.90	FLECK	Yes	Yes
9	Greartisan DC 24V 120 RPM Gear Motor (For Testing)	$14.99	2	$0.00	$29.98	FLECK	Yes	Yes
10	Battery Meter, Battery Capacity Voltage Indicator	$10.99	1	$0.00	$10.99	FLECK	No (2/11)	NO
11	Battery Quick connectors	$39.95	1	$0.00	$39.95	TEAM	No (2/11)	NO
12	Cable terminal connectors	$17.33	1	$0.00	$17.33	TEAM	No (2/11)	NO
13	Thrust Washer (McMaster Carr - Pack of 5)	$0.00	1	$0.00	$0.00	HAMILTON CAS	Yes	Yes
14	1/2-20 x 2" Grade 5 Hex Head Bolts (McMaster Carr)	$0.00	5	$0.00	$0.00	HAMILTON CAS	Yes	Yes
15	Die Springs (Associated Spring Raymond)	$0.00	9	$0.00	$0.00	HAMILTON CAS	Yes	Yes
16	10-32 x 1" Socket Head Cap Screw	$0.55	2	$0.00	$1.10	TEAM	Yes	Yes
17	#10 Lock Washer	$0.12	2	$0.00	$0.24	TEAM	Yes	Yes
18	1/4-20 x 3/4" Hex Drive Flat Head	$0.85	8	$0.00	$6.80	TEAM	Yes	Yes
19	1/4-20 x 1" Hex Head Grade 5 Bolt	$0.17	6	$0.00	$1.02	TEAM	Yes	Yes
20	1/4" Lock Washer	$0.15	6	$0.00	$0.90	TEAM	Yes	Yes
21	10-32 Hex Nut	$0.13	4	$0.00	$0.52	TEAM	Yes	Yes
22	10-32 x 3/4" Socket Head Cap Screw	$0.50	4	$0.00	$2.00	TEAM	Yes	Yes
23	Extension Spring w/Hook, Bushing, External Retaining Ring	$30.21	1	$15.16	$45.37	TEAM	Yes	Yes
24	D-Shaped Shaft - 6 mm Diameter	$4.00	1	$12.50	$16.50	TEAM	Yes	Yes
25	Potentiometer	$30.00	1	$16.58	$46.58	TEAM	Yes	No
26	Back Cabinet for Batteries	$79.99	1	$15.00	$94.99	FLECK		
27	Battery Charger	$290.00	1	$0.00	$0.00	ENT DEPT.		
28	Various Wire	$180.00	N/A	$0.00	$180.00	TEAM	Yes	Yes
29	Butt Connectors	$25.00	1	$0.00	$25.00	TEAM		
30	eSUN 3D Printer Filament	$20.00	2	$0.00	$40.00	TEAM		
				Total:	**$2,814.75**			
				Budget Left:	**-$314.75**			

Figure 2: Final Project Budget

Expected Findings

Design Calculations

In order to extrapolate the requirements into specifications for part selection we needed to perform several calculations (Reference Appendix G). Based on the requirements and our assumptions we were able to determine the physical quantities that we could expect the cart to be working with. We found that the torque for continuous motion was 274 lb-in and the peak torque to move the cart from a standstill was 547 lb-in on a flat surface. The torque for continuous motion was 1278 lb-in and the peak torque to move the cart from a standstill was 2557 lb-in on an inclined surface. We also determined the RPM of the motor to maintain 3 mph was 126 rpm.

Drive Caster

We were able to design a portion of the drive caster knowing we would have to make small modifications depending on the gear motor that would be chosen. The first designs were sketches produced from brainstorming in order to get started. During this time, we had conversations with Hamilton Caster and discovered that one design element that was required was a drive caster that had shock absorbers. Hamilton Caster already offered a number of shock absorbing casters and we selected their Workhorse shock absorbing caster. This specific caster assembly had the mounting plate size, wheel size and load capacity we required. We requested the S-SPWH-8TRB-2 shock absorbing swivel casters from Hamilton Caster and designed our drive caster to match these casters characteristics.

Once we determined the gear motor we were going to use, we requested the appropriate drive caster wheels from Hamilton Caster. We supplied them with the part number for the caster wheel we were going to use (W-820-TRB-1/2 referenced from the -SPWH-8TRB-2 shock absorbing swivel casters) and a drawing of the bore and key that we needed machined in the caster wheel. We finalized the design of the drive caster and started to create detail drawings so that the components could be manufactured (See Figure 3).

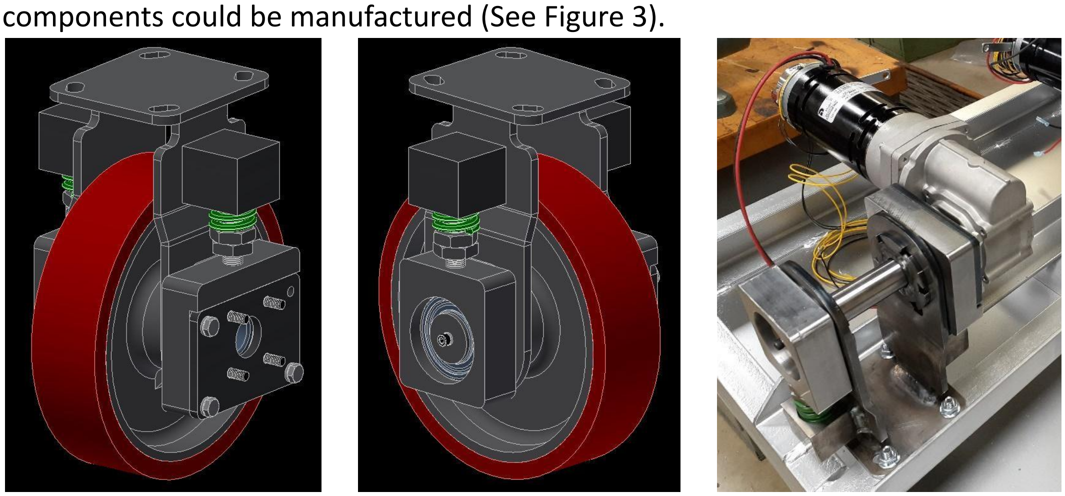


Figure 3: Final Drive Caster Design

One design change that we had to resolve was moving the bearings from the wheel hub to a stationary support somewhere on the frame of the drive caster. On a standard caster, the wheel has bearings in the hub that ride on an axle that stays stationary. On our drive caster, the axle would be the gear motor shaft that rotates. The wheel hub needed to be bored and keyed to accept the gear motor shaft in order for the gear motor shaft to drive the caster wheel. We decided to move the bearings to bearing blocks that could move vertically allowing us to keep the shock absorbing portion of our design. With this, we needed a way to attach the bearing blocks to the main frame while still allowing them to move vertically. We came up with a bearing block nut that would thread into the bearing blocks allowing the gear motor shaft to pass through uninhibited and allow 0.005” clearance for the nut to be tightened to the bearing block while allowing the vertical movement we desired. The bearing block nut also has cutouts on it for a spanner wrench that we designed, to tighten or loosen the nut while the drive caster assembly is still assembled. We also did not want the entire surface of the bearing block riding on the leg of the main frame. To avoid this, we had a large circle machined on the backside of the bearing block in order to have less surface friction when the bearing blocks move vertically.

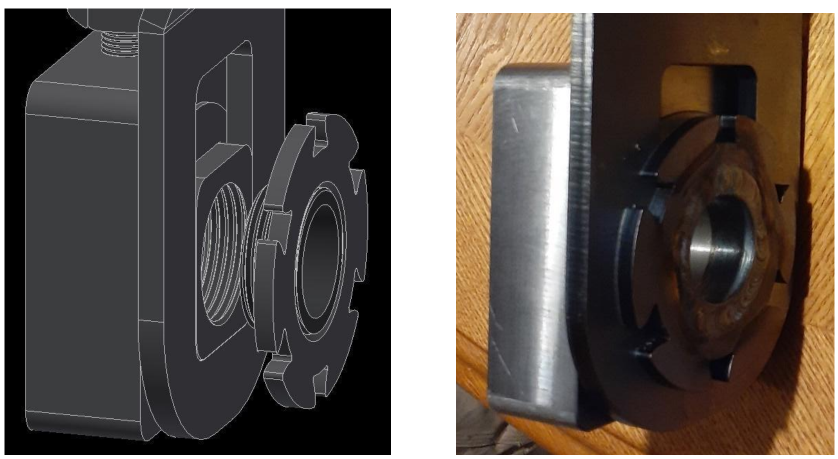


Figure 4: Bearing Block Nut Attachment

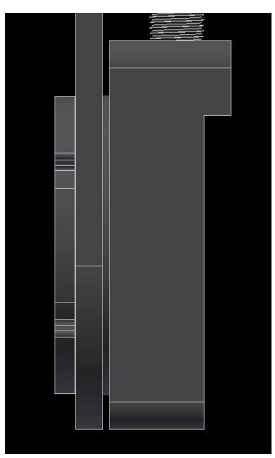


Figure 5: Motion Clearance

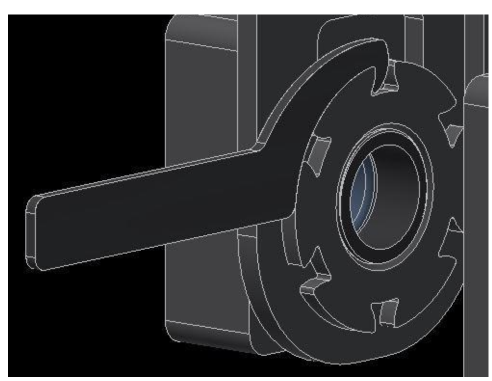


Figure 6: Spanner Wrench

The standard axles for the Workhorse casters we used were 1/2” diameter. The gear motor shaft is 1” diameter so the bearings we needed (SKF RLS 8-2RS1) are oversized for this application (Dynamic load 4,002 lb and a static load of 2,169 lb) but we had to size the bearing to fit the gear motor shaft. The bearings were lightly press fit into the bearing blocks with a 0.001” in interference fit. The bearing blocks were wider than the bearings themselves so we had a slightly larger hole machined in the bearing block body (only a few thousandths to allow for guidance) allowing us to only have to press fit the bearings into the bearing blocks the thickness of the outer race of the bearing (See Figure 7).

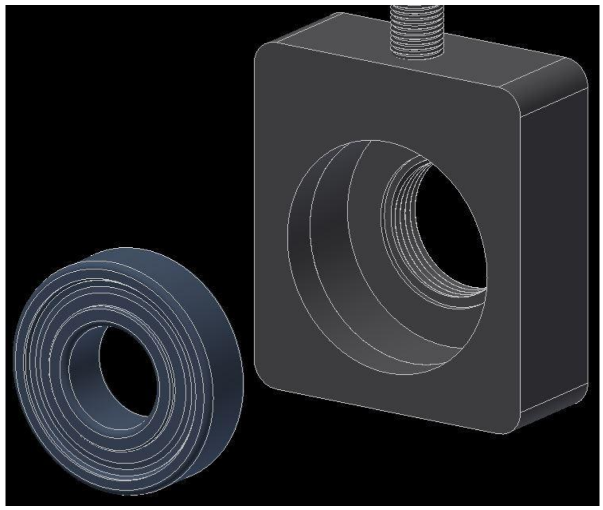


Figure 7: Bearing Block and Bearing

The width of the bearing blocks was dictated by the spring preload system. We chose to mount a 1/2-20 stud on each bearing block to allow nuts threaded on the stud to pre-load the springs for operation. The springs have a 0.655” diameter center opening that could accept a 5/8” guide pin. We chose to go with a 1/2” bolt to give a bit more room so the springs didn’t rub on the threads causing possible issues in the future. We did not use standard 1/2-20 hex nuts as we were afraid that they did not have enough surface area for the springs to seat properly and they were much too thick for the vertical space we had to work with. We had nuts machined from hex bar that had more surface area (1” across the flats as opposed to standard nuts with 3/4“ across the flats) and were thinner (5/16” thick as opposed to standard nuts 7/16” thick). In order to be able to turn these nuts with a wrench, we had to make sure they were far enough away from the leg of the main frame. This caused the stud to move out, causing the bearing block to be thicker (See Figure 8).

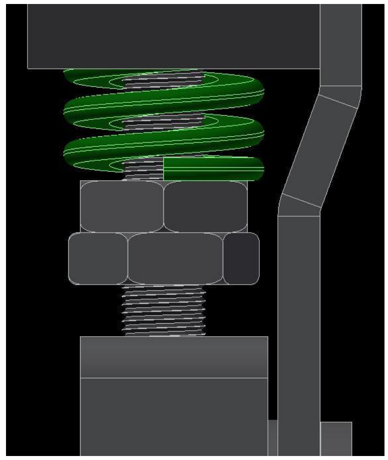


Figure 8: Bearing Block Stud and Hex Nuts

The spring preload system was designed so that the springs could be preloaded after the gear motor was assembled onto the drive caster assembly. This allows the bearing blocks to be adjusted as needed in order to fit the gear motor shaft through the bearings. The 1/2-20 nut could be adjusted up to pre-load the springs (1 1/2" turns will pre-load the springs to approximately 154 lbs) while the bottom nut is used to lock the top nut into place. The design of the pre-load system allows the caster assembly to constantly be 10 3/16" tall as this system displaces the bearing blocks down into their seated position in the slot of the legs (See Figure 9).

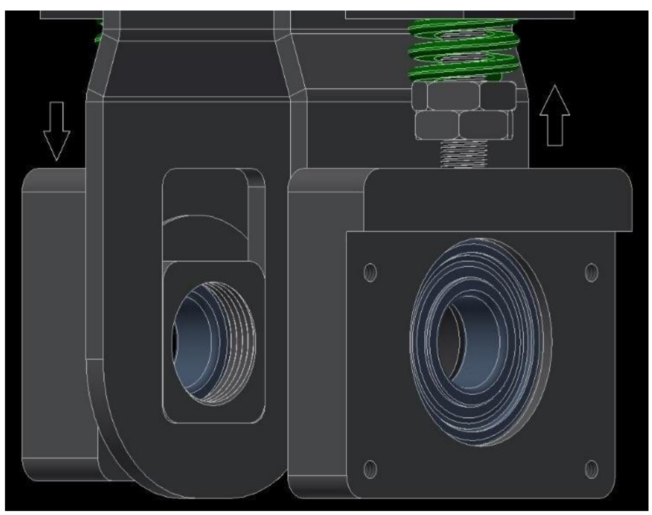


Figure 9: Bearing Block Preload System

Another aspect that dictated the bearing block thickness was the fact we designed the drive side bearing block to be able to have the gear motor mount to it but also be able to remove the gear motor from the bearing block without having to disassemble the entire drive caster assembly. The gear motor is mounted to a 1/4" plate with four 1/4-20 flathead machine screws and then the plate is mounted to the bearing block with three 1/4-20 hex head machine screws. If there is an issue with the gear motor, the mounting plate can be removed from the bearing block to service the gear motor. As you can see from Figure 14 above, we got as close as we could to the bearing with the steel plate leaving some room for the bearing to move freely. The powered cart will still have to be lifted off of the ground (with a jack of some type) as the gear motor shaft is the axle for the caster wheel. However, it is a more effective way to access the gear motor as the majority of the drive caster unit can stay assembled (See Figure 10).

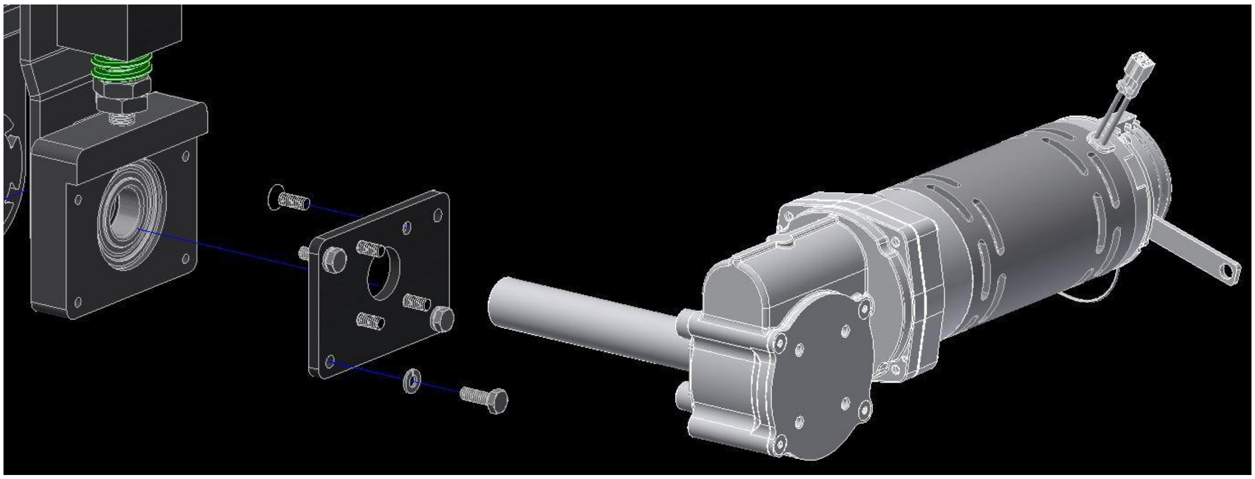


Figure 10: Bearing Block/Mounting Plate/Gearmotor Assembly

The design of the main frame of the drive caster was dictated by the bearing blocks and spring positions. We used the top plate from Hamilton Caster's standard rigid caster. The legs had to accommodate the bearing blocks and their vertical motion. The top of the legs had to be the same width as the standard rigid caster legs in order for the mounting bolts to work the way they were originally intended. We kept the width of the leg for 7/8" before we made the legs wider. The bearing blocks had to move vertically within a slot on both legs. The slot in the legs had a 0.003" clearance to allow the bearing blocks to move but not too much clearance to allow the bearing blocks to rotate within the slot causing excessive wear over the life of the components. The slot also had to be tall enough to allow for the vertical movement of the bearing blocks. We kept 15/16" of material on both sides of the slot in order to keep the strength we needed for the legs. We had to form an offset into the legs in order to keep the top of the legs in the proper position on the top plate but at the bottom. We needed room for the bearing block nuts and thrust washers that we placed between the bearing block nut and the caster wheel. The spring covers needed to go out far enough to capture the springs correctly but vertically, we had some space to play with. The spring covers needed to be placed so the springs could compress to the correct deflection under load but still not have the threaded stud interfere with it. The vertical placement was a compromise between total deflection of the spring, necessary stud length and where the offset form needed to be on the legs. The height of the spring covers was set so that the 1/2-20 studs would always be inside of the spring covers by about 3/8", even when no load was on the cart (See Figure 11 & 12).

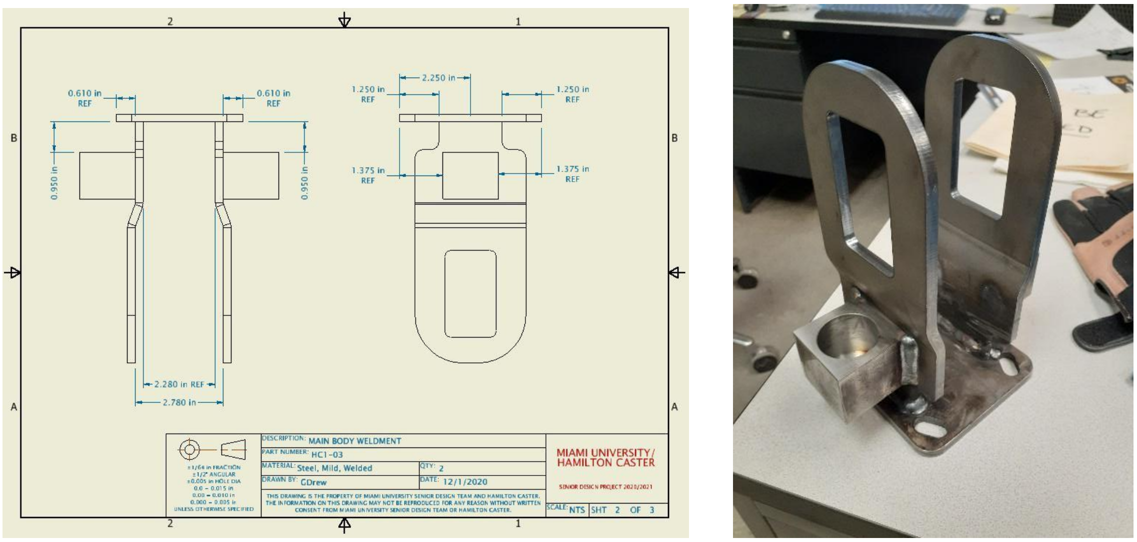


Figure 11: Main Body Weldment

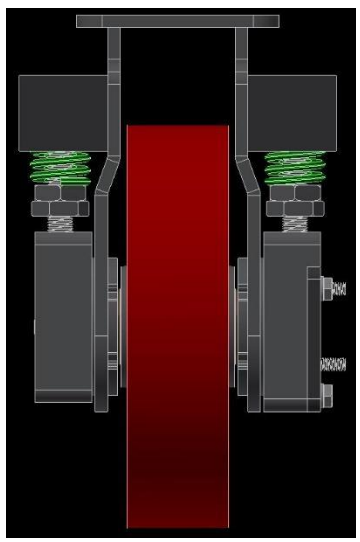
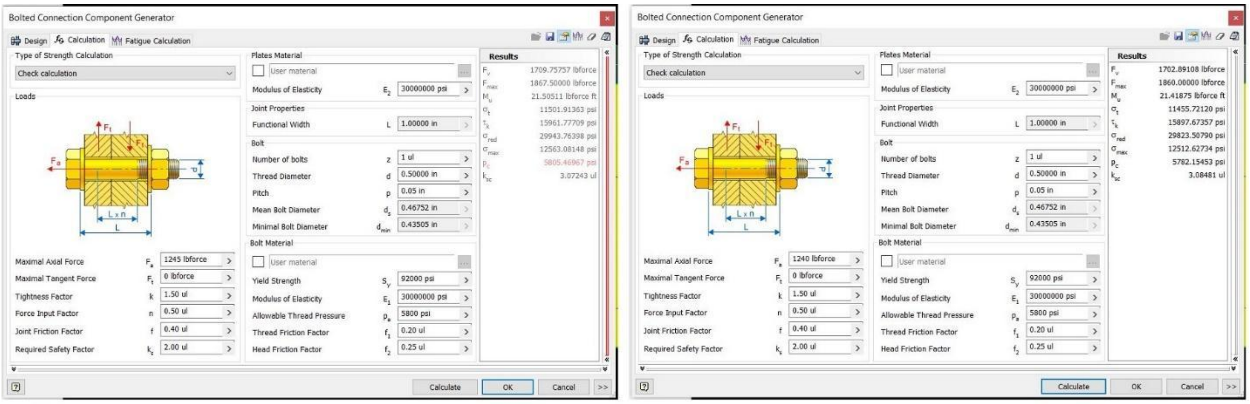


Figure 12: Front View of Drive Caster

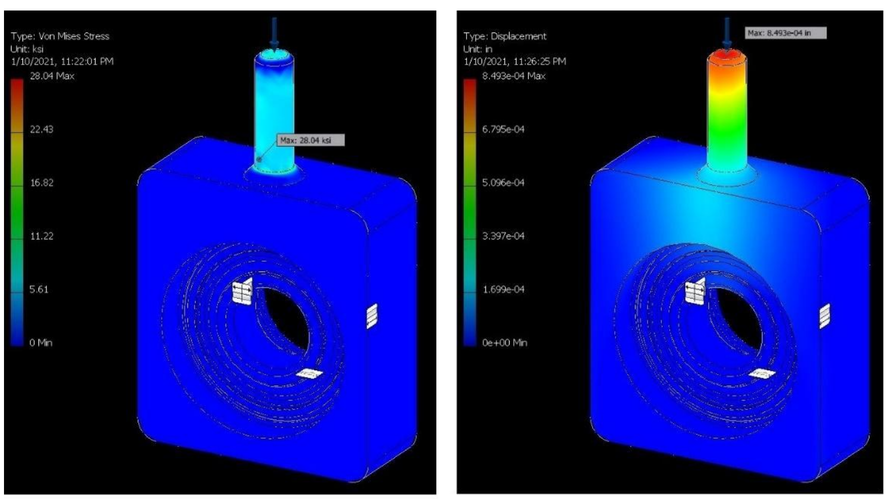
Through the design phase, we tried to come up with a way to use as many parts from the existing Hamilton Caster design as possible (top plate, wheel, springs). However, the only component we were able to use without modification was the top plate. We sent a step file of the drive caster assembly to Hamilton Caster so that they could see our design. The Hamilton Caster engineers had a few concerns. One concern was that we had the springs being compressed by nuts on a stud. The concern was that the threads would not be able to take the force that the loaded cart would exert on them. We performed a bolted connection calculation in Autodesk® Inventor® and found that the threads on the bolts we chose would sufficiently carry the force that the loaded cart would exert on them (Figure 13).



1/2-20 Bolt
- Grade 5
- Tensile Strength - 120,000 psi
- Rockwell C25
- ASTM Designation – A449
- Minimum Proof Strength – 85 kpsi
- Minimum Tensile Strength – 120 kpsi
- Minimum Yield Strength – 92 kpsi
- Proof Load – 13600 lb
- Stress Area – 0.1599 in

Figure 13 Results from Bolted Connection Calculation in Autodesk® Inventor®

We also ran an FEA simulation in Autodesk® Inventor® of the stud in the bearing block. We ran the FEA simulation with 1500 lbs of force directed downward on the stud. Since there are two bearing blocks, one on both sides of the drive caster, each with its own stud, this 1500lb would actually be cut in half for each threaded stud. However, with the FEA simulation coming back with an acceptable result with the 1500 lbs, this led us to believe that the design would be successful (See Figure 14).



AISI 1018
- Tensile Strength (Ultimate) – 63800 psi
- Tensile Strength (Yield) – 53700 psi
- Modulus of Elasticity – 29700 ksi
- Poisson's Ratio – 0.29
- Shear Modulus – 11600 ksi

Grade 5 Bolt
- ASTM 449
- Minimum Proof Strength – 85000 psi
- Minimum Tensile Strength – 120000 psi
- Minimum Yield Strength – 92000 psi
- Modulus of Elasticity – 31910 ksi

Die Spring 106-608
- 820 lb @ Maximum Spring Deflection

Force used in FEA
- 1500 lb Force on Top of Bolt
  - Bolt height used is location of top of top nut in assembly.
  - Minor diameter of bolt used for size of stud in FEA Analysis.

Figure 14: Results from FEA Simulation in Autodesk Inventor

Another concern was that the original design was to TIG weld the stud into the bearing block. The engineers at Hamilton Caster brought up a concern that welding the stud, especially if it was grade five or higher, would result in the stud becoming brittle around the weld. These bolt grades are heat treated so when they are welded, they can become brittle due to the high heat they are exposed to. We decided to keep the design but instead of welding the stud to the bearing block, we used LOCTITE® 271 thread locker to secure the stud to the bearing block. Solvents do not weaken the adhesive bond of this thread locker and it also requires the application of heat and hand tools to break the bond. With only a vertical load being applied to the stud, we felt like the overall design would be sufficient to allow the stud to work properly. The only thing we were not able to check was fatigue over time, for this as well as the threads. We determined that this would be a measurement that could be obtained through future testing of the prototype.

There were also some manufacturing concerns with the design. The first was the depth of the tapped hole for the stud on the bearing blocks. The tapped hole was too shallow to get enough threads to adequately hold the stud in place. We increased the depth of the hole as well as increasing the height of the bearing block in order to accommodate this change. Another concern was the top spring mounts that we designed. The top spring mounts would need to be machined compared to the top spring mounts on the Hamilton Caster unit that was constructed of cut metal bars and tubing. This machining was a cost concern as it would be more expensive to machine than to cut parts from standard metal stock. However, our design wasn't exactly like the Hamilton Caster unit and the machined components would allow us easier welding to the legs with no fixturing or shimming. With this realization, we proceeded with our design. Overall cost differences between the two types of manufacturing would need to be tested through a complete cost analysis from machining to cutting, to the different types of welding fixtures needed and the time differences between the two different processes. Also, the manufacturing capabilities of companies will be a large factor in such an analysis. This project did not allow for such a cost analysis. However, the design of the top spring mounts may be changed to accommodate manufacturing preferences.

Gearmotors

We talked with many motor vendors to try to find a gear motor with the requirements that we needed. The more we talked with the vendors, the more questions they had for us and the more questions we had for them. We learned a few valuable lessons in being clear and concise when discussing product requirements in a technical context. Throughout this process we discovered that requirements other than speed and torque were necessary to get the gear motor that would work the best for our project (voltage, amperage draw, etc.). After much discussion, we requested quotes from three gear motor vendors, Dumore Motors, Electro Craft and Kollmorgen. We chose Dumore Motors as they were able to meet our required gear motor specifications at an acceptable cost of $315.00 per gear motor. Kollmorgen was cost prohibitive by a large margin ($3303.00 per gear motor and $4678.50 for engineering drawings, tooling and other one time charges). They did not produce a drawing for this specific ½ horsepower gear motor leading us to have concerns on the under-cart clearance. Electro Craft would have had to make changes to castings on the gear motor that would not have been able to have their gear motors completed in the timeframe of our project. We also had concerns about the duty cycle the Electro Craft gear motor was rated for. The peak amperage to be applied for five seconds or no more than twice without ten minutes between cycles which would not be sufficient for our purposes.

We placed the order for the Dumore gear motor. We provided Dumore a drawing that showed the length of the shaft we needed along with other information (key size, tapped hole on the end of the shaft). We requested step files of the gear motors for our powered cart model to verify the fitment. The day before the gear motors were due to ship we received these files and noticed that the shafts on the gear motors were too short. After a conference call with Dumore, we decided to make a spacer that we could bolt to the end of the shaft to make up for the difference in the length of the shorter shaft. Even with the shorter length, the shaft fit through the bearing more than half way giving us confidence that the spacer addition would be an acceptable alternative to remaking the gear motor shafts and delaying shipment for at least another week. Dumore machined these spacers for us without additional cost because they missed the information that we provided them (Figure 15). The gear motors were scheduled to arrive in the first week of January but did not receive the gear motors until February 4th, significantly delaying the project timeline.

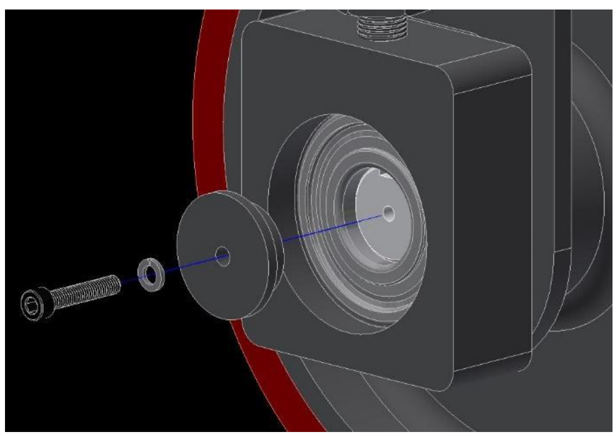


Figure 15: Shaft Spacer Alternative

We initially requested a performance curve of the gear motor that showed torque, amperage and rpm so we could order electrical components that would adequately handle our system. Dumore gave us some information about the gear motors characteristics through conversation but was not able to supply us with a performance curve until they tested the gear motors before shipment. During our conversations about performance of the gear motors, we were told that the motors would draw an amperage of somewhere around 35 amps peak. We purchased some components such as our motor controller based on this information. When we received the detailed performance curve (Figure 16 & 17) we noticed the peak amperage was significantly higher than 35 amps. We were not anticipating two curves, one for each direction of the motors' rotation.

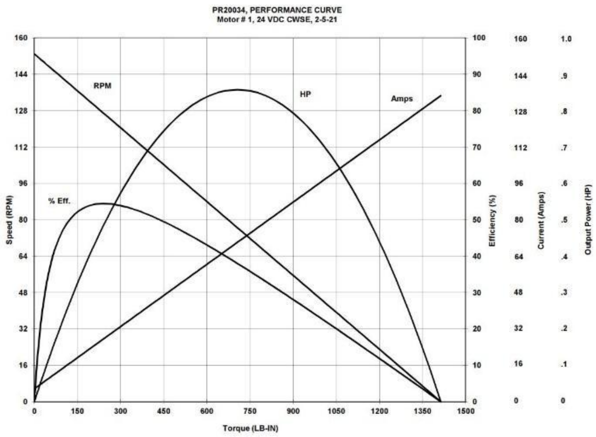


Figure 16: Clockwise Graph

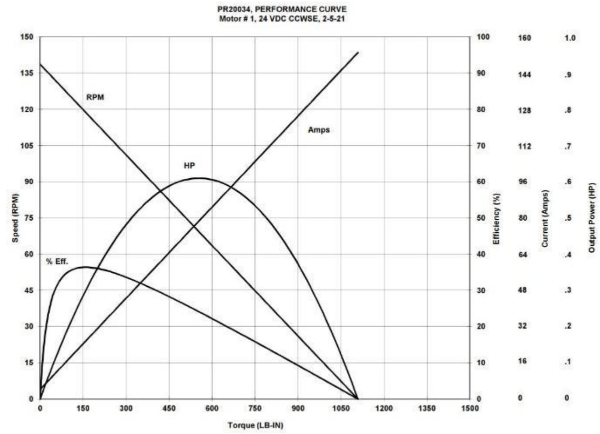


Figure 17: Counterclockwise Graph

We informed Dumore that the mounted orientation of the gear motors needed right-hand and left-hand gearboxes when we initially contacted them. They could not provide right-hand and left-hand gearbox housings in the timeframe we required. In order to continue using these gear motors we had to use the same gearbox for both motors. This causes one gear motor to rotate in a clockwise position while the other gear motor would rotate in a counterclockwise position. This was before we discovered the separate direction dependent curves for these motors. Already being behind schedule by a month, we moved forward compensating for the differences in RPM with the Arduino motor controller code.

Due to using the same gearbox for both motors, one gear motor would mount with the housing closer to the bottom of the cart while the other gear motor would have to rotate 180° along the armature axis in order to be mounted. This caused the ground clearance to decrease beyond our initial layout. We were able to verify the new ground clearance by mocking up the mounting in Autodesk® AutoCAD® (Figure 18) and determined that while less than ideal, this would have to be sufficient for our prototype given the scheduling constraints. We were also concerned that the wire leads of the lower motor could get caught on something and get torn off. We were able to disassemble the electromagnetic brake and body of the gear motor in order to rotate the armature of the motor 180°. This positioned the leads of the gear motor facing up into the bottom of the cart, avoiding any hazards.

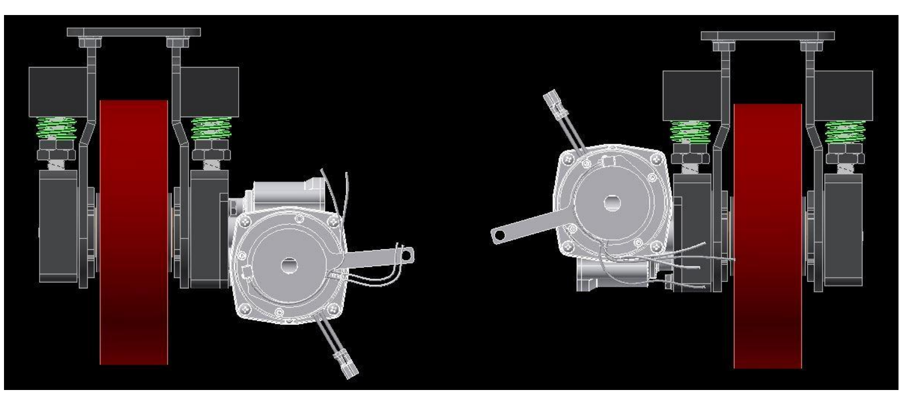


Figure 18: Mounted Gearmotor Orientation

One unexpected issue that we ran into was our original calculated torque requirement for each gear motor was insufficient. When verifying our math with Hamilton Caster we found that one of the equations used to get a torque value on the three degree incline was incorrect. After correcting ourselves we found that the torque required to overcome a full stop on the incline and to continue driving was significantly higher than we had initially determined. Referring to our performance curves we found that the new torque requirement was achievable but not without drawing significantly higher amperage. This posed a problem for our motor controller as it was only capable of continuously supplying 60 amps per motor channel to each of our gear motors. Our new calculations found that at full load, a continuous current of 120 amps (a 2x safety factor) would be drawn to continuously drive the cart up a three degree incline. Even without such a high safety factor, the current drawn when starting from a stop on the incline would exceed the 100 amps for less than one second limitation of the motor controller. With few options short of a full redesign which was not feasible considering our project timeline, we decided to verify the carts final capabilities through testing in order to determine our performance limitations.

Programming Controls

We had initially wanted to tackle the cart controls with a PLC from either Siemens or Allen Bradley since this was what our team was most familiar with. However after some consideration we realized that this would be completely unnecessary as these PLCs would not be the appropriate form factor and would not be able to easily interface with the motor controllers we required. The nature of the "industrial" applications these PLCs are typically applied to, also made the cost prohibitive for our project. In order to achieve customizable control with a small form factor that was within our budget, we opted to use the Arduino® UNO R3. From previous ENT courses we had a basic familiarity with the platform as well as a backup supply of several units should that need arise. We determined that this Arduino had the ideal number of I/O ports and could be attached to a terminal shield for easier wiring installation. For the Cytron SmartDrive DC motor controller we selected, we had to convert the analog to digital signal from the joystick read into a usable number. One of the features that caused us to select this specific controller was its out of the box Arduino support that allowed it to control the motor speed based on a -255 to 255 value sent from the Arduino over PWM input. We were able to normalize the 0 - 1024 reading from our 8 bit analog to digital input reading to 0 - 255 using the equation below. Because a negative value would actually drive the motors in a reverse direction, we had to implement some conditions to ensure this would only happen when the cart was in reverse mode. For example, if the normalized value was below zero, then we would change the value sent to the motor controller to be zero. If the normalized value was above the maximum value (in some cases less than 255), we would then set the value that was sent to the controller to that predetermined max value. We decided to only allow the cart to reverse when in a reverse drive mode because we were concerned that reversing the motors while they were already driving in the forward direction would cause a spike in current and greatly increase the temperatures of the motors.

$$\mathbf{v'} = \frac{\mathbf{v} - \mathbf{min(A)}}{\mathbf{max(A)} - \mathbf{min(A)}}(\mathbf{new\_max(A)} - \mathbf{new\_min(A)}) + \mathbf{new\_min(A)}$$

Figure 19: Normalization Equation

Once we had the normalization implemented we were able to test a single joystick as the throttle control for both motors. While we did not realize this at the time, this test turned out to show us that the motors were in fact not turning at the same speeds when given the same throttle value. To compensate for this deviation we were able to continuously scale back the maximum value for the motor that was spinning too quickly for the other to keep up. We had initially tried to use a tachometer and take measurements throughout the full range of speed for each motor in order to construct a motor specific scale for each of our motors. We found that this was a more complex task and ultimately were able to minimize the drift of the cart with simple trial and error. In order to effectively turn the cart while it was loaded we determined that we still require two analog to digital values from two joysticks, one for each motor. At this time we realized that we would need to use the normalization equation for each input and each joystick would have its own range somewhere between the 0-1024 range we were reading initially with just the one joystick. To minimize the written code and improve runtime, we undertook our first full rewrite. The new iteration independently normalized both joystick reading values and also features a press and hold button in order to toggle the solenoid motor breaks. This press and hold feature prevents the relays that are used to switch the 24 volt brake solenoids, from short cycling as well as from being activated by mistake should the operator accidentally press the button.

The next main issue we encountered when programming the speed control was the jerky behavior of the cart as it decreased speed. We were concerned that rapidly slowing down the cart from 100% throttle to 0% throttle too quickly would dump the load off the bed. This was due to the immense back emf from the motors which worked quickly to bring the cart to a stop as soon as the throttle was released. To overcome this issue we decided to ramp down the throttle over a set period of time in order to reduce the jerk produced by the deceleration of the cart. This portion was a significant amount of the code as it had to be performed for each motor in forward and reverse modes. Those ramp down code had to work alongside the other portions of the code and would not be allowed to delay the execution of each loop of the Arduino’s runtime (See Appendix F for full code). With the ramp down implemented we began to finely tune several parameters of the cart including ramp down duration, maximum speed while turning, and button press duration. For a breakdown of the operating procedure, please refer to Appendix H.

Control Housing

We discussed different types of controllers to drive the powered cart. We thought joysticks would give us the most precise control of the gear motors. There are many types and sizes of joysticks that we thought we could just build a housing around so we could focus on programming the system. First, we bought gaming joysticks but they did not have enough throw, or physical resolution, to give us the desired control we were looking for. The joysticks made operation very jerky and allowed only for stop, medium speed and high speed. While we were experimenting with the joysticks, we were also designing a housing that would accommodate the joysticks and other components we were going to need; voltage display, control buttons and an emergency stop button. We started with a sketch for an idea for a control housing by designing the housing to limit the movement of the joysticks to only vertical movement as the joysticks can move in a 360° fashion. The housing was designed to be in two pieces so that the front housing and the rear housing could be fastened around the cart handle giving it stability. This design was continuously adjusted in order for the assembly to be quickly and efficiently 3D printed. We planned to run the wires from the joysticks, and other wires from the rear housing, through the cart handle by drilling holes in the handle and running the wires down to the Arduino® controller (See Figure 20 & 21).

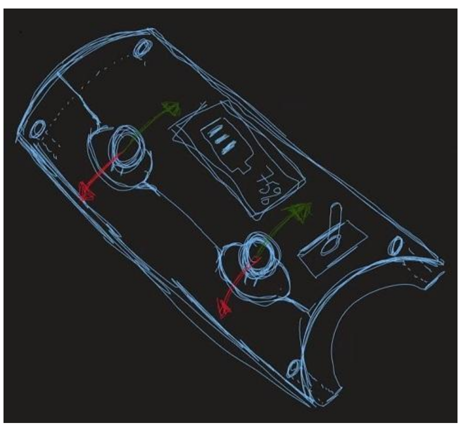


Figure20: Original Control Housing Concept

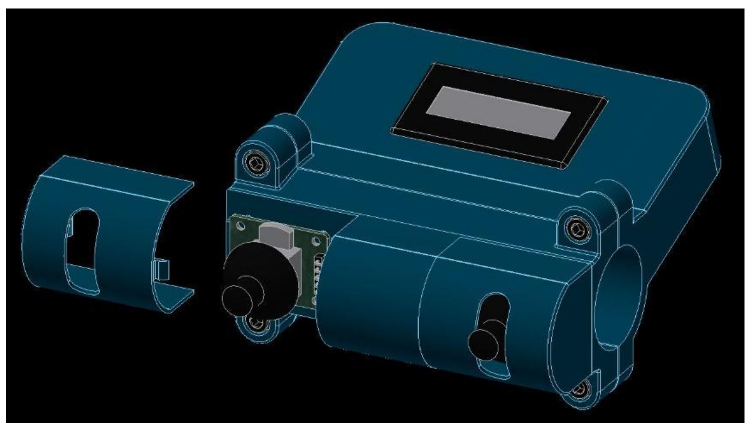
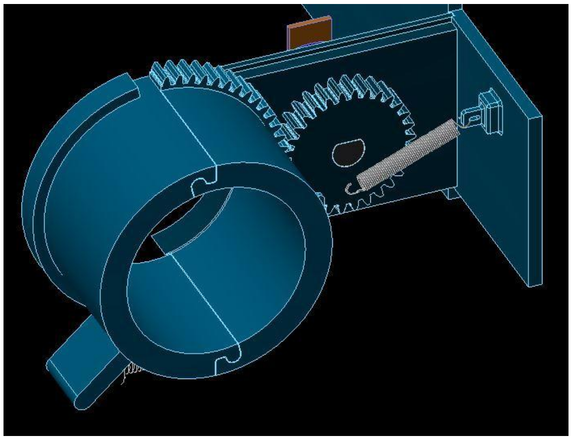


Figure 21: First Iteration of Control Housing

With the gaming joysticks not giving us the smooth operation we required, we bought a joystick for a RC hobby aircraft controller. With this change, we had to redesign the controller housing but we waited to do any revisions until we proved the new joystick would function to our needs. The new joystick was much larger with a larger throw than the gaming joysticks but still did not have enough resolution to give us the desired control we were searching for. This new joystick would not home to a zero reading meaning that we would have to further reduce our input range in order to prevent reading a negative value in the Ardunio's normalization equation. At this time we determined that neither joysticks would work for our application. After brainstorming what we would like to have, we came up with a mechanically controlled potentiometer assembly as seen in Figure 22 & 23.



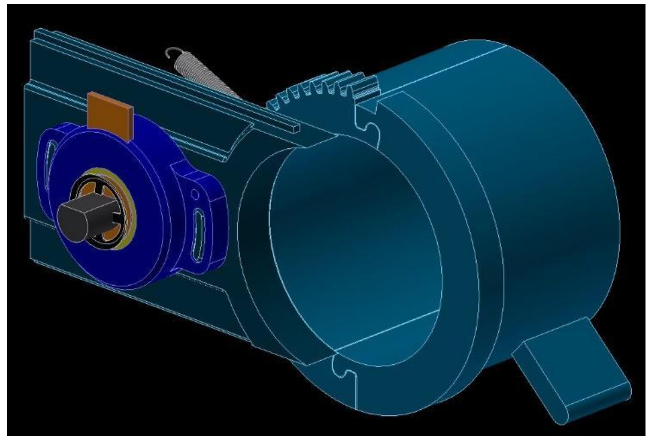


Figure 22: Thumb Paddle Drive **Figure 23: Driven Potentiometer**

This would function as the thumb paddles would be moved up and down to rotate a set of gears and ultimately adjust the potentiometer. The front housing's main purposes would be for the stable connection of the entire unit to the cart handle and for the thumb paddles to be housed with restricted movement of 85° of rotation. The rear section of the housing would carry the rear section of the thumb paddles with gearing, the pinion gears, the potentiometers, the return springs, the e-stop button, the voltage display and the other buttons and lights for safe operation. The thumb paddle wheels were 3D printed in two sections so that we could assemble and/or disassemble them around the cart handle easily. Each front section of the thumb paddle wheels had a lever protruding from the wheel so that the operator could manipulate the wheel in a vertical fashion. Each rear section of the thumb paddle wheels has a spring that is attached to it and to the rear housing. This is to make sure the thumb paddles always return to zero even when the powered cart is not in operation. The rear section also had enough gear teeth on it to rotate the pinion gear (which was attached to the potentiometer) for operation. The gears were set up to be a 2:1 ratio so that when the thumb paddle moves 85°, the potentiometer would move 170°. With the larger angular displacement we would be able to access more of the potentiometer's resolution. All of the components would be 3D printed giving us the flexibility to rapidly adjust the prototype as required. This would also give us the ability to place a voltage display, e-stop button and other buttons within the main housing as needed for safe operation of the powered cart. Although our first prototype had some issues of fitment, we were able to prove that the potentiometers would give us the control we desired for smooth operation. We would go through 4 or 5 iterations to get the tolerances correct for smooth movement, optimum 3D printing (time, minimal thermal warping, smallest parts and minimum components) and placement of necessary components for safe operation (See Figure 24).

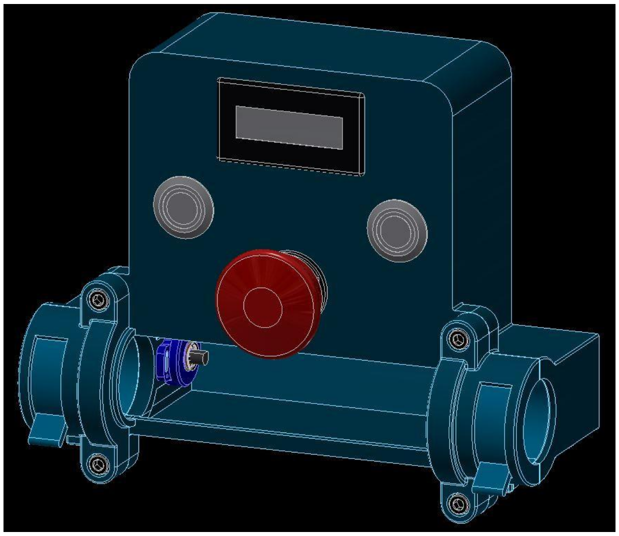


Figure 24: Final Control Housing Design

While in development of the control housing, we noticed that our original idea of running the control wires through the cart handle was not the optimal design. It would be much easier and more convenient to run the wires out from the rear of the control housing and into the battery cabinet on the rear of the cart. This would allow access to the wires if any service was required and it allowed us to more easily connect the wires to the Arduino® controller which was housed inside of the battery cabinet (See Figure 25).

Figure 25: Control Housing Wire Path

Conclusions & Recommendations

Once the cart was fully assembled and programmed we were able to validate its operating capacity at 4000 lbs on a smooth and flat concrete surface (See Appendix J). Due to the limitations of our motor controller's maximum current for each motor channel, we were not able to drive the cart up an incline of 3 degrees. Based on our calculations we would be exceeding the maximum 100 A draw for less than one second per channel, by nearly 30% and would be required to do this continuously. We tested the cart on a 5 degree incline with 3100 lbs and quickly tripped the 100 ampere resettable fuse before traveling a significant distance. Our peak ammeter reading during this test was 228.7 amps (see Figure 26) We were not able to verify the max run distance of the cart due to restrictions on the availability of weight and the time required to fully run down the batteries.

<u>Figure 26: Max Current Reading on 5° Incline Test</u>

There are several areas for improvement that we would recommend for a second iteration of this cart. We would like to increase the capabilities of the motor in order to access higher amounts of torque at a safety factor of at least 2 while operating a continuous duty cycle. This would likely result in a higher current draw from our batteries which would then have two more outcomes. First, the motor controller would need to be sized appropriately to a higher amperage rating. We would recommend the 160 amp single channel motor driver from Cytron technologies as the Arduino® code would seamlessly integrate with this controller. However, this would implicate a second Arduino®, one for each of the motor controllers and would complicate the synchronous control of reverse mode and the brakes. Alternatively another motor controller could be sourced so long as it would be capable of receiving a value from an Arduino®, which then the values would need to be adjusted in the code accordingly. Secondly we would recommend investing in another form of batteries as the ones we have selected would likely not support the required range if higher amperage drawer motors were selected. We would hope to see Lithium polymer batteries that could produce the voltage and amp-hours required while in a smaller and lighter form factor.

We would also recommend using a large diameter caster in order to lift the cart off the ground and improve the clearance issues that we experienced. This would likely improve the variety of compatible gearboxes and motor combinations. Alternatively, we would recommend adding shims between mounting plate and cart body mounting brackets so that the cart would sit higher from the ground if other caster diameters are not available. Increasing the caster diameter is preferable as it would not only reduce the torque required from the motors to move the same load, it would also improve the manual operation of the cart by reducing the force required by the operator.

The manual operation of the cart while powered off with the brakes mechanically disengaged is still difficult with any sufficient load on the cart. While this is useful in some cases, we would like to see a motor that had a true neutral mode so that the wheels could spin freely on the motor stator. In sourcing a motor that could be capable of this it is also worth noting that we would prefer to have had right hand and left hand specific gearboxes for our motors. This would have allowed us to have greater ground clearance as well as nearly identical performance curves as each of our motors would be turning the same clockwise direction when driven forwards or reverse.

Lastly, we would recommend adding in some form of active current monitoring. This would allow the cart to dynamically allocate power as the load increases and decreases. Through our testing we found that in certain situations (such as turning) full throttle would be dangerous to the operator. In attempts to improve the safety of the cart we limited the turning throttle to 40% to prevent the end of the cart from kicking the operator into a pinch scenario. As we began testing the cart with significant loads over 2000 lbs, we noticed that the 40% max throttle was limiting the carts capability as the mass had enough interia that the operator could use the cart safely. Through load sensors or a hall effect sensor, max throttle could be determined on an as needed basis allowing the cart to be operated safely throughout the range of its design capability. Note that adding more inputs or outputs to the Arduino® would require a model such as an Arduino® MEGA.

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Appendices

A-Meeting Journal

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[X]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[ ]
Student:	**Gregory Drew**	[X]

Meeting Date: 9/17/2020
Meeting Location: Virtual/WebEx

Topics Discussed
Design Ideas for Drives, Battery mounts, Control/Steering, etc.
Requirements for final cart product(emergency stop, reversable motor, etc.)
Implementation of various features like control and breaking
Battery Ideas and how to mount them, space constraints
Working on Proposal
Working with Project from Microsoft

Responsibilities/ Actions Taken
Greg reached out to Gary Regaring Finanical questions and funding
We collectivbely worked on documenting our ideas and design features

Next Meeting Date: **9/24/2020** **Location** Virtual/WebEx

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[X]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 9/9/2020
Meeting Location: Webex

Topics Discussed

Video Review

Demands- Weight, power, time duration, caster types, safety

Options- Stand alone system versus on wheel attachments

Current Technology

Whats out there right now? Powered pallet jacks

Responsibilities/ Actions Taken

Create Group Chat

Make contact with Hamilton Caster
-Set up meeting with finalized questions.

Next Meeting Date: 9/10/20 **Location** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[x]
Student:	**Tyler Sargent**	[x]
Student:	**James O'Brien**	[x]
Student:	**Greg Drew**	[x]

Meeting Date: 09/24/20
Meeting Location: Virtual/Webex

Topics Discussed

Add to design ideas: type of motor, type of drive system
Need a charging system for desired battery
Working on Proposal
Working on Gant Chart

Responsibilities/ Actions Taken

Everyone is going to work on the proposal on Google Drive
Professor Drigel is reaching out to Hamilton Caster to question funding based on previous email from team
Email Hamilton Caster to ask for wheels and handle (if not supplied with cart)
Email Bodine Motors to see if they can supply a motor with our requirements

Next Meeting Date: 10/01/20 **Location:** Virtual/Webex

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 10/1/20
Meeting Location: Webex

Topics Discussed

Tour:	-October 13th @ 9:00 AM		3-D software?	
		Current modeling Analysis?		
Meeting:	-October 8th @ 4:30 PM			
Progress:	Finalize Proposal, Continue Gnatt Chart, and prepare for meeting.			
Ideas:	Control Systems	-Rasp Pi	-PLC	-Arduino?
			PLC costs? Size?	
	Deadman Switches		Joystick controls?	

Responsibilities/ Actions Taken

Gnatt Chart -Kendall and Tyler

Contacting Motor Suppliers -James and Greg

Working on Controls design container -Tyler

Wheel Coupler to electric motor -Greg

Next Meeting Date: **10/8/2020** **Location:** In Person Phelps 102

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 10/8/20
Meeting Location: Phelps 102

Topics Discussed

Tour: -October 13th @ 9:00 AM — 3-D software? Current modeling Analysis?

Meeting Discussion:
-Seeing new drive wheels for the first time/ how to use
-Design concepts for battery tray, control panel
-Recalculated torque and rpm specs
-Control system specs and looking for electrical components

Work on finishing proposal and gnatt chart / turn in for Gary for alterations

Responsibilities/ Actions Taken

Gnatt Chart -Kendall and Tyler

Contacting Motor Suppliers -James and Greg

Tour of Hamilton Caster on Tuesday -Everyone

Next Meeting Date: 10/15/2020 **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[ ]
Student:	**James O'Brien**	[ ]
Student:	**Gregory Drew**	[X]

Meeting Date: 10/13/20
Meeting Location: Hamilton Caster

Topics Discussed

Tour: -October 13th @ 9:00 AM

-Operation and history of the company

-Variety of products and services to help with the modifying of our project

-Different types of bearings and mounts we can use to help with drive wheel

-Inventor 3-D modeling used in their company / give project back in same form

Responsibilities/ Actions Taken

Contacting Motor Suppliers -James and Greg

-Get spec sheets from all motor supplier options.

-Turn in Proposal with sketches / information.

-Finalize emergency and parking brake situation

-Continue to look for control systems and control types.

Next Meeting Date: 10/22/2020 **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 10/22/20
Meeting Location: Webx

Topics Discussed
Meeting with Kollmorgen Motor
Various frames of DC brushless motors and which would fit our application
Switching to DC Brushed motor to reduce cost and simplyify control

Thursday Meeting
Motor Mounting, transferring power to the caster wheel
Deciding to key the shaft of the motor
How best to approach assembly with a keyed shaft in between two bearings and a caster

Responsibilities/ Actions Taken

-Requesting 3-D model of Kollmorgen Motor that fits our specs
-Quote for motors
-Keyway for length of shaft

-Contacting Hamilton about Keying and Bearings for modified setup
-Keyway for 1 inch diameter shaft
-Ball bearings for 1 inch shaft
-Solid forged wheel custom bored to our 1 inch shaft (including key)

Next Meeting Date: 10/29/2020 **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[X]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 11/18/2020
Meeting Location: WebEx

Topics Discussed
Purchase order form requesting purchase of motors

Kollmorgen motor quote was way out of budget at nearly 16,000 for two.
Dumore has temporarily closed due to covid we are waiting to hear back Monday

Electrocraft is the best option at this time. Waiting to hear from Dumore on Monday 11/23
before we submit the finalized purchase form

Reviewed Presentation and finalized slides

Responsibilities/ Actions Taken

Greg is reaching out to contact at Dumore for a last chance response.

Tyler filled out the purhase request form and is awaiting dumore response

We are all brainstorming on what to do if we select the eltro craft motor and how
we should try to mount it to the cart

Next Meeting Date: 11/26/2020 **Location** WebEx

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[X]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 10/29/2020
Meeting Location: WebEx

Topics Discussed

-Fleck Grant
-Futher Motor Selection Discussion, which combinations of motors andcasters and caster mounts motors and casters and caster mounts should be used.
-Shaft selection, how this impacts our braking systems selection.
- Ethics assignment

Responsibilities/ Actions Taken

-Recieve motors and final offers for drive motors for our applicaitons

-Process working combinations for the project.

-(Future) Possibly present findings to Hamilton Caster to help pick a choice

Next Meeting Date: **11/5/2020** **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 12/1/2020
Meeting Location: Webex

Topics Discussed

Finalize Motor Choice:
-Dumore adapted to our requirements
-Dumore clear choice, with electro craft as back up.
Quantity:
Buy 2+? -Get two for now to mock up
-buy spares after system running
Purchase Request:
-fill out and send to Gary FWD to Frank
Next:
-Batteries, control components, other orders.

Responsibilities/ Actions Taken

Orders Sent Out -Tyler

Hamilton Caster Contact -Greg/Kendall

Battery Calculations -James

Final Report / Reflections -Everyone

Next Meeting Date: **12/15/2020** **Location:** **Hamilton**

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 1/7/21
Meeting Location: Webex

Topics Discussed -Controls
-Arduino Testing / Start Code for process
-Battery Storage |-> Test Rig
-Compartments for batteries / 4 batteries positioning /
-Calculations
-Correct and update weights for calculations
-Check incline calculations to find correct torque for cart max load
-Run updated numbers pass engine manufacturer
-Machining
-Quotes from HC internal and two external companies
-Process of manufacturing with bearings / bearing blocks / spring tension
-Spring tensioning style analysis, discussing methods of attachment

Responsibilities/ Actions Taken

-Calculation Finalization
-Greg / Kendall

-Recieve Orders
-James / Greg (Waiting on Frank)

-Controls and Coding
-Tyler / Kendall

Next Meeting Date: 1/14/2021 **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 1/14/21
Meeting Location: Webex

Topics Discussed Deliveries:
-All Batteries arrived, motors shipped
Battery Case:
Free 8" deep drawers donated by MacTool Co. (Cut to fit)
Stress Analysis:
-FEA analysis sent to H.C. (fatigue issue of bearing block) and reconfigured calculations on torque.
Controls:
-Test system works good with arduino, list out wants for code, find paddles to work with the system. -Ramp speed, reverse toggle, safety
Mock Up Plans:
-Batteries are with the cart in Phelps, rig up batteries, battery compartments , motors, wheels, and future controls.

Responsibilities/ Actions Taken

Greg: -Contact Dumore with updated calculations / future motors
-Motors that could provide all torque

James: -Support machining track of parts

Kendall: -Look for controls and work on code requirements for motor.

Tyler: -Continue testing with motor controller/code analysis

Next Meeting Date: 1/21/2021 **Location:** Webex/Maybe Ham.

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	Gary Drigel	[ ]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[ ]
Student:	Gregory Drew	[X]

Meeting Date:	1/28/21
Meeting Location:	Webex

Topics Discussed

Motors: -Shaft too short/There fix to ship on time -Strength of components

Motor Guard: -Design brush guard to protect motors under the front of the cart

Controls: -Safety concerns, OSHA regulations, Triggers-buttons

Wheel Bearing Brackets: -Picking up parts and puting items together soon

Battery Compartments: -Kyle Purdy (Stanley B&D) custom made drawers for batteries, custom made brackets for tracks, Black paint.
-Double check dimesions of cart and see the terminal length on the batteries

Responsibilities/ Actions Taken

Greg:	-Check terminal Length On Battery, Press bearings
Tyler:	-Controls progression and added features to code
Kendall:	-Motor guard built and features to the code/Order drawers
James:	-Charging system for batteries

Next Meeting Date:	2/4/2021	Location:	Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	Gary Drigel	[ ]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date:	2/4/21
Meeting Location:	Webex

Topics Discussed

Mechanical assembly of cart on campus
Conductor sizing based off peak current for connecting batteries and motor controller
Fuse sizing based off current from motor
Caster and shaft do not mate, need to get with Hamilton Caster to machine the Caster

Responsibilities/ Actions Taken

Greg:	Contacting Dumore for peak amps and motor specs documentation working with Hamilton Caster to a make shaft and caster fit
Tyler:	Working on code for Arduino and motor controller
Kendall:	Researching charging system with James, looking into parking sensor
James:	Looking into purchasing conductor based on response for peak amps looking into battery terminal connections

Next Meeting Date: 2/11/20	Location:	Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	Gary Drigel	[X]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date:	2/18/21
Meeting Location:	Webex

Topics Discussed

-Wheel fixed to fit on shaft, assembly and preload springs on drive casters

-Initial wiring and testing based off test rig

-Check mechanical wear on components (Concerns about power wires on left motor)

-Budget sheet - finalize orders and add minor piece parts

Responsibilities/ Actions Taken

Greg:	-Check with dumore about different motor speeds
Tyler:	-continue programming with two controls (ramp in formula?)
Kendall:	-Program aid and go through safety feature
James:	size conductor based off currents read during testing

Next Meeting Date:	2/25/2021	Location:	Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	Gary Drigel	[X]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date:	2/25/21
Meeting Location:	Webex

Topics Discussed

-Conductor Needed for official wiring

-Ramp in motor controller vs ramp in delay

-Budget Analysis for Battery charger

-Motor casing orientation for power wires (pointed at ground, rotate 180 degrees)

-Buttons, joysticks, lights, and control panel design -Higher sensitivity needed

-Safety standards, OHSA

Responsibilities/ Actions Taken

Greg:	Control Design Panel and RPM info back to Dumore
Tyler:	Programming and Development
Kendall:	Safety and Programming aid
James:	Battery charging system

Next Meeting Date:	3/4/2021	Location:	Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	Gary Drigel	[X]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date: 3/4/21
Meeting Location: Phelps Lab

Topics Discussed

-New toggle switch testing

-Update on MacTool Custom drawers for battery compartments (in Process now)

-Limit speed based on load size or off toggle switch

-Run relay to electro magnetic brakes controlled by button press (Parking brake)

-Finalize small purchases to see how much we have left for final big purchase

Responsibilities/ Actions Taken

Greg:	-Control panel design based off 2-1 potentiometer design
Tyler:	-Programming based off basic controls and ramp in speed
Kendall:	-Push through on drawer production
James:	-\Purchase battery life indicator and battery charger.

Next Meeting Date: 3/11/2021 Location: Phelps Lab

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	Gary Drigel	[ ]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date: 3/18/21
Meeting Location: Phelps Lab

Topics Discussed

-Prototype of potentiometer control setup with 3d printed

-Battery drawer is finished and is being shipped

-Order control wire, battery cable, terminals, buttons, switches

-Finish programming / smooth out ramp up or ramp down functions

-Wheels spinning at different speeds (still need to fix)

Responsibilities/ Actions Taken

Greg:	Design controls with improvements
Tyler:	Continue ramp in programming
Kendall:	Aid with programming / drawer plans
James:	Order small items and price battery controller

Next Meeting Date: 3/25/2021 Location: Phelps Lab

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	Gary Drigel	[ ]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date: 3/25/21
Meeting Location: Hamilton

Topics Discussed

-Recieve battery compartment drawer and set under cart

-Take measurements for brackets

-Shift focus from ramp up to ramp down

-New controls remove the need for ramp in function

-Bugs in program/ redo calculations

Responsibilities/ Actions Taken

Greg:	-Redo controls to include buttons and E-stop (tolerances)
Tyler:	-Switch ramp in to ramp down only (debug)
Kendall:	-Build brackets for drawer and mount
James:	-Order buttons, estop, and 90 degree connectors

Next Meeting Date: 4/1/2021 Location: Phelps Lab

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	Gary Drigel	[ ]
Student:	Kendall Purdy	[X]
Student:	Tyler Sargent	[X]
Student:	James O'Brien	[X]
Student:	Gregory Drew	[X]

Meeting Date: 4/1/21
Meeting Location: Hamilton

Topics Discussed

-Final Assemlby of the battery drawer under the cart

-Rewire system in the drawer under the cart

-Test system with ramp down and reverse / try to find solution to delay issue

-Make final list of hardware needed for the last few weeks

-Organize weight payload tests for final testing

Responsibilities/ Actions Taken

Greg:	Help with final print of controls system with buttons/screen
Tyler:	Print final controls / Add to code for final rendition
Kendall:	Aid with programming for final form/ finish battery box
James:	Set up weight test and gather final hardware for electrical connections

Next Meeting Date: 4/7-8/21 Location: Hamilton

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 4/7-10/21
Meeting Location: Phelps Lab

Topics Discussed

(7th)
-Move wiring and arduino into drawer temperarily
-Take cart to Deshazo in Monroe for Payload test.
-Test 0-4000lbs in forward and reverse
-Test on slight incline
-Get documented weight file and video documentation of results

(8th)
-Test indepedent motor controls
-Start assebly on secondary battery cabinet
-Work on safety code for turning (dangerously fast)

(10th)
-Mount secondary cabinet for batteries (support brackets, handle brackets)
-Figure out battery cable routing and orientation for final configuration.
-Find ways to secure batteries, arduino, and control wire in back cabinet
-Control system internal supports, spade contectors, and tweaking

Responsibilities/ Actions Taken

Greg: Final check of controls and start presentation board

Tyler: Turning safety code and schematic for final wire up

Kendall: Battery secure system and documentation

James: Final wire up and routing

Next Meeting Date: 4/15/2021 **Location:** Phelps

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 4/15/21
Meeting Location: Phelps

Topics Discussed

-Rubber mat the drawer and cabinet for safety

-Cut holes in cabinet and install gromets to keep incoming wires safe.

-Find best path for cables under the cart

-research and secure battery parallel - series connections

-Where to put e stop relay and fuse

Responsibilities/ Actions Taken

Greg: Final sand on controller parts, new front coming

Tyler: Print controller parts and adjust code for new findings

Kendall: Finish battery secure mounts

James: Frank orders battery charger

Next Meeting Date: 4/17/2021 **Location:** Phelps

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[X]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 4/17/21
Meeting Location: Webex

Topics Discussed

-Final assembly for secondary cabinets brackets, selves, and battery tie-down blocks

-Double check power cables (found one in wrong spot)

-Spade connect all control components and cut wire

-Tie up cables under cart using tie pads and zip ties

-mount motor controller, fuse, estop relay, and other things to stand off in drawer.

-Schedule out finishing touches, poster, presentation, speakers, and other final dates

Responsibilities/ Actions Taken

Greg: -Touch up controls

Tyler: -Finish control wire pin out and calibration monday

Kendall: -Finish control wire pin out and calibration monday

James: -Battery charger

Next Meeting Date: 4/19/2021 **Location:** Phelps

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: Hamilton Caster Project

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date: 4/19/21
Meeting Location: Phelps

Topics Discussed

-Finalize and check power wiring for all 4 batteries

-Sort out cabinet wiring
-Tie common wires together from controller to stand off
-Re-do arduino standoff board
-Add 24 volt terminals and bread board

-Solder and make final in line connections for running wire.

-Power up buttons and battery status guage / they work

Responsibilities/ Actions Taken

Greg: Smooth up left trigger, final controls assembly

Tyler: Get final controls pin out for controls wiring.

Kendall: redo arduino stand off and ferrel connections

James: Purchase order for battery charger

Next Meeting Date: 4/21/2021 **Location:** Webex

MIAMI UNIVERSITY

Meeting Journal
Department of Engineering Technology
ENT 497 - Senior Design Project
Project Title: **Hamilton Caster Project**

		Present
Advisor:	**Gary Drigel**	[ ]
Student:	**Kendall Purdy**	[X]
Student:	**Tyler Sargent**	[X]
Student:	**James O'Brien**	[X]
Student:	**Gregory Drew**	[X]

Meeting Date:	4/20-22/21
Meeting Location:	Webex

Topics Discussed

20:
-Fix sticking left trigger | -Final controls pin out

-Add turn safety code | -Test for bugs

21:
-Add final pictures to poster -Increase font of code

-Discuss presentation -Start presentation aid -Turn in poster

22:
-Finish presentation aid, divide up slides, write notes and practice run thoughs.
-Record and turn in presentation

Responsibilities/ Actions Taken

-Poster due 21st

-Video presentation due 23rd

-2 minute pitch (James) on the 30th at 1-3:30

-Final Report due May 10th

Next Meeting Date:	**4/28/2021**	**Location:**	**Phelps**

B-Oral Presentation Slides

Introduction:

- Design competition with other senior design groups for electric drive assist cart.
- Seeking creative solutions for a bolt on design.
- End product of a functioning prototype, basis for market research.

Objective:

- 4000 lbf capacity
- 3 mph minimum travel speed
- Capable of climbing 3 degree incline
- Safety features

Goals:

- Receive major components from Hamilton Caster:
  - Cart
  - Static Casters
  - Swivel Casters
- Brainstorming :
  - Drive System
  - Control System
  - Breaking System
- Design
  - Calculations to meet requirements
  - Select Motor
  - Select components that support drive system

Electric Drive System:

- Constraints
  - Clearance
  - Mounting orientation
  - Shaft length
  - Duty cycle
  - Current draw
  - RPM
  - Torque

Parts: Motor/Design

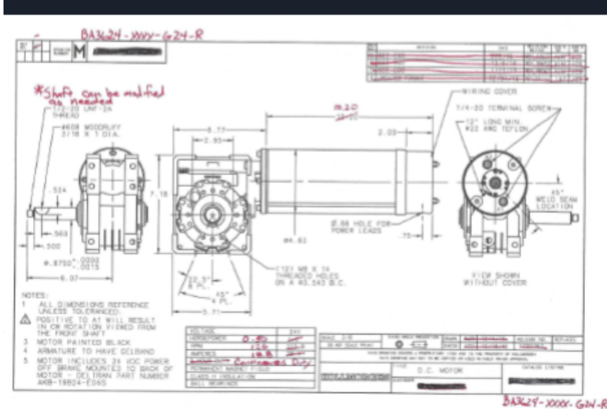
The drive system will consist of two Brushed 24V DC Geared motors. These photos are two ways we can mount the motors based on rotation.

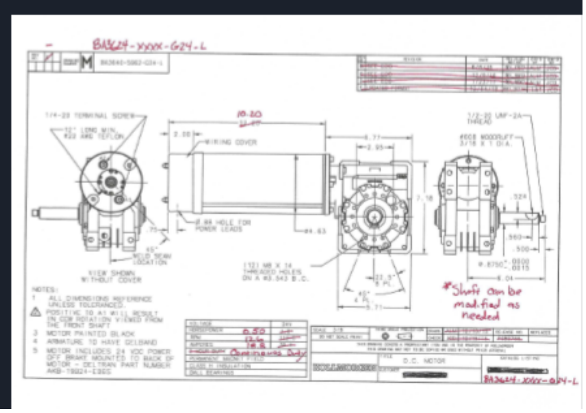
Left and Right Motor Orientation

Right and Right Motor Orientation

Parts: Motor/Design

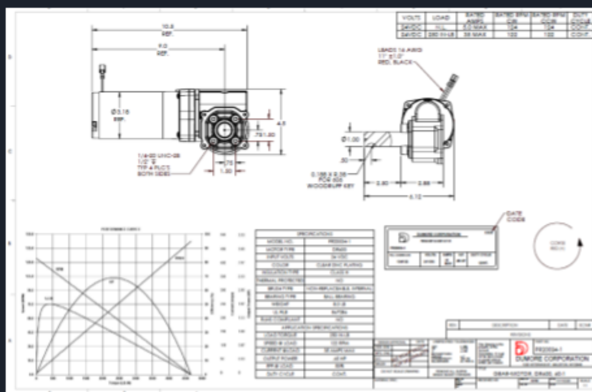
Kollmorgen provided us motors to reach the specifications required by Hamilton Caster. The print on the left is for the right hand motor and the print on the right is for left hand motor.

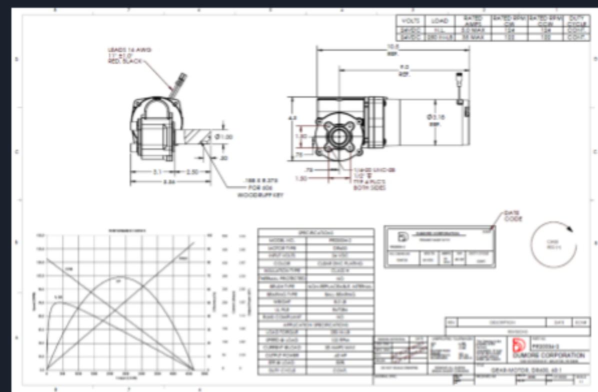




Parts: Motor/Design

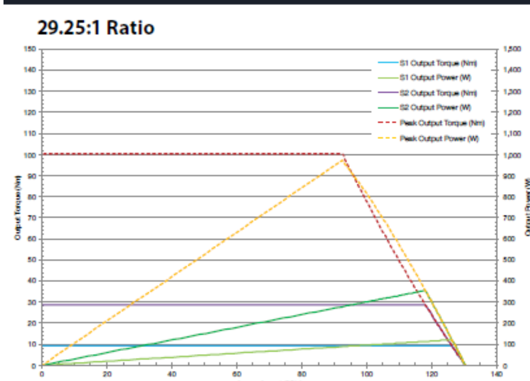
Dumore provided us motors to reach the specifications required by Hamilton Caster. The print on the left is for the right hand motor and the print on the right is for left hand motor.

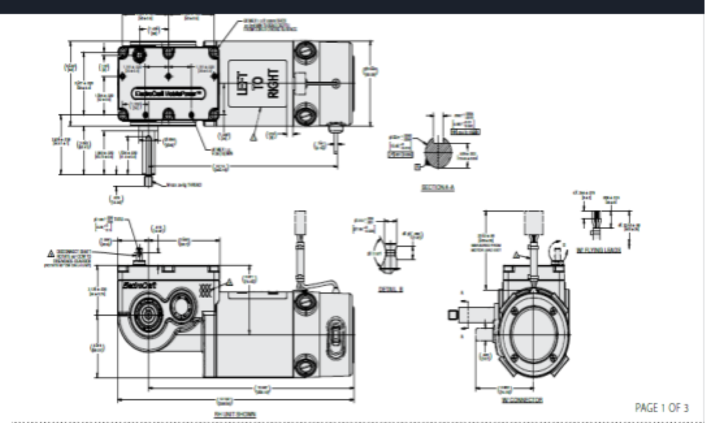




Parts: Motor/Parts

Electrocraft motors are another selection of a motor but have no direct way to mount the gearbox to the caster. This motor though has great specifications for what is required.





Parts: Motor Options / Data

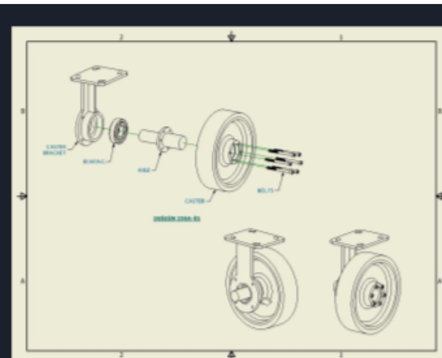
Supplier	Motor Part Number	Price per Motor	Peak Torque	Continuous Torque	Peak Amps	RPM	Voltage	Motor Brake	Restrictions	Lead Time
Electro Craft	MP36-WR-029V24-400-X	$300.00	100.45 Nm (889 lb in)	9.16 Nm (81.1 lb in)	80 Amps (5 sec)	126 (No Load)	24 VDC	Yes	Time allowed at peak torque, No mounting holes	4 Weeks for 29:1 Ratio, Gear Ration Up or Down is 2 Days for Delivery
Kollmorgen	BA3620-6001-G26	$7,981.50				126 (No Load)	24 VDC	Yes	Cost prohibitive, Talking with motor vendor to understand pricing	Not specified, must be designed and manufactured - not an off the shelf motor
Dumore	DR600	$250.00		250 lb in	35 Amps	126 (No Load)	24 VDC	No	Can only be mounted from one side, Casting cannot be changed to accommodate mounting for opposite rotation, Shaft bearings of motor will not support weight	4-6 Weeks ARO

Dumore DR600

Electro Craft MP36

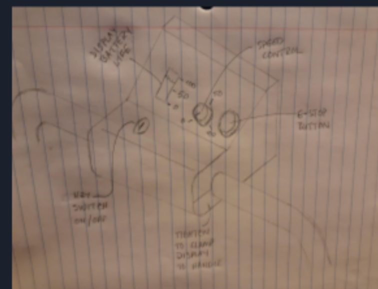
Parts: Caster Design

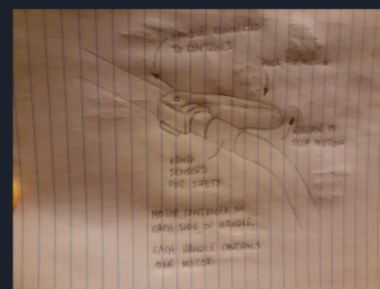
- Will need a mounting solution for either motor
- Reused standard shock absorbing suspension spring
- Dumore should bolt on to the newly designed caster bracket
- Electro Craft motor needs special mounting to newly designed caster bracket



Current State

- Actively choosing our drive motor
  - Dumore DR600
  - Electro Craft MP36
- Mechanical Design features
  - Motor shaft length
  - Bearing support for load
  - User Interface
- Pro's and Con's of controls systems
- Batteries (Depends on motor)
  - Battery Bank system





Gantt Chart

Hamilton Caster Project	**170 days**	**Thu 8/20/20**	**Wed 4/14/21**	
Planning	**66 days**	**Thu 8/20/20**	**Thu 11/19/20**	
Determine Project	13 days	Thu 8/20/20	Mon 9/7/20	
Brainstorm Project Design	12 days	Tue 9/8/20	Wed 9/23/20	
Prepare Proposal	**22 days**	**Thu 9/24/20**	**Fri 10/23/20**	
Create Work Breakdown Structure	3 days	Thu 9/24/20	Mon 9/28/20	
Cost Analysis	2 days	Tue 9/29/20	Wed 9/30/20	6
Gantt Chart	6 days	Thu 10/1/20	Thu 10/8/20	7
Compose Proposal	6 days	Mon 10/12/20	Mon 10/19/20	8
Submit Updated Proposal if Required	**7 days**	**Thu 10/15/20**	**Fri 10/23/20**	
Prepare Presentation	**11 days**	**Thu 11/5/20**	**Thu 11/19/20**	
Create PowerPoint	5 days	Thu 11/5/20	Wed 11/11/20	
Practice Presentation	3 days	Mon 11/16/20	Wed 11/18/20	
Oral Presentation (WebEx)	1 day	Thu 11/19/20	Thu 11/19/20	
Design	**48 days**	**Fri 10/16/20**	**Tue 12/22/20**	5
Calculations for design Requirements	5 days	Fri 10/16/20	Thu 10/22/20	
Drive System	**22 days**	**Fri 10/23/20**	**Mon 11/23/20**	
Motor Determination	7 days	Fri 10/23/20	Mon 11/2/20	
Battery Determination	7 days	Fri 11/6/20	Mon 11/16/20	
Power Transfer Determination	7 days	Fri 11/13/20	Mon 11/23/20	
Control System	14 days	Tue 11/24/20	Fri 12/11/20	19
Breaking System	7 days	Mon 12/14/20	Tue 12/22/20	23
Purchase/Receive Parts	**93 days**	**Mon 9/14/20**	**Wed 1/20/21**	
Receive Cart	1 day	Mon 9/14/20	Mon 9/14/20	
Buy Parts	21 days	Wed 12/23/20	Wed 1/20/21	24
Fabrication	**56 days**	**Thu 1/21/21**	**Thu 4/8/21**	
Mock fitting	7 days	Thu 1/21/21	Fri 1/29/21	27
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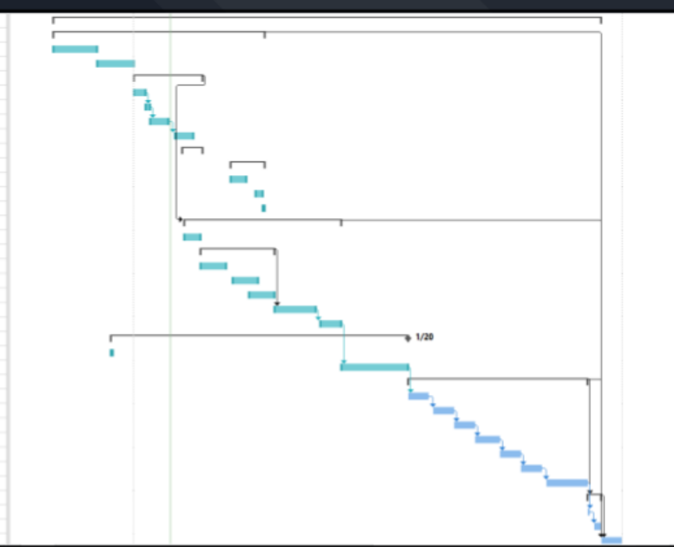
Final Presentation of Completed Project	7 days	Thu 4/15/21	Fri 4/23/21	2,17,28,36



Cost Analysis:

1. Hamilton Caster Cart (Supplied by Hamilton Caster)
2. Electrical motors/ 90 degree gearbox (BA3624-XXXX-G24-R, BA3624-XXXX-G24-L, for both wheels)........................$1000
3. Batteries for Cart (2 110 AH)..$550
4. Programmable logic controller and wiring……………....$300
5. Safety devices and sensors…………………………….....$250
6. Steel for fabrication…………………………………….....$200
7. Bearings and Miscellaneous Hardware………………….$200
8. Final Cost…………………………….........................$2500

Fleck Grant Approval for $2500!

Conclusion:

- In a Good Spot
  - After motor selection everything starts moving
- Hamilton Caster
  - Open communication with Hamilton Caster engineers
  - Once design of caster bracket is complete, we will contact them for manufacturing of components
- Motor Vendors
  - Have been helpful
  - Some take time to respond

Questions?

References

1. "Ace." *Velocio Networks*, 2020, velocio.net/ace/.
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3. "Bodine Motors." *JT Fewkes*, 2020, bodinemotors.net/.
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5. "DR250 Permanent Magnet DC (PMDC) Right Angle Worm Drive Gear Motors." *DR250 Right Angle Gear Motors | Permanent Magnet DC Right Angle Gear Motors*, www.dumoremotors.com/dr250-gear-motors.html.
6. *Hamilton Caster*, 2020, www.hamiltoncaster.com/.
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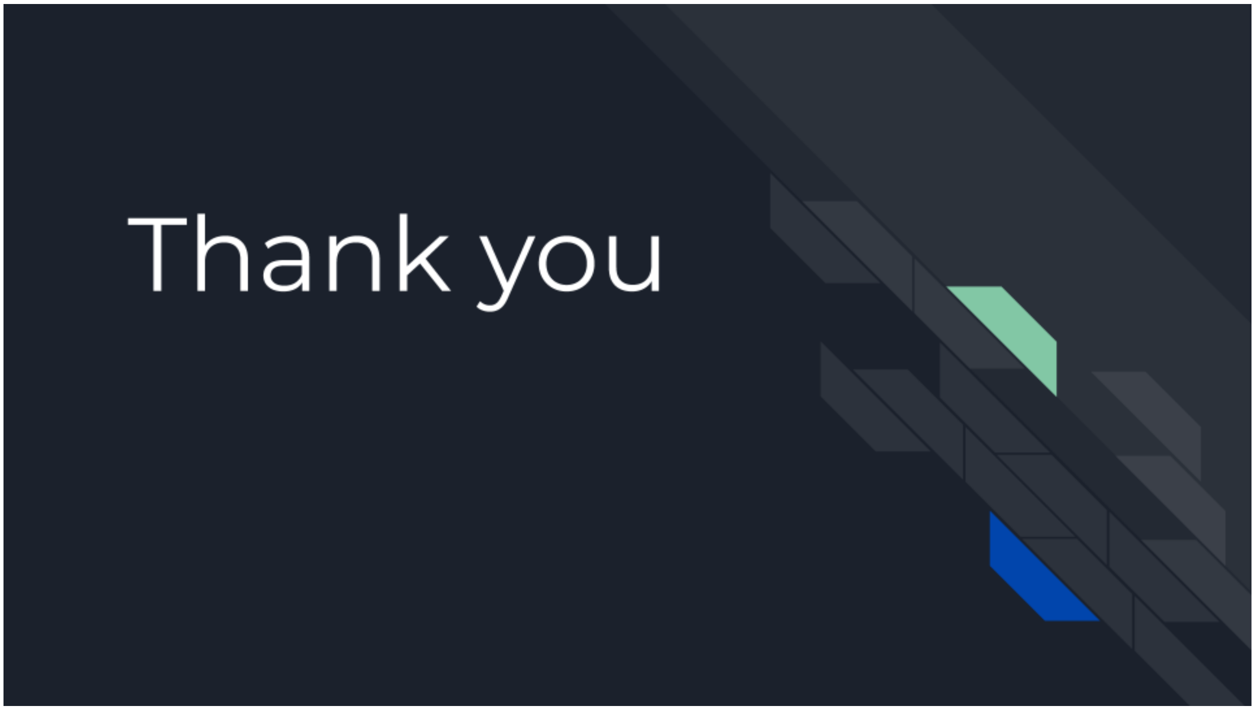
8. "MP36 Right-Angle Gearmotor MobilePower™ Series." *ElectroCraft*, 2020, www.electrocraft.com/products/gearmotors/MP36/.
9. Saunders, John, director. *Control Large DC Motors with Arduino! SyRen Motor Driver Tutorial*, 2020, www.youtube.com/watch?v=OW-Bf3yjUyE.
10. "Wesco Industrial Products 272415 Battery-Powered 1100 Lb. Platform Truck with 30' x 48' Platform - 24V." *WebstaurantStore*, www.webstaurantstore.com/wesco-industrial-products-272415/934272415.html?utm_source=google.


Thank you

C-Final Oral Presentation Slides

Design Concept for Motorized Caster Cart

Existing Manual Cart
Supplied by Hamilton Caster

Powered Cart Design based on
Manual Cart Platform

Design Criteria

- Start with a cart that has a flat steel deck, a handle and two swivel casters at the handle end
- Motorized cart should be able to achieve minimum speed of 3 mph
- Motorized cart should be able to carry a load of 4,000 lbs
- Should have the capability to traverse a slope of 5.4% (3°)
- Should have the capability to travel for 10 miles fully loaded between full charge and complete discharge of battery system
- Control system should be easy and intuitive to operate
  - Confidently control speed of cart
  - Safeguards to protect operator while in use

Systems Present

- Casters and Wheels supplied by Hamilton Caster
    - Spec sheets, whitepapers, CAD Models, etc.
- Drive System
    - Motors, Gearbox(es), etc.
- Power Delivery System (Batteries)
    - Battery charging station
- Control System
    - Speed Regulation, E-Stop Button(s), Battery Status Display

Cost Analysis

What we planned our budget to be...

1. Hamilton Caster Cart (Supplied by Hamilton Caster)
2. Electrical motors/ 90 degree gearbox (BA3624-XXXX-G24-R, BA3624-XXXX-G24-L, for both wheels)........................$1000
3. Batteries for Cart (2 110 AH)..$550
4. Programmable logic controller and wiring………..……….....$300
5. Safety devices and sensors………………………………...…....$250
6. Steel for fabrication……………………………………………….…....$200
7. Bearings and Miscellaneous Hardware………...………….$200
8. <u>Final Cost</u>……………………………..$2500

Cost Analysis

What our budget actually was...

ITEM#	PART NAME	COST/UNIT	QTY	SHIPPING	TOTAL:	Paid By:	Ordered?	Delivered?
Fleck Grant: $2,500.00								
1	Apex APX12-200 12V 200AH Sealed AGM Battery	$264.99	4	$343.64	$1,403.60	FLECK	Yes	Yes
2	Sample DR600 Gear-Motor, Right Hand w/ Electromechanical Brake	$315.00	2	$50.00	$680.00	FLECK	Yes	Yes
3	Bearing Holder-Driver Side	$0.00	2	$0.00	$0.00	HAMILTON CAS	Yes	Yes
4	Bearing Holder-Idler Side	$0.00	2	$0.00	$0.00	HAMILTON CAS	Yes	Yes
5	Bearing Block Nut-Threaded Body	$0.00	6	$0.00	$0.00	HAMILTON CAS	Yes	Yes
6	1/2-20 Large Hex Nut	$0.00	10	$0.00	$0.00	HAMILTON CAS	Yes	Yes
7	DEVMO Joystick Modules (5 per pack)	$11.99	1	$9.99	$21.98	TEAM	Yes	Yes
8	Cytron SmartDriveDuo60-60A	$149.90	1	$0.00	$149.90	FLECK	Yes	Yes
9	Greartisan DC 24V 120 RPM Gear Motor (For Testing)	$14.99	2	$0.00	$29.98	FLECK	Yes	Yes
10	Battery Meter, Battery Capacity Voltage Indicator	$10.99	1	$0.00	$10.99	FLECK	No (2/11)	NO
11	Battery Quick connectors	$39.95	1	$0.00	$39.95	TEAM	No (2/11)	NO
12	Cable terminal connectors	$17.33	1	$0.00	$17.33	TEAM	No (2/11)	NO
13	Thrust Washer (McMaster Carr - Pack of 5)	$0.00	1	$0.00	$0.00	HAMILTON CAS	Yes	Yes
14	1/2-20 x 2" Grade 5 Hex Head Bolts (McMaster Carr)	$0.00	5	$0.00	$0.00	HAMILTON CAS	Yes	Yes
15	Die Springs (Associated Spring Raymond)	$0.00	9	$0.00	$0.00	HAMILTON CAS	Yes	Yes
16	10-32 x 1" Socket Head Cap Screw	$0.55	2	$0.00	$1.10	TEAM	Yes	Yes
17	#10 Lock Washer	$0.12	2	$0.00	$0.24	TEAM	Yes	Yes
18	1/4-20 x 3/4" Hex Drive Flat Head	$0.85	8	$0.00	$6.80	TEAM	Yes	Yes
19	1/4-20 x 1" Hex Head Grade 5 Bolt	$0.17	6	$0.00	$1.02	TEAM	Yes	Yes
20	1/4" Lock Washer	$0.15	6	$0.00	$0.90	TEAM	Yes	Yes
21	10-32 Hex Nut	$0.13	4	$0.00	$0.52	TEAM	Yes	Yes
22	10-32 x 3/4" Socket Head Cap Screw	$0.50	4	$0.00	$2.00	TEAM	Yes	Yes
23	Extension Spring w/Hook, Bushing, External Retaining Ring	$30.21	1	$15.16	$45.37	TEAM	Yes	Yes
24	D-Shaped Shaft - 6 mm Diameter	$4.00	1	$12.50	$16.50	TEAM	Yes	Yes
25	Potentiometer	$30.00	1	$16.58	$46.58	TEAM	Yes	No
26	Back Cabinet for Batteries	$79.99	1	$15.00	$94.99	FLECK		
27	Battery Charger	$290.00	1	$0.00	$0.00	ENT DEPT.		
28	Various Wire	$180.00	N/A	$0.00	$180.00	TEAM	Yes	Yes
29	Butt Connectors	$25.00	1	$0.00	$25.00	TEAM		
30	eSUN 3D Printer Filament	$20.00	2	$0.00	$40.00	TEAM		
				Total:	$2,814.75			
				Budget Left:	-$314.75			

Project Schedule

Hamilton Caster Project	**170 days**	**Thu 8/20/20**	**Wed 4/14/21**	
Planning	**66 days**	**Thu 8/20/20**	**Thu 11/19/20**	
Determine Project	13 days	Thu 8/20/20	Mon 9/7/20	
Brainstorm Project Design	12 days	Tue 9/8/20	Wed 9/23/20	
Prepare Proposal	**22 days**	**Thu 9/24/20**	**Fri 10/23/20**	
Create Work Breakdown Structure	3 days	Thu 9/24/20	Mon 9/28/20	
Cost Analysis	2 days	Tue 9/29/20	Wed 9/30/20	6
Gantt Chart	6 days	Thu 10/1/20	Thu 10/8/20	7
Compose Proposal	6 days	Mon 10/12/20	Mon 10/19/20	8
Submit Updated Proposal if Required	**7 days**	**Thu 10/15/20**	**Fri 10/23/20**	
Prepare Presentation	**11 days**	**Thu 11/5/20**	**Thu 11/19/20**	
Create PowerPoint	5 days	Thu 11/5/20	Wed 11/11/20	
Practice Presentation	3 days	Mon 11/16/20	Wed 11/18/20	
Oral Presentation (WebEx)	1 day	Thu 11/19/20	Thu 11/19/20	
Design	**48 days**	**Fri 10/16/20**	**Tue 12/22/20**	5
Calculations for design Requirements	5 days	Fri 10/16/20	Thu 10/22/20	
Drive System	**22 days**	**Fri 10/23/20**	**Mon 11/23/20**	
Motor Determination	7 days	Fri 10/23/20	Mon 11/2/20	
Battery Determination	7 days	Fri 11/6/20	Mon 11/16/20	
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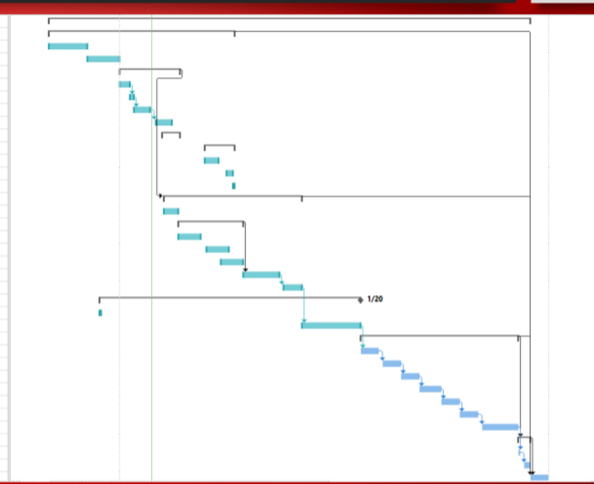
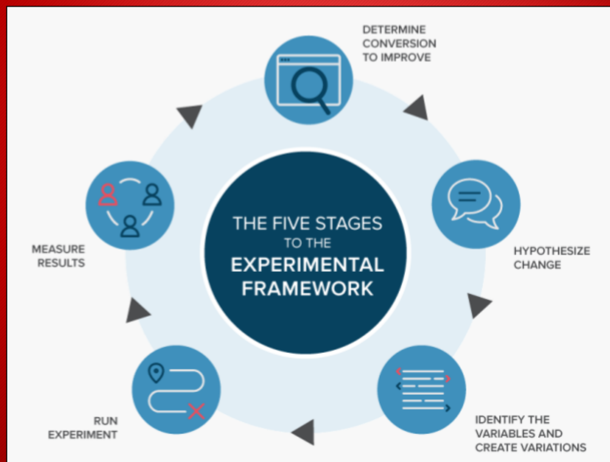


Project Schedule



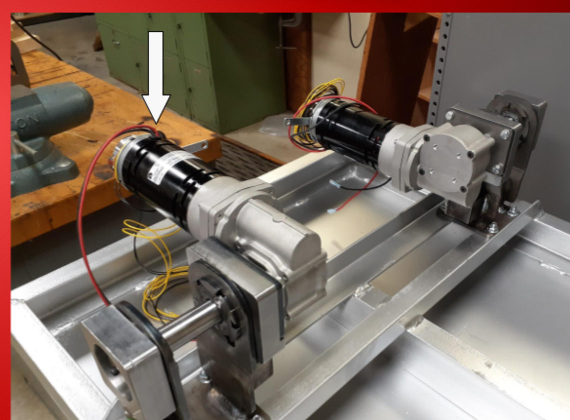
Drive System

Requirements

- 4,000 lbs from a dead stop on a 3° incline
- Each motor will need to produce 2557 lb-in of torque with a 2x safety factor

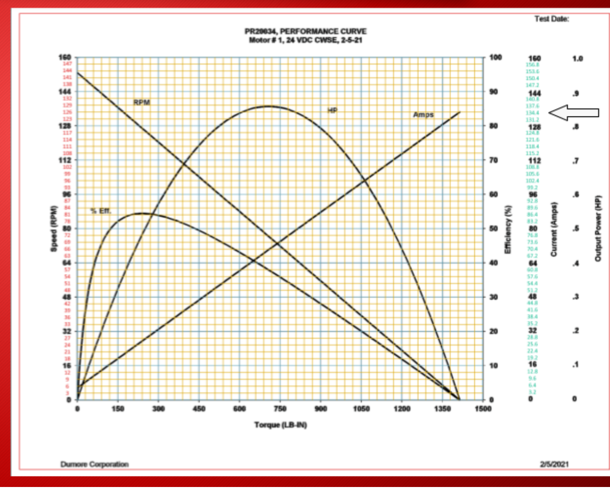
Final Selection

- Our 24VDC, 0.86 HP Dumore Motors, produce 1410 lb-in of torque providing a safety factor of 1.10
- More powerful motors were too expensive ($3,300 each plus $4,700 for development), didn't meet size constraints



Drive System

- Current draw became cause for concern
- Originally told that the motor was operating at 35A before we received graphs
- Curves indicate at full load
  - 134A draw from stop on 3° incline
  - 64A continuous draw on 3° incline
- Motor Controller rated for 60A per channel continuously and 100A per channel peak (less than 1 sec)
- Realized we need a 100A fuse to protect controller



Power Delivery System

Requirements

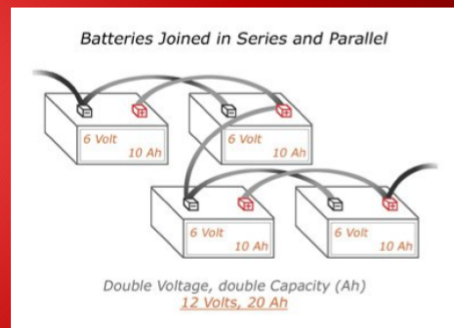
- 12 or 24 Volt batteries
- Liquid gel sealed batteries (safety concerns)
- Runtime of 10 hours fully loaded at 3 mph
- Calculated 233 amp hours of capacity
  - Assume 35A continuous per motor
  - Assume 3.33 hours of runtime

Motor Changes

- Motors drew more current than anticipated
- Current draw for max load continuously on a flat surface is 68.8A
- Now requires 458 amp hours in batteries
- Too late, batteries already on the way

Power Delivery System

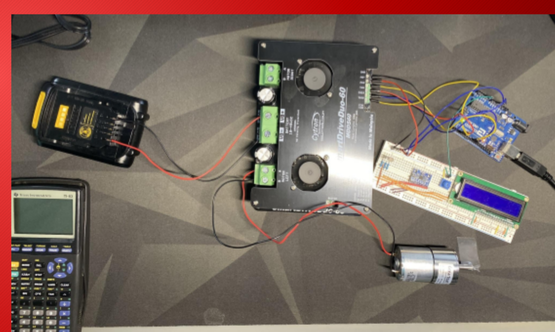
- Opted for four 12 Volt batteries
- 2 in parallel and both pairs in series
- Sealed batteries to avoid eyewash station requirements
- Sealed batteries can be oriented in any position
- 12 Volt batteries are smaller than 24 Volt batteries of the same type



Programming Control System

Requirements

- Operator should be able to interact with the cart with minimal training
- Cart should operate predictably and safely
- Emergency stop for safe operation and main power cutoff
- Indicate battery life
- Provide drive mode switching for forward or reverse
- Disengage brake solenoids for driving or engage for parking



Programming Control System

Implementation

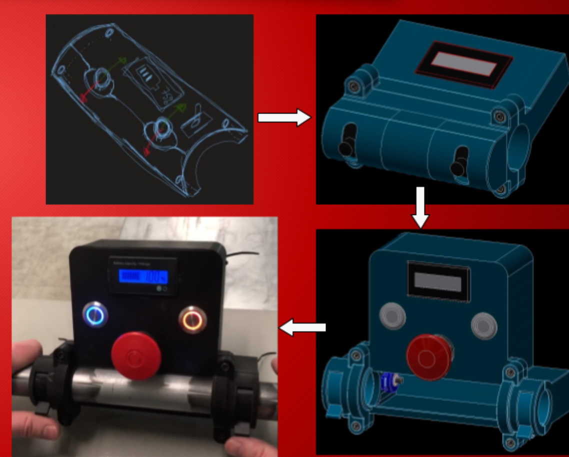
- Arduino UNO Microcontroller
- Analog to digital conversion, scaled to digital output to the motor controller
- Ramp down function to prevent payload shift from acceleration
- Press and hold buttons to prevent inadvertent activation.
- Turn speed limit for operator safety
  - 40% max throttle while one input is less than 10%

```
//This function Reads all Inputs
void readInputs(){

  brakeReq = digitalRead(brakeReqPin);
  reverseReq = digitalRead(revReqPin);

  float sensorValue0 = analogRead(joystick1Pin);
  float sensorValue1 = analogRead(joystick2Pin);

  //Use linear scaling to map analog inuputs to digital output value for motor Contoller
  float tempValue0 = (((scaled_max - scaled_min)/(pot0_max - pot0_min))*(sensorValue0 - pot0_min)) + scaled_min;
  float tempValue1 = (((scaled_max - scaled_min)/(pot1_max - pot1_min))*(sensorValue1 - pot0_min)) + scaled_min;

  //Type cast the tempValues to integers for use with Motor Controller function
  scaledValue[0] = (int) tempValue0;
  scaledValue[1] = (int) tempValue1;
```

```
//*************BRAKE RELAY CODE*******************
//IF brake toggle request is pressed and timer has not started, start timing.
if(brakeReq == HIGH && brakeRequestLatch == false) {
  brakeReqStartTime = millis();
  brakeRequestLatch = true;
  if(debugMode == true){
    Serial.println("Brake Toggle Requested");
  }
}
//IF brake toggle has been released before brakeTimer is done, reset timer.
else if(brakeReq == LOW && brakeRequestLatch == true) {
  brakeReqStartTime = 0;
  brakeRequestLatch = false;
  if(debugMode == true){
    Serial.println("Brake Toggle Request Denied");
  }
}
//IF brake toogle is pressed and timer has started, check timer is done.
else if (brakeReq == HIGH && brakeRequestLatch == true){
  //IF current time minus timer start is greater than brakeTimer, toggle break relay and reset timer
  if(millis() - brakeReqStartTime >= brakeTimer){
    brakeRelay = toggleBool(brakeRelay);
    brakeRequestLatch = false;
    if(debugMode == true){
      Serial.println("Brake Toggled, Request Completed");
    }
  }
}
//*************END OF BRAKE RELAY CODE*******************
```

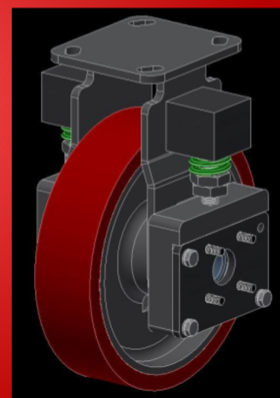
Design Control Housing

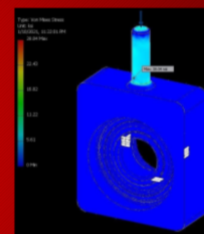
- Sketched concept for controls interface
- Model of first functional prototype using gamepad joystick
  - Joysticks did not possess enough resolution in the throw for our purposes
  - Bought second joystick with more resolution, did not "auto zero"
- Second Iteration of prototype
  - 2:1 gear ratio driven potentiometers
  - Spring return to zero
  - E-Stop button
  - Brake Toggle button/light
  - Drive Mode button/light

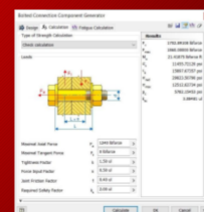


Design of Drive Caster

- Use as many parts from the existing caster product as possible
  - Top plate
  - Caster wheel
  - Spring
- Type of caster
  - Rigid
  - Shock absorbing
- Capable of mounting and dismounting motor relatively easy
- Bearings for motor shaft and drive wheel
- FEA Analysis and Thread Analysis of spring pre-load redesign







Issues Encountered and Remedies

Issues

- Clearance beneath the cart
  - Motors attachment orientation
  - Size of motors
- Joystick control
  - Range of throw
- One thumb control
  - Motor control
  - Amperage Spike when turning
- Storage of Components

Remedies

- No remedy, based on envelope of cart supplied
  - Increase caster diameter to provide more clearance
  - Rotate motor case to reorient lead wires
- Gear driven potentiometers
- Two thumb controls
  - Can control motors separately
  - Less amperage drawn from motors in turns
- Under cart drawer / handle cabinet

Demonstration of Operation

Forward
Operation

Reverse
Operation

4000 lb Load Drive Test

Conclusion

Model Design of Motorized
Caster Cart

Finished Prototype of Motorized
Caster Cart

Questions

Greg Drew – drewgs@miamioh.edu
James O'Brien – obrienj8@miamioh.edu
Kendall Purdy – purdykm@miamioh.edu
Tyler Sargent – sargent2@miamioh.edu

D-Individual Reflective Essays

Reflective Essay - Greg Drew

The Senior Design capstone class is designed to challenge students in a way that brings together all that we have learned during our tenure at Miami University and all that we know from our work and life experiences. In order to succeed, the students must use the math, science and engineering learned, along with the liberal education aspects like critical thinking, understanding context and engaging with people. Although all of these elements are needed to be successful as a student throughout one's academic career, they are not always needed at one time nor are the normal academic classes set up to evaluate how we connect all of these elements into a cohesive, productive system. The Senior Design capstone class gives students a chance to experience real life situations but also gives students a chance to see how much they have grown over their academic career.

Even though our Senior Design project was continuous over two semesters, each semester had its own purpose. The first semester was evaluating what was needed, talking with vendors, ordering long lead time components and the beginning of the design portion of the project. The second semester was finishing the design, receiving and evaluating long lead time components, manufacturing components and building the product for testing. Although the same elements are used to accomplish tasks in both semesters, they have different nuances to them that are noticeable. For example, engaging with vendors about a product takes a different set of communication skills than engaging with team members about an issue that arises during the building process. Another example would be, understanding the calculations that you have done for your portion of the project and trying to understand the calculations that a team member has done, that you are unfamiliar with, in order to try to help solve an issue. Both are communication and math but the student must know what the situation is and how to navigate it in order to be successful. These are nuances that this class brings together that may otherwise not be encountered until the student has entered the workforce.

While in other classes throughout our academic career we would be put in groups to do projects, these projects usually were very short in time. We might have a group project due at the end of semester for a class or group labs for some classes. However, these group activities only lasted for a few weeks at most. In our Senior Design project, this group activity lasted two complete semesters so a student's interactions with team members becomes much more important. One doesn't want to come into a group being too pushy as if their ideas are the only ideas or taking over conversations as if their way is the only way. If this happens, the Senior Design project could become a long, frustrating year. There has to be a balance of each team member presenting ideas, recognizing when there is an idea presented that is more practical than their own or allowing different ideas to meld into one best idea. Talking and listening are equally important when working in a group setting. This is true in the design phase and especially in the build phase when all of the team members are working together on the same task. No one team member is more important than the project.

There are so many important aspects of the Senior Design project that it's hard to pick one thing that is the most important. However, having team members who are each knowledgeable, proficient and considerate, has to be three of the most important aspects of this course. If any one team member is given a task and is unable to perform that task, it can put the entire project in jeopardy. If any one team member is given a task and completes the task when they feel like it or doesn't complete the task at all, the project can be put in jeopardy. Consideration for the project and the other team member's time and effort is invaluable. No one team member is more important than the team.

During this capstone class, not only have we learned how to handle stress, deadlines, complications and people but we should have learned a little about ourselves. When a project is finished, one of the most important things to reflect on is, "What was learned?". Not only about our field of study but what was learned about ourselves. This will help us to continue to get better with each endeavor as long as we are open to the concept that we are not done learning or growing. Each project should make us aware that we have learned new things about our field of study as well as ourselves. If we are only working to get finished then we have neither learned nor grown in any capacity.

I feel like the group that I worked with for the Senior Design project was the best group I could have been a part of. We worked well together, listened to each team member, had knowledgeable, proficient and considerate team members, and worked to create the best product that we were capable of building. It was a team in every sense of the word. In my first reflective essay I asked, "Did we grow as a team? Did we overcome adversity? Does the team still work well together?". I believe the answer to all of my questions were answered with a confident, "Yes.". As much as I feel that completing this class with a working prototype was a success, I also feel that the fact that I can answer yes to my questions from the first semester is a success to be recognized as well. The Senior Design Capstone class brought together everything it thought we needed to be successful in our future careers. With what we have accomplished here at Miami University, I feel that we have proven we have learned and grown, starting us on a successful path.

Reflective Essay - James O'Brien

The start of senior design in ENT 497 was 4 guys getting placed together that had never worked together on any group projects ever. Kendall, Tyler, Grew and myself (James). When we started our group and planning our attack on this project Hamilton Caster had presented, I was very adamant that we started trying to find a motor to accomplish what we needed for Hamilton Caster. The specifications for this motorized cart were being able to pull a 3-degree incline with 4000 pounds of weight, go 10 miles between charges, and have safety devices in place to stop a rolling 4000-pound weight. My thought process behind figuring out the motor specification was that we would build a control system around a selected motor. If we would have done it the opposite way, we could have had to start back over with the control system if the currents were incorrect or the voltages were off.

With the motor being our main focus, we started ENT 497 looking for the perfect motor to fit the footprint of the front spring casters. We talked with many vendors and motor manufacturers to only find out that to find exact what we wanted; we did not have enough room under the cart. Also, these motors would have been 5hp motors, costing around 1500 dollars apiece. Then Dumore Motors came up with a preexisting design set up that would accommodate almost all requirements other than the 3 degree from a start with 4000 pounds. This motor however fit the footprint provided, was less than a 2hp motor and ran off of a 24 volt system. Once we found out the system requirements on voltage and current draw from our motors, I started looking for sealed batteries to put under our cart. The batteries ranged in all shape and size and cost. I found a set of seal batteries from APEX. They were not my first choice but with them being on sale and able to be placed in the bin under the cart and on the back of the cart, if it became obvious that these would work. With 1300 dollars for 4 of the 12v 200-amp hour batteries purchased we could then move onto the control system. We had to select 4 batteries due to the fact we needed 24 volts (which requires two batteries in series). Then we need capacity which requires 2 batteries in parallel for added capacity.

Two things I learned by the middle of ENT 498; it takes some time to completely scope out only two components. We need to get moving to finish out the project. By this time Greg had already designed and manufactured our motor to caster drive system in how we mount the motors to the casters. We still thank him to this day for his mechanical engineering experience to design and manufacture these components. Having the motors scoped and prints available now has allowed us to get a jump and mounting hardware, battery sizes and amounts, and now bins to place these batteries. Kendall's brother is an engineer for Matco tools. His brother took our design of the size and weight the bin needed to be under the cart and created the size and weight requirements we needed. This bin took awhile to get built which kind of created some schedule issues with the final product being finished. While we were waiting for our bins to get delivered to place the components in, we kept testing the cart with temporary power from two batteries to the motor controller and the Arduino. We went at least 4 to 6 weeks of continuing testing on Tyler's program to get the speed correct, the turning correct, whether we should use one joystick or two joysticks, how to do the turning speed, and how to integrate the safeties into the program. Kendall and Tyler really worked hard on all the programming specifications and features on the cart. Tyler bought some small motors to test his program at his house to try and eliminate the amount of time we all were at school. In the beginning we tried to minimize the amount of time at the school due to covid but once we had all the parts and components at hand, we spent at least 120 hours at the school putting together the final product for Hamilton Caster.

We all work full time, some of us travel full time for our jobs, and I have kids to keep up with. Even with these bumps in the road we all still worked great together. Never once did I ever feel like I did everything, or did I feel like I could not work or voice my opinion or concerns. This group had heart and desire to produce something great for Hamilton Caster. They provided us a goal and we accomplished it. It was close on time but what project is not pushing the timeline. Anything we needed from Miami and Gray always was provided. This was a great experience to improve my project management experience and engineering experience with a great group of engineers. We also received a letter from Hamilton Caster, stating that out of all the groups they tasked with this challenge, we were the only group to have a fully functional prototype!

Reflective Essay - Kendall Purdy

Many things have grown over the past two semesters. The Senior Design class and engineering program prepared us for designing things in the real world. The classes, instructors, homework, projects, tests, and papers have given us the tools to go out and succeed. This duration in our college timeline is to show how we have grown through this training. The goal is to use every skill learned along the way to design, search, build, test, and deliver the best product possible. The only thing left to do was to apply it.

One thing that ended growing more than anything was our comradery. Our team was tasked with a problem that needed a solution. It was not an easy solution by any means. Four classmates grew exponentially over the two semesters. We became a team that would not take no for an answer and that would always try to optimize the productivity of the task at hand. Each member of the team had a vital role in the design, assembly, and testing of our Electric motor cart project. When you think about many work environments you tend to think about different departments all working in conjunction toward a common goal of delivering the customer the best product possible. Our group did the exact same thing for Hamilton Caster Co. Greg became the main design lead on the mechanical system of the drive casters. James became our industry expert and power system head. Tyler became our programming division over controls and motor drive systems. I also became part of the programming division and logistics when it can be installed. The collection of all the strengths from each member put us ahead and gave us an opportunity to learn from one another. From the first day of this second semester, we knew our roles. This allowed us to all work simultaneously on the project without getting in each other’s way. We did everything we could to maximize productivity during our time in the lab.

This semester set itself apart from the previous by allowing us to receive our designed pieces and start the process of mocking up the prototype. This part of the project allowed us to put our hands on something that was thought of through 3-D renderings. We added a whole new aspect to the process by being able to see the real-world constraints and possibilities to the project. For example, when we received the motors, caster brackets, and bearing blocks they were assembled and installed. That point is where you find the difference between theoretical and experimental. These cases allow for adaption or re-designs which only make the product better. Once you meet the design requirements you enter the testing phase. This part of the project finds more experimental challenges, but most impasses are making sure that our cart does what it's supposed to while keeping the operator safe. Testing helps find the strengths and weaknesses of the design. We then can sit down to find a fix to our problem that improves usability. After debugging the system we can then calibrate the product to set standards. The standards, in our case payload, give validation to the product's design features. After all the steps through this semester's process we can look back to see what worked, what we could have done differently, and how our idea came to fruition.

Senior Design taught us many valuable lessons over the past year. We learned how to manage a project to industry standards. We learned how to seek companies and find the best parts for each aspect of our project. We came together to use each of our abilities to make something that we can stand behind. I am very proud of my teammates and know that we gave everything we had to this project. We delivered a working prototype during the hardest point of most lives. We overcame the environment around us and other teams. I believe wholeheartedly that this experience will transfer to my career post-graduation.

Reflective Essay – Tyler Sargent

As the project is coming to a close, I am relieved that this whole year-long journey is finally coming to an end. I am tremendously proud of our team's dedication and willingness to put in the amount of effort and time that it has taken to see this project through to the end. I think that this coming Thursday is the first in nearly nine months that will not be spent working on one aspect or another of this project. Thinking about that is a little sad as now this cart is in someone else's hands, maybe another team for next year or maybe Hamilton Caster will make their own changes. Either way, I feel that our team has made a lasting mark on this project as it hopefully moves from prototype to live product someday in the future.

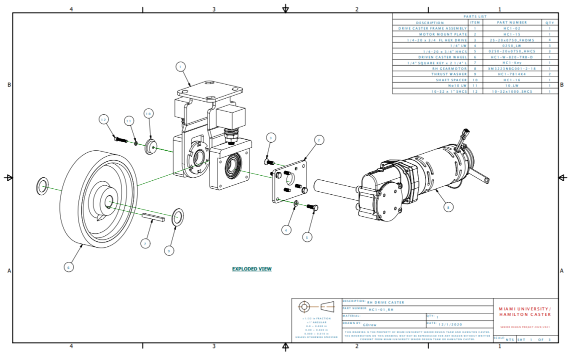
We have learned many things on this project, and I do not believe that we would have been able to learn them in a typical classroom or lab setting. Working with others from other academic backgrounds and professional backgrounds has opened my mind to what is possible with an engineering team. What this project has taught me is that the teamwork of several minds can accomplish what seems impossible to any one on their own. The number of times that we have collaborated and "wow'd" each other is enumerable. While some were able to be very comfortable and competent with the mechanical aspects of the project, I was more so with the electrical and control portions. Together, with each side of experience complementing the other we were able to produce something that was impressive to all of us.

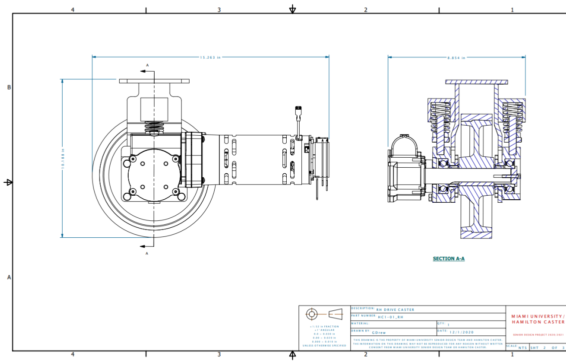
One of the challenges that I faced this past year was managing my time between work and school and this project. I make a distinction between all three because I feel that they were three separate parts of what I consider to be my professional career building experience. There were times where I would work a normal eight-hour workday and they get to the lab to put in another 5 hours on our project. There were also some days where I would spend my lunch hour at work coding a last-minute idea I had for the cart, excited to plug it all in and see it come to life. While there were definitely ups and downs to this, the lesson that I can pull from all of this is that sacrifice, and hard work will always pay off. Pushing through till the end even when I realized we were all home free in terms of getting the grade has given me a great sense of pride in our willingness to exceed even our own expectations.

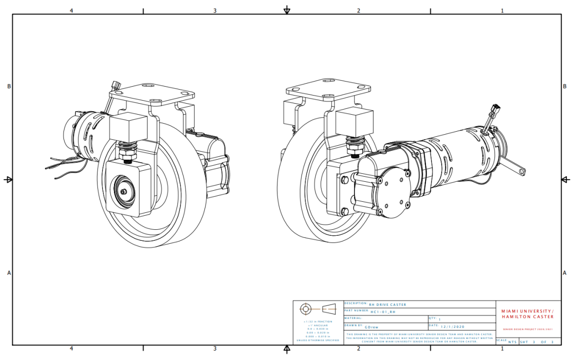
To top it all off we ended up winning the competition as the other schools that were involved were unable to produce a functional prototype. This to me reiterates and confirms our ability to think creatively and execute on a plan in order to produce results. There is no better feeling than receiving the congratulations and recognition that this team has earned with all our hard work over the past year. I am looking forward to carrying this momentum into the start of the next stage in my professional career and I am excited about what the future holds.

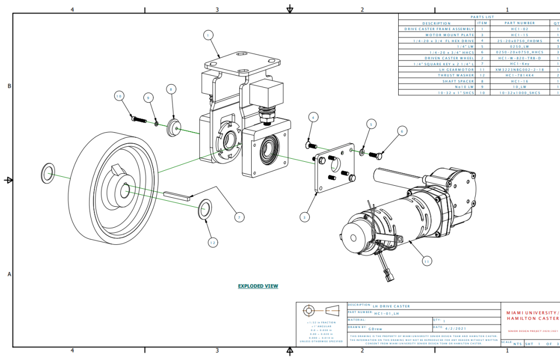
E-Drawings/Spec Sheets

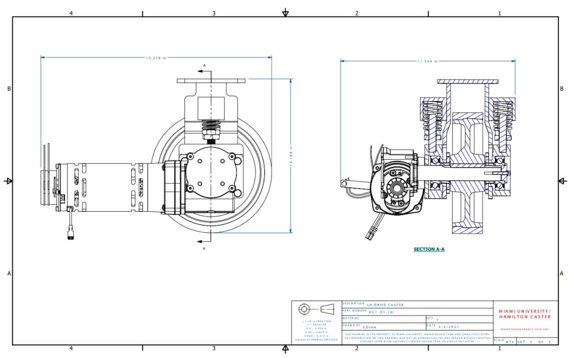
Drive Caster Drawings

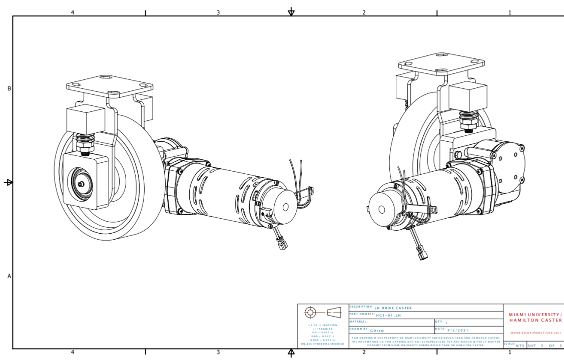


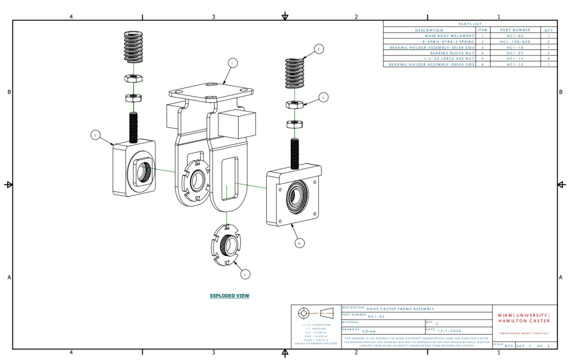


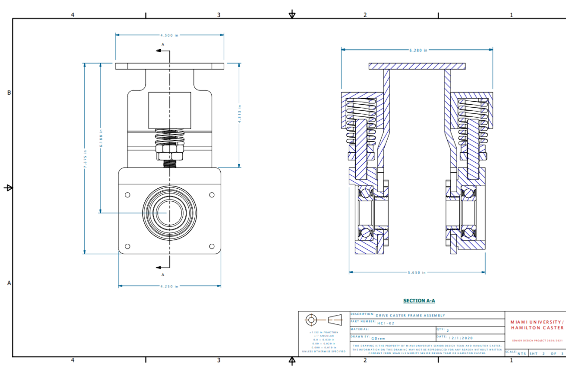


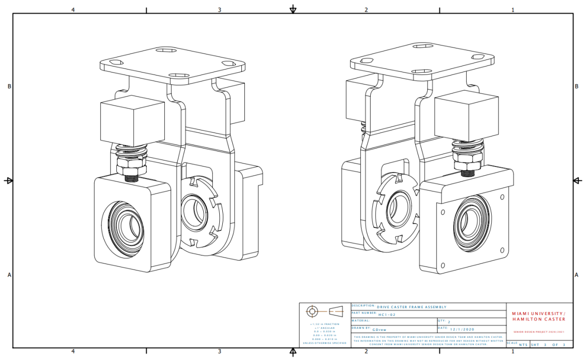


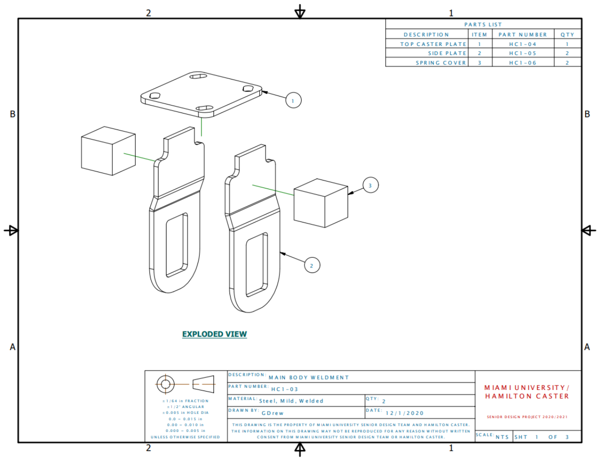








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SIDE PLATE 2 HC1-05 2
SPRING COVER 3 HC1-06 2
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PART NUMBER: HC1-03
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DRAWN BY: GDrew
DATE: 12/1/2020
MIAMI UNIVERSITY / HAMILTON CASTER
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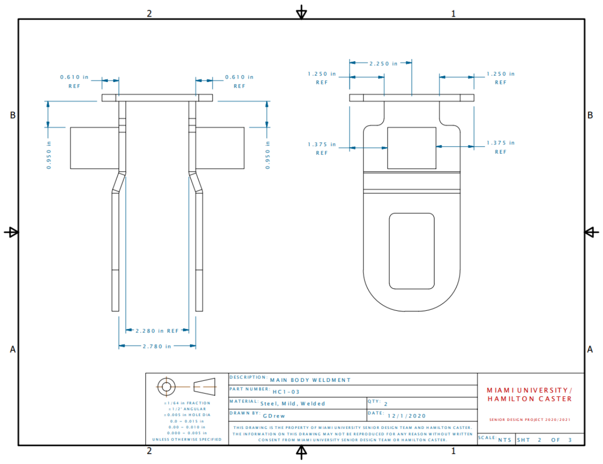
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0.610 in REF
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0.950 in
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1.375 in REF
1.375 in REF
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PART NUMBER: HC1-03
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DRAWN BY: GDrew
DATE: 12/1/2020
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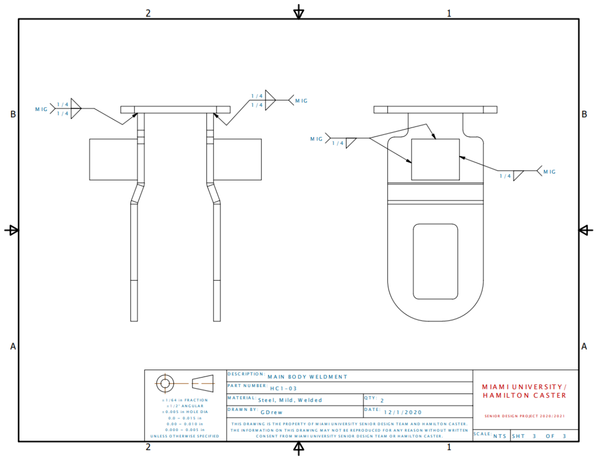
MIG
1/4
1/4
MIG
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PART NUMBER: HC1-03
MATERIAL: Steel, Mild, Welded
QTY: 2
DRAWN BY: GDrew
DATE: 12/1/2020
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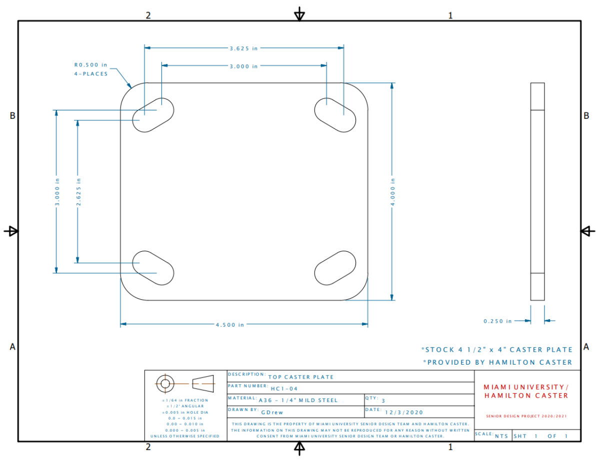
R0.500 in 4-PLACES
3.625 in
3.000 in
3.000 in
2.625 in
4.000 in
4.500 in
0.250 in
*STOCK 4 1/2" x 4" CASTER PLATE
*PROVIDED BY HAMILTON CASTER
DESCRIPTION: TOP CASTER PLATE
PART NUMBER: HC1-04
MATERIAL: A36 - 1/4" MILD STEEL
QTY: 3
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY / HAMILTON CASTER
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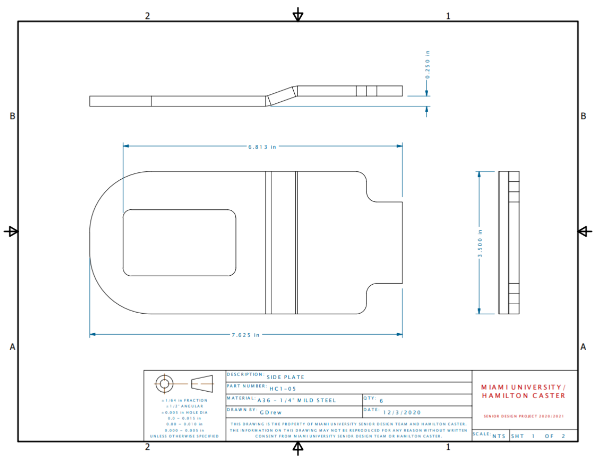
0.250 in
6.813 in
7.625 in
3.500 in
DESCRIPTION: SIDE PLATE
PART NUMBER: HC1-05
MATERIAL: A36 - 1/4" MILD STEEL
QTY: 6
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY / HAMILTON CASTER
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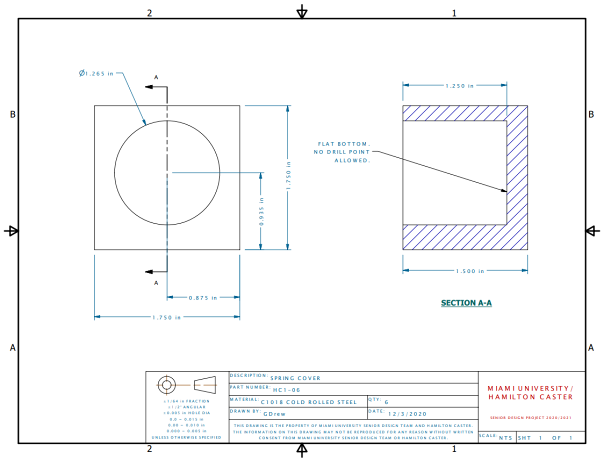
Ø1.265 in
FLAT BOTTOM. NO DRILL POINT ALLOWED.
1.250 in
1.750 in
0.935 in
1.500 in
0.875 in
1.750 in
SECTION A-A
DESCRIPTION: SPRING COVER
PART NUMBER: HC1-06
MATERIAL: C1018 COLD ROLLED STEEL
QTY: 6
DRAWN BY: GDrew
DATE: 12/3/2020
±1/64 in FRACTION
±1/2° ANGULAR
±0.005 in HOLE DIA
0.0 = 0.015 in
0.00 = 0.010 in
0.000 = 0.005 in
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MIAMI UNIVERSITY/ HAMILTON CASTER
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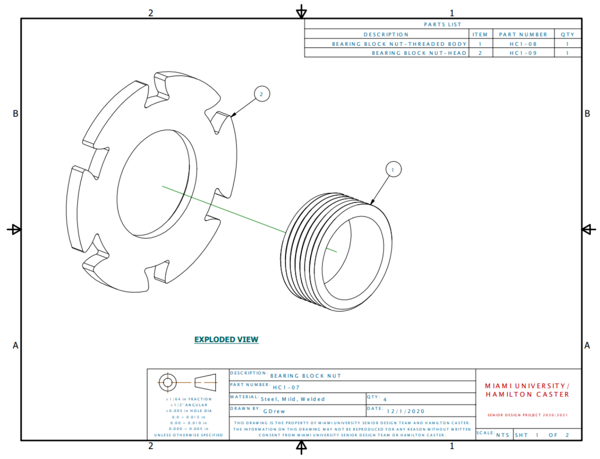
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PART NUMBER: HC1-07
MATERIAL: Steel, Mild, Welded
QTY: 6
DRAWN BY: GDrew
DATE: 12/1/2020
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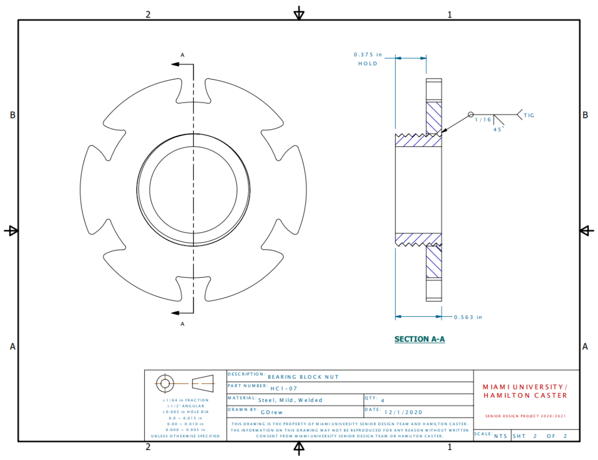
0.375 in HOLD
TIG
45°
0.563 in
SECTION A-A
DESCRIPTION: BEARING BLOCK NUT
PART NUMBER: HC1-07
MATERIAL: Steel, Mild, Welded
QTY: 6
DRAWN BY: GDrew
DATE: 12/1/2020
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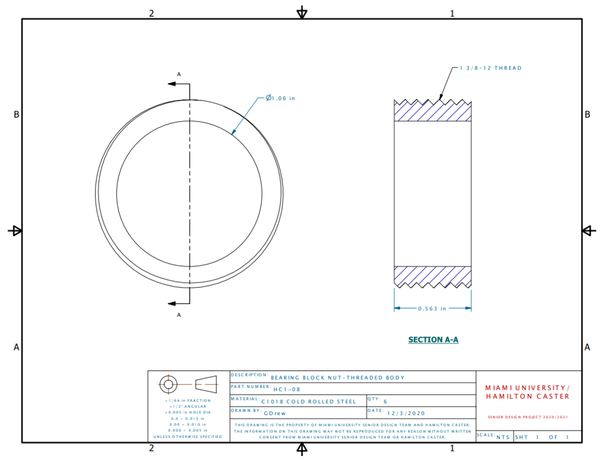
Ø1.06 in
1 3/8-12 THREAD
0.563 in
SECTION A-A
DESCRIPTION: BEARING BLOCK NUT-THREADED BODY
PART NUMBER: HC1-08
MATERIAL: C1018 COLD ROLLED STEEL
QTY: 6
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY/ HAMILTON CASTER
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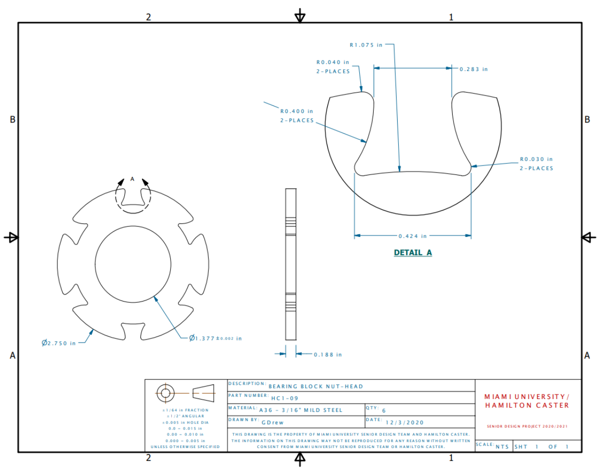
R1.075 in
R0.040 in 2-PLACES
0.283 in
R0.400 in 2-PLACES
R0.030 in 2-PLACES
0.424 in
DETAIL A
Ø2.750 in
0.188 in
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PART NUMBER: HC1-09
MATERIAL: A36 - 3/16" MILD STEEL
QTY: 6
DRAWN BY: GDrew
DATE: 12/3/2020
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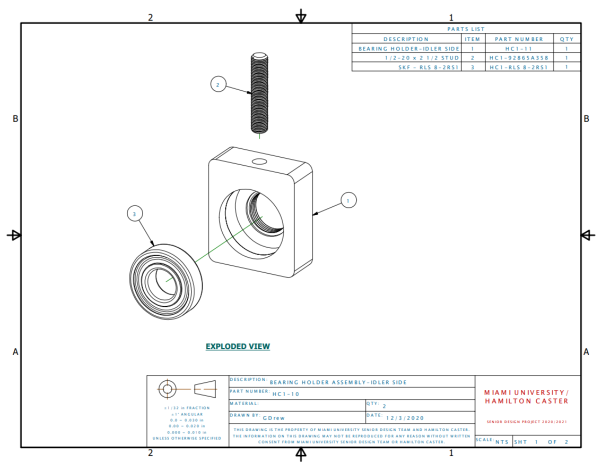
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SKF - RLS 8-2RS1 | 3 | HC1-RLS 8-2RS1 | 1
EXPLODED VIEW
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PART NUMBER: HC1-10
DRAWN BY: GDrew
QTY: 2
DATE: 12/3/2020
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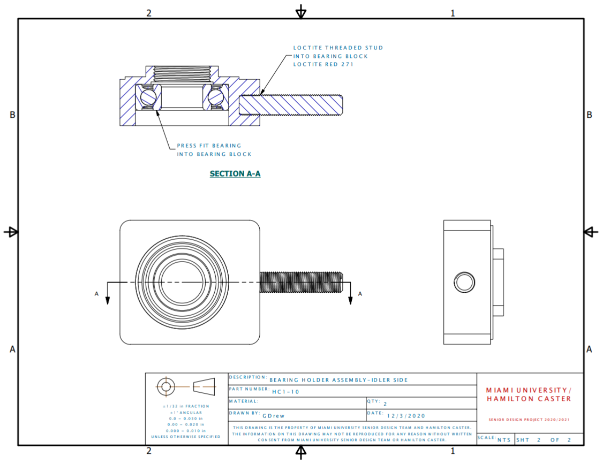
LOCTITE THREADED STUD
INTO BEARING BLOCK
LOCTITE RED 271
PRESS FIT BEARING
INTO BEARING BLOCK
SECTION A-A
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PART NUMBER: HC1-10
MATERIAL:
QTY: 2
DRAWN BY: GDrew
DATE: 12/3/2020
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HAMILTON CASTER
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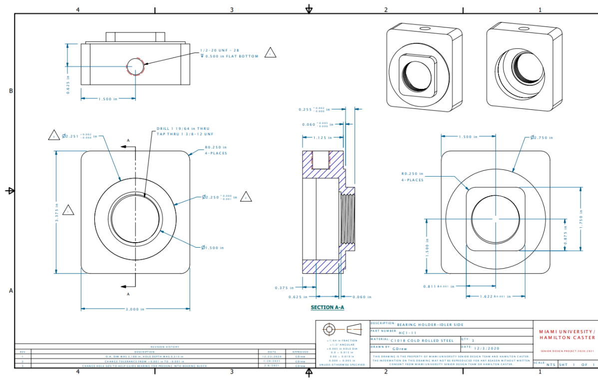
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DATE: 12/3/2020
MIAMI UNIVERSITY/
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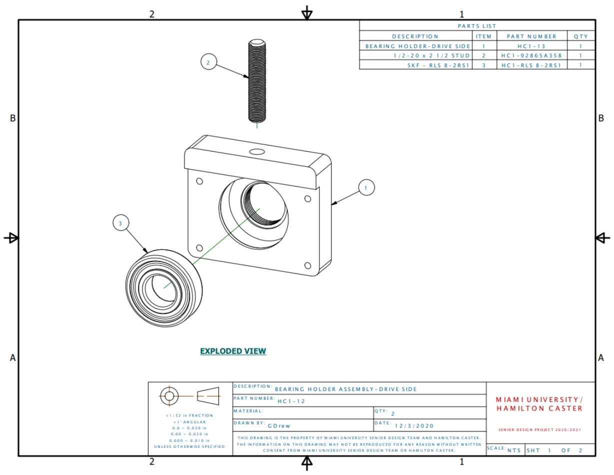
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SKF - RLS 8-2RS1 | 3 | HC1-RLS 8-2RS1 | 1
EXPLODED VIEW
DESCRIPTION: BEARING HOLDER ASSEMBLY-DRIVE SIDE
PART NUMBER: HC1-12
MATERIAL:
QTY: 2
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY/
HAMILTON CASTER
SENIOR DESIGN PROJECT 2020-2021
SCALE: NTS
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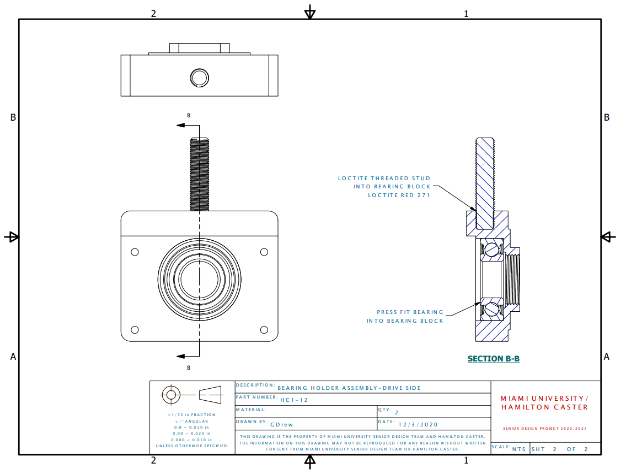
LOCTITE THREADED STUD
INTO BEARING BLOCK
LOCTITE RED 271
PRESS FIT BEARING
INTO BEARING BLOCK
SECTION B-B
DESCRIPTION: BEARING HOLDER ASSEMBLY-DRIVE SIDE
PART NUMBER: HC1-12
MATERIAL:
QTY: 2
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY/
HAMILTON CASTER
SENIOR DESIGN PROJECT 2020-2021
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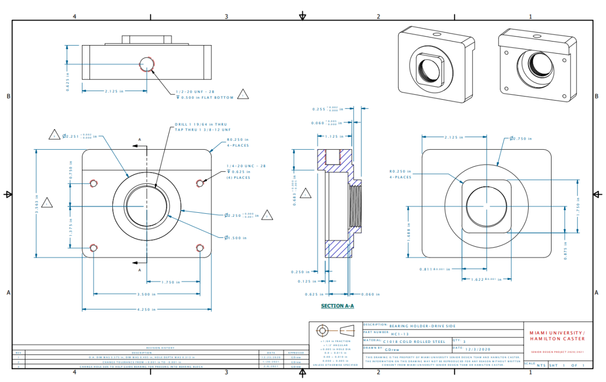
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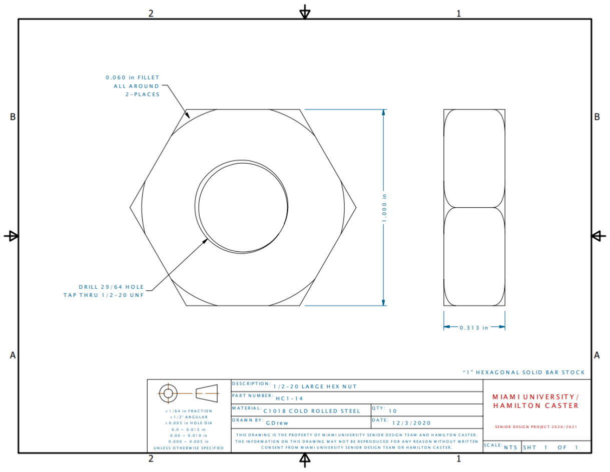
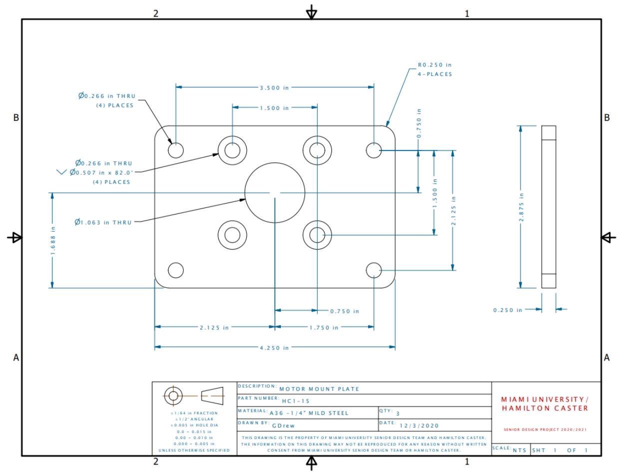
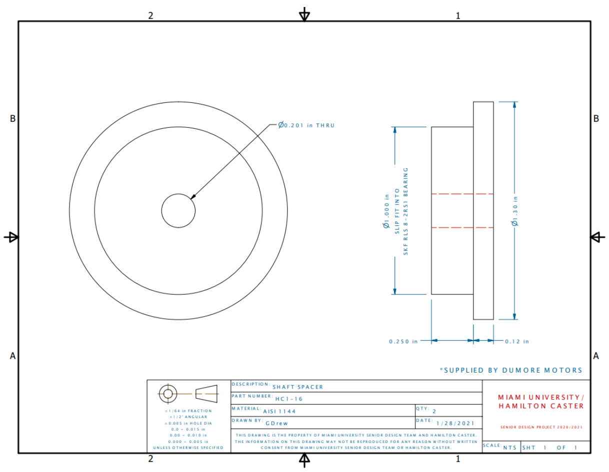
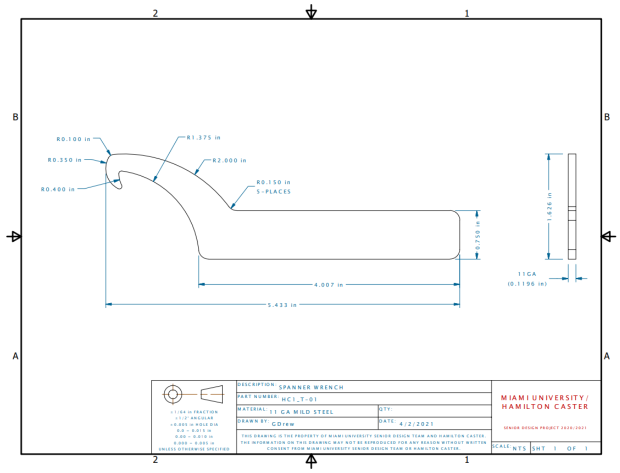
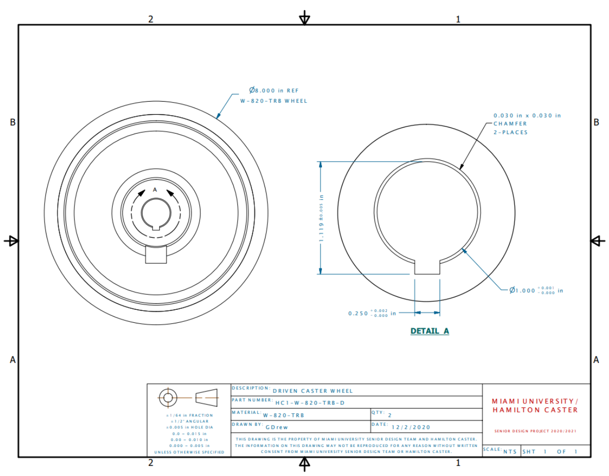
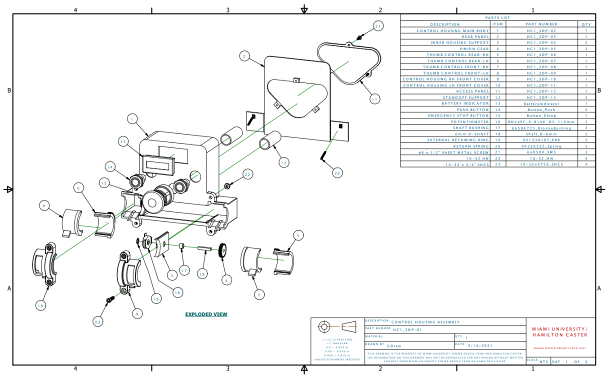
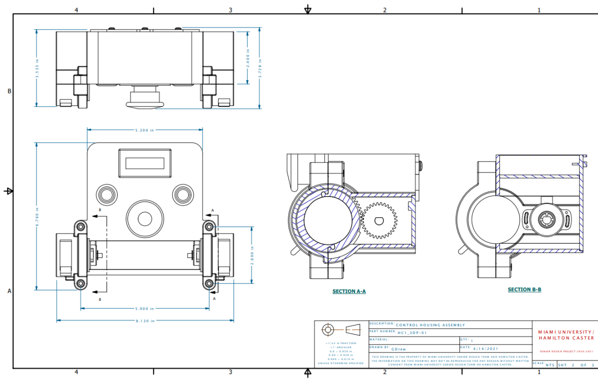
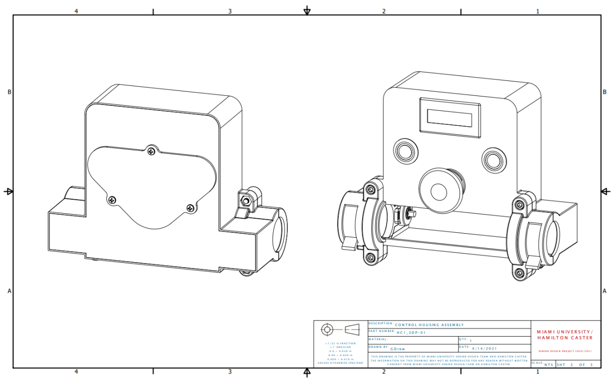
MIAMI UNIVERSITY/
HAMILTON CASTER

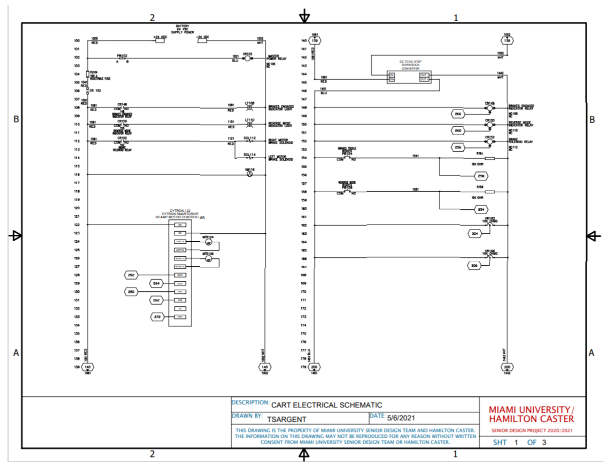

0.060 in FILLET ALL AROUND 2-PLACES
1.000 in
DRILL 29/64 HOLE TAP THRU 1/2-20 UNF
0.313 in
"1" HEXAGONAL SOLID BAR STOCK
DESCRIPTION: 1/2-20 LARGE HEX NUT
PART NUMBER: HC1-14
MATERIAL: C1018 COLD ROLLED STEEL
QTY: 10
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY / HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

R0.250 in 4-PLACES
Ø0.266 in THRU (4) PLACES
3.500 in
1.500 in
Ø0.266 in THRU
Ø0.507 in x 82.0° (4) PLACES
Ø1.063 in THRU
0.750 in
1.500 in
2.125 in
2.875 in
1.688 in
0.750 in
2.125 in
1.750 in
4.250 in
0.250 in
DESCRIPTION: MOTOR MOUNT PLATE
PART NUMBER: HC1-15
MATERIAL: A36 - 1/4" MILD STEEL
QTY: 3
DRAWN BY: GDrew
DATE: 12/3/2020
MIAMI UNIVERSITY / HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

Ø0.201 in THRU
Ø1.000 in SLIP FIT INTO SKF RLS 8-2RS1 BEARING
Ø1.30 in
0.250 in
0.12 in
*SUPPLIED BY DUMORE MOTORS
DESCRIPTION: SHAFT SPACER
PART NUMBER: HC1-16
MATERIAL: AISI 1144
QTY: 2
DRAWN BY: GDrew
DATE: 1/28/2021
MIAMI UNIVERSITY / HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

R0.100 in
R1.375 in
R0.350 in
R2.000 in
R0.400 in
R0.150 in 5-PLACES
1.626 in
0.750 in
4.007 in
5.433 in
11GA (0.1196 in)
DESCRIPTION: SPANNER WRENCH
PART NUMBER: HC1_T-01
MATERIAL: 11 GA MILD STEEL
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY / HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

Ø8.000 in REF W-820-TR8 WHEEL
0.030 in x 0.030 in CHAMFER 2-PLACES
DETAIL A
DESCRIPTION: DRIVEN CASTER WHEEL
PART NUMBER: HC1-W-820-TR8-D
MATERIAL: W-820-TR8
QTY: 2
DRAWN BY: GDrew
DATE: 12/2/2020
MIAMI UNIVERSITY / HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

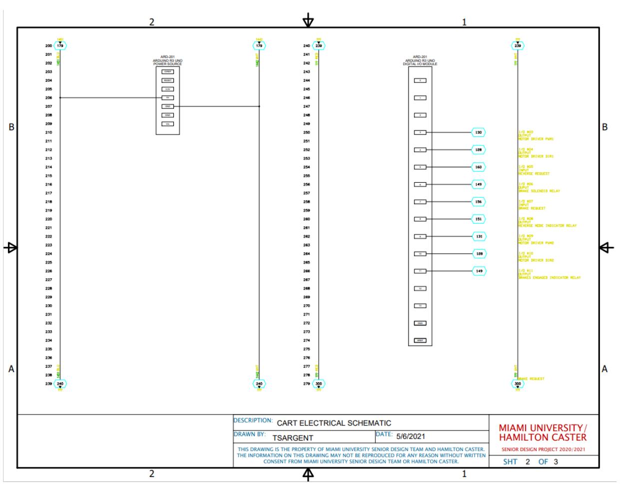
Control Housing Drawings and Electrical Diagrams

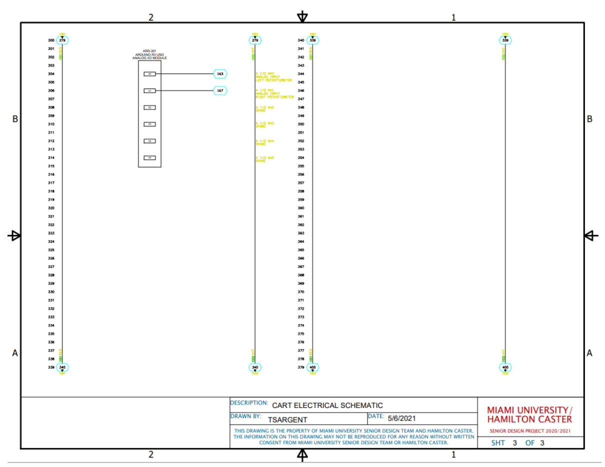




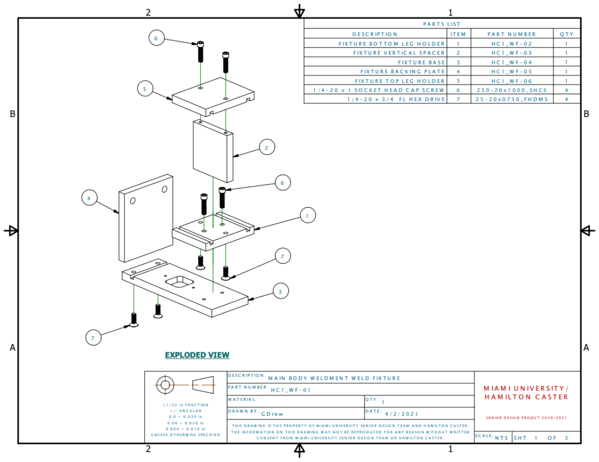


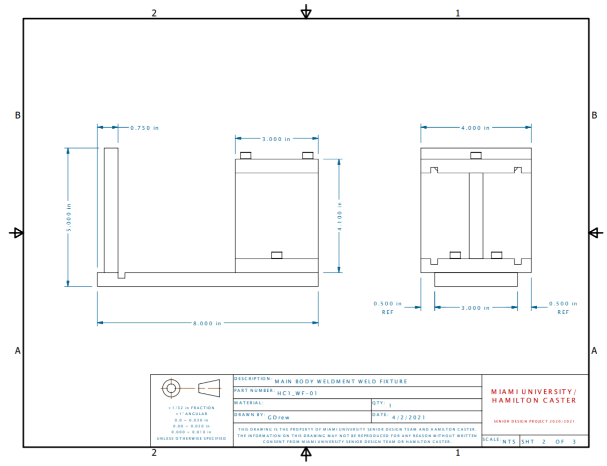


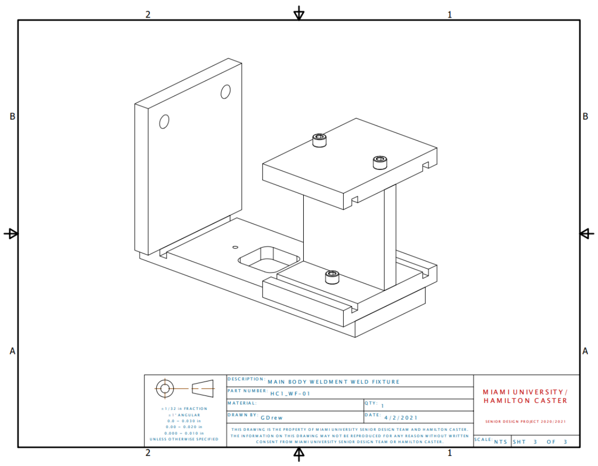


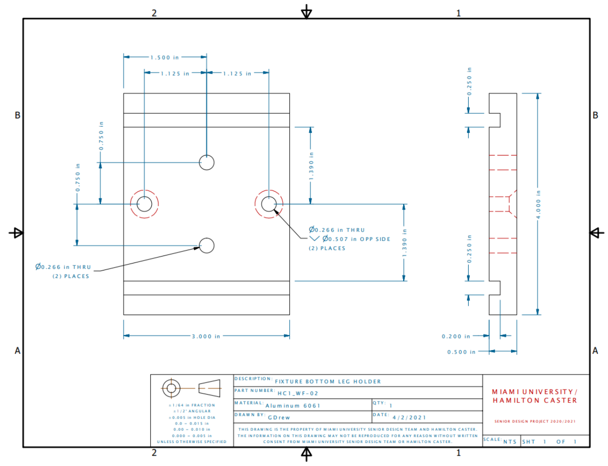


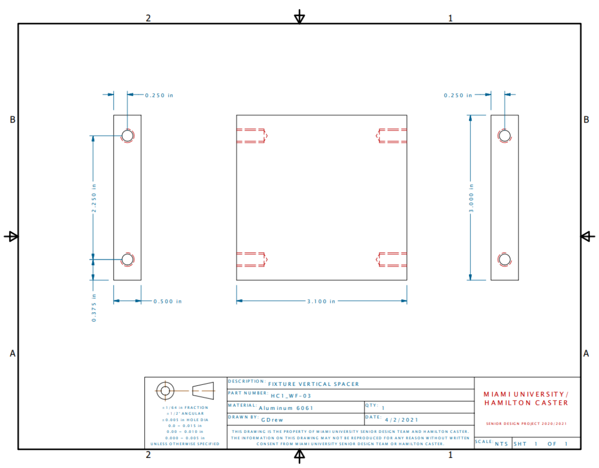
Weld Fixture Drawings

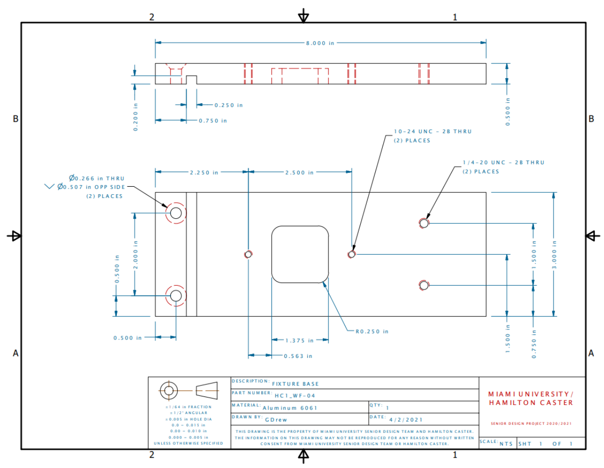


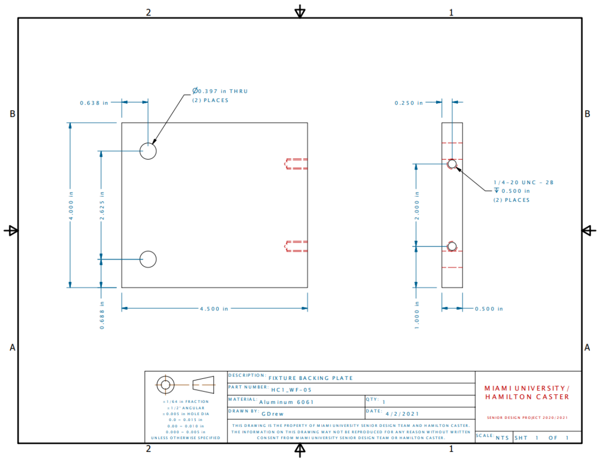


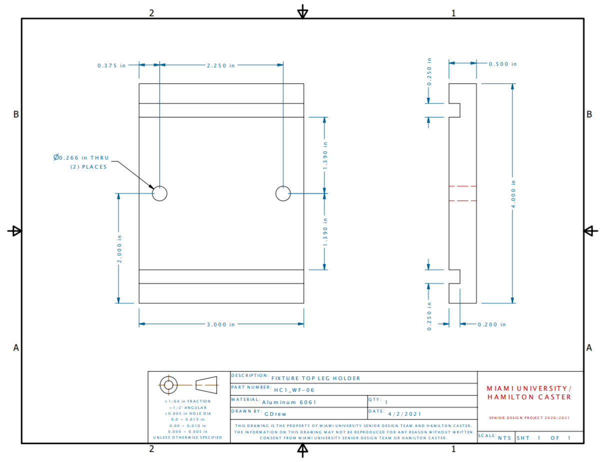


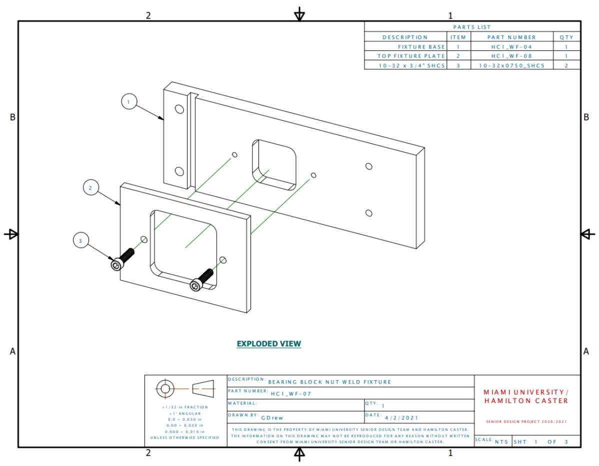


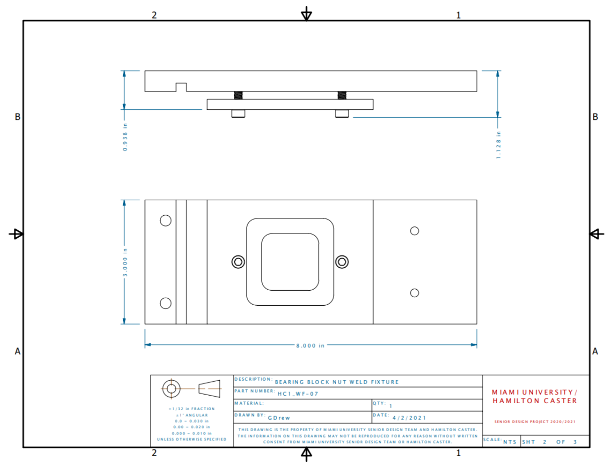


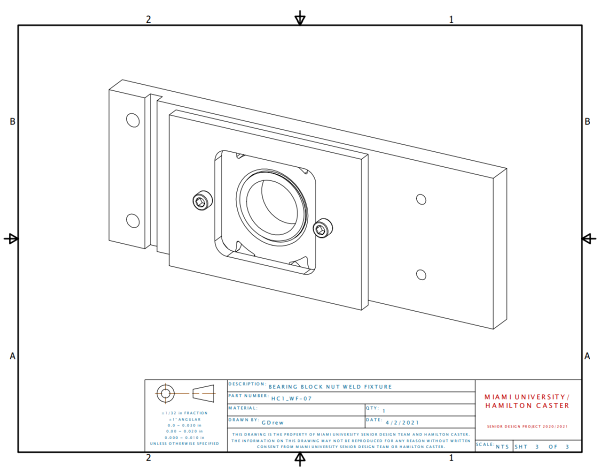


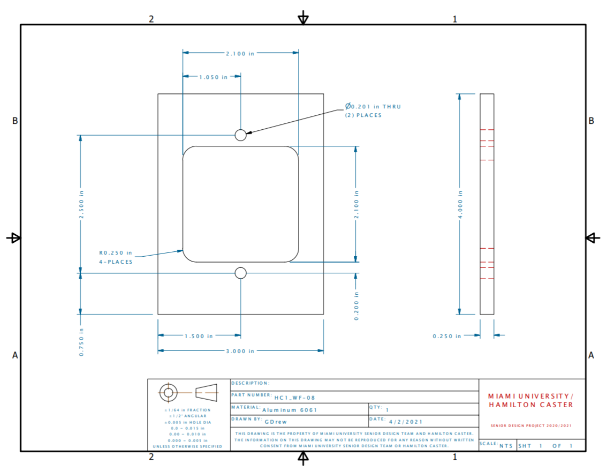

Ø0.397 in THRU
(2) PLACES
0.638 in
4.000 in
2.625 in
0.688 in
4.500 in
0.250 in
1/4-20 UNC - 28
0.500 in
(2) PLACES
2.000 in
1.000 in
0.500 in
DESCRIPTION: FIXTURE BACKING PLATE
PART NUMBER: HC1_WF-05
MATERIAL: Aluminum 6061
QTY: 1
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 1 OF 1


0.375 in
2.250 in
0.500 in
Ø0.266 in THRU
(2) PLACES
1.390 in
4.000 in
2.000 in
3.000 in
0.250 in
0.200 in
DESCRIPTION: FIXTURE TOP LEG HOLDER
PART NUMBER: HC1_WF-06
MATERIAL: Aluminum 6061
QTY: 1
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

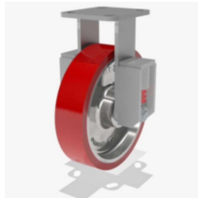

PARTS LIST
DESCRIPTION ITEM PART NUMBER QTY
FIXTURE BASE 1 HC1_WF-04 1
TOP FIXTURE PLATE 2 HC1_WF-08 1
10-32 x 3/4" SHCS 3 10-32x0750_SHCS 2
EXPLODED VIEW
DESCRIPTION: BEARING BLOCK NUT WELD FIXTURE
PART NUMBER: HC1_WF-07
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 1 OF 3


0.938 in
1.128 in
3.000 in
8.000 in
DESCRIPTION: BEARING BLOCK NUT WELD FIXTURE
PART NUMBER: HC1_WF-07
QTY: 1
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 2 OF 3


DESCRIPTION: BEARING BLOCK NUT WELD FIXTURE
PART NUMBER: HC1_WF-07
QTY: 1
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 3 OF 3


2.100 in
1.050 in
Ø0.201 in THRU
(2) PLACES
2.500 in
2.100 in
4.000 in
R0.250 in
4-PLACES
0.200 in
0.750 in
1.500 in
3.000 in
0.250 in
PART NUMBER: HC1_WF-08
MATERIAL: Aluminum 6061
QTY: 1
DRAWN BY: GDrew
DATE: 4/2/2021
MIAMI UNIVERSITY/
HAMILTON CASTER
SCALE: NTS SHT 1 OF 1

Hamilton Caster Drive Wheel Specs



Key Features

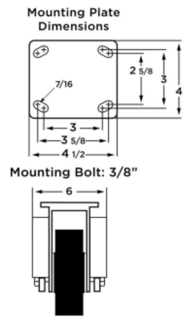
- **Product Finish:** Powder Coated - Caster rigs are powder coated with Hamilton's new Platinum Powder, a metallic HAA Polyester providing a premium look and excellent durability for both interior and exterior environments.
- **Rigid Construction:** 1/4" thick drop forged steel mounting plate; 1/4" x 2" plate steel legs robotically welded inside and outside to forged base.

HAMILTON®

PDF Data Sheet

Model No.
R-SPWH-8TRB-2

Hamilton Spring Loaded Workhorse Rigid Caster with 8" x 2" Ultralast™ Premium Polyurethane (95A) on Cast Iron Wheel with 1/2" Sealed Precision Ball Bearings



Caster Specs

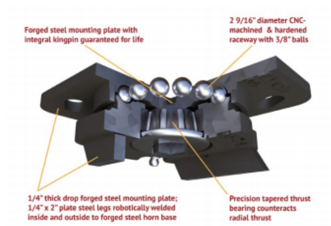
- Load Capacity (lbs.):
- Wheel Diameter: 8
- Wheel Face: 2
- Overall Height: 10.1875
- Bearing Type: Precision Ball
- Caster Rig Type: Weldment
- Wheel Type: Ultralast®
- Replacement Wheel: W-820-TRB-1/2
- Caster Color: Platinum Powder

Wheel Specs

- Type: Ultralast®
- Material: Polyurethane
- Cushioning(Resilience): Medium
- Impact Resistance: Medium
- Moisture Resistance: Medium
- Abrasion Resistance: Medium
- Low Temp. Range (F): -50
- High Temp. Range (F): 200
- Chemical Resistance: Medium

Rear Swivel Wheel Specs

Key Features



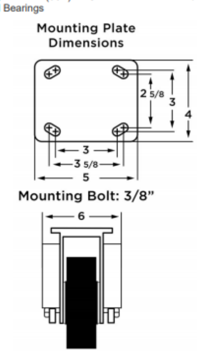
- **Product Finish:** Powder Coated - Caster rigs are powder coated with Hamilton's new Platinum Powder, a metallic HAA Polyester providing a premium look and excellent durability for both interior and exterior environments.
- **Swivel Construction:** 1/4" thick drop forged steel mounting plate; 1/4" x 2" plate steel legs robotically welded inside and outside to forged steel horn base.
- **Kingpin:** Sturdy 3/4" diameter integrally forged with mounting plate, guaranteed for life, and threaded for 3/4" lock nut.
- **Main Load Bearing:** CNC-machined 2 9/16" diameter raceway; 3/8" diameter hardened and polished steel balls.
- **Secondary Load Bearing:** 3/4" precision tapered thrust bearing counteracts radial thrust.
- **Lubrication Fittings:** Ball-check type in swivel assembly and in wheel hubs with tapered or straight roller bearings.

HAMILTON®

PDF Data Sheet

Model No.
S-SPWH-8TRB-2

Hamilton Spring Loaded Workhorse Swivel Caster with 8" x 2" Ultralast™ Premium Polyurethane (95A) on Cast Iron Wheel with 1/2" Sealed Precision Ball Bearings



Caster Specs

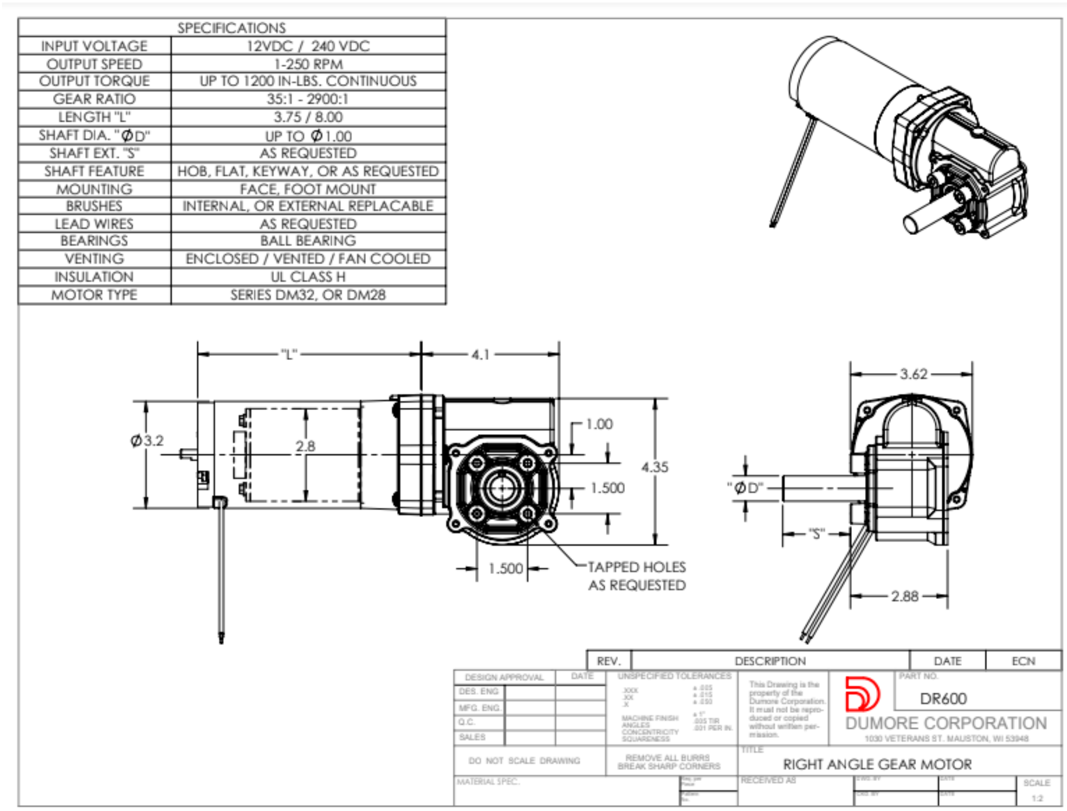
- Load Capacity (lbs.):
- Wheel Diameter: 8
- Wheel Face: 2
- Overall Height: 10.1875
- Bearing Type: Precision Ball
- Caster Rig Type: Integral Forged Kingpin
- Wheel Type: Ultralast®
- Replacement Wheel: W-820-TRB-1/2
- Caster Color: Platinum Powder

Wheel Specs

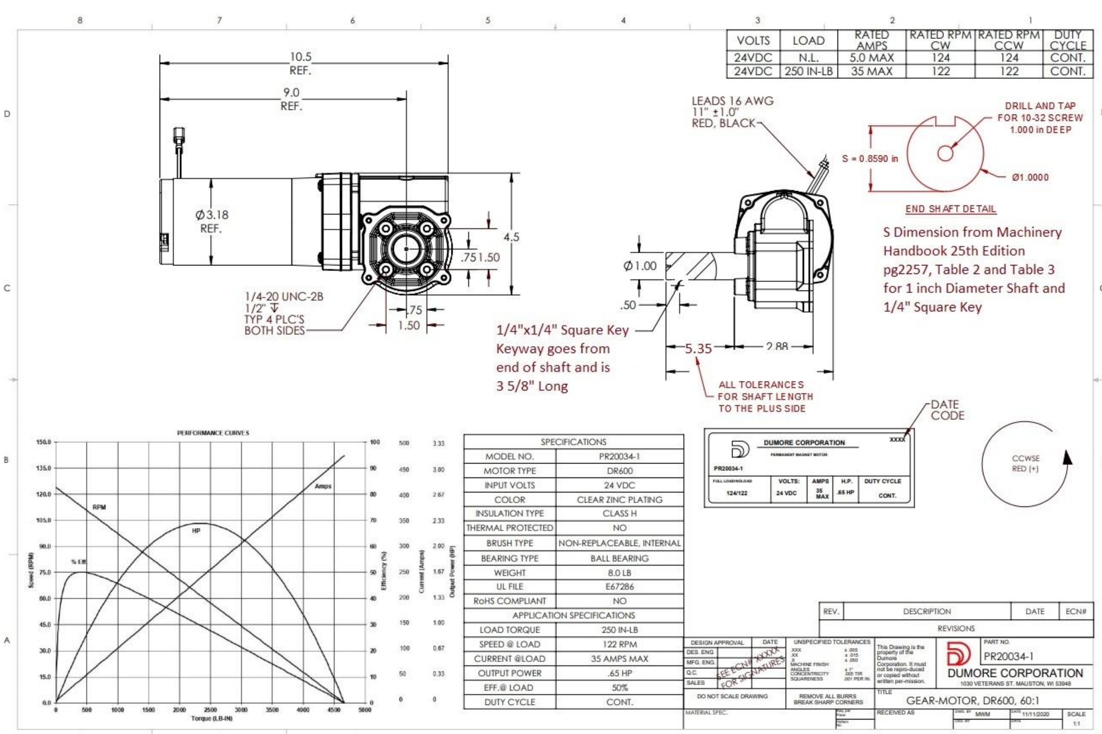
- Type: Ultralast®
- Material: Polyurethane
- Cushioning(Resilience): Medium
- Impact Resistance: Medium
- Moisture Resistance: Medium
- Abrasion Resistance: Medium
- Low Temp. Range (F): -50
- High Temp. Range (F): 200
- Chemical Resistance: Medium

Dumore Motor Drawing/Spec Sheet

SPECIFICATIONS	
INPUT VOLTAGE	12VDC / 240 VDC
OUTPUT SPEED	1-250 RPM
OUTPUT TORQUE	UP TO 1200 IN-LBS. CONTINUOUS
GEAR RATIO	35:1 - 2900:1
LENGTH "L"	3.75 / 8.00
SHAFT DIA. "ØD"	UP TO Ø1.00
SHAFT EXT. "S"	AS REQUESTED
SHAFT FEATURE	HOB, FLAT, KEYWAY, OR AS REQUESTED
MOUNTING	FACE, FOOT MOUNT
BRUSHES	INTERNAL, OR EXTERNAL REPLACABLE
LEAD WIRES	AS REQUESTED
BEARINGS	BALL BEARING
VENTING	ENCLOSED / VENTED / FAN COOLED
INSULATION	UL CLASS H
MOTOR TYPE	SERIES DM32, OR DM28

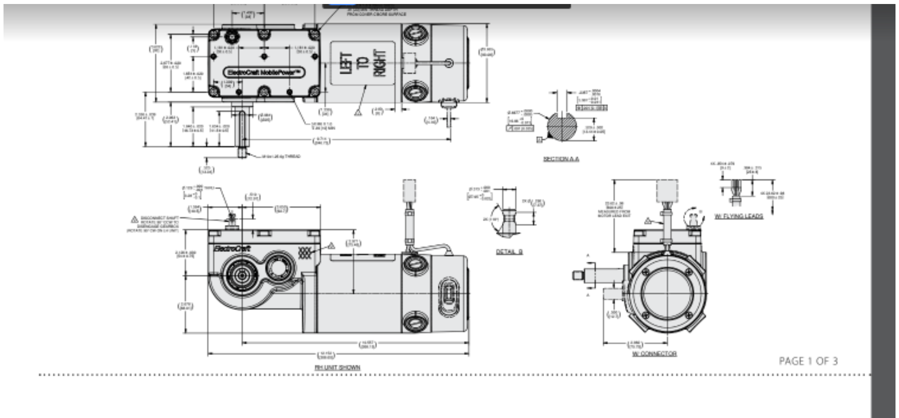


VOLTS	LOAD	RATED AMPS	RATED RPM CW	RATED RPM CCW	DUTY CYCLE
24VDC	N.L.	5.0 MAX	124	124	CONT.
24VDC	250 IN-LB	35 MAX	122	122	CONT.



SPECIFICATIONS	
MODEL NO.	PR20034-1
MOTOR TYPE	DR600
INPUT VOLTS	24 VDC
COLOR	CLEAR ZINC PLATING
INSULATION TYPE	CLASS H
THERMAL PROTECTED	NO
BRUSH TYPE	NON-REPLACEABLE, INTERNAL
BEARING TYPE	BALL BEARING
WEIGHT	8.0 LB
UL FILE	E67286
RoHS COMPLIANT	NO
APPLICATION SPECIFICATIONS	
LOAD TORQUE	250 IN-LB
SPEED @ LOAD	122 RPM
CURRENT @LOAD	35 AMPS MAX
OUTPUT POWER	.65 HP
EFF.@ LOAD	50%
DUTY CYCLE	CONT.

ElectroCraft Motor Drawing/Spec Sheet



MP36 MobilePower™

MP36 ElectroCraft MobilePower™

Geared Motor

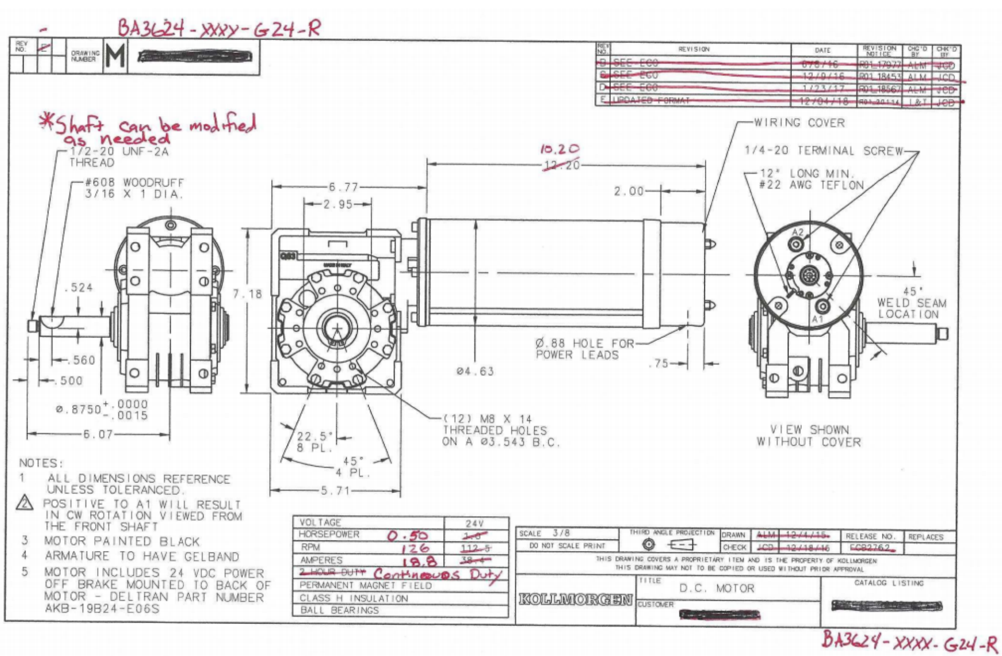
Low Voltage - High Torque

ElectroCraft® powering innovation™

MP36 Motor Parameters

Gear Ratio	32.00:1	29.25:1	26.82:1	24.67:1	21.33:1	19.50:1	17.88:1	16.44:1
Operating Voltage (VDC)	24							
No Load Speed (RPM)	115	126	137	149	173	189	206	224
Peak Torque (Nm)	109.89	100.45	92.11	84.72	73.25	66.97	61.4	56.46
Peak Current (Amps)	80.0							
Peak Power (Watts)	972							
S2 Torque (15 min) (Nm)	31.42	28.72	26.34	24.22	20.94	19.15	17.56	16.14
S2 Current (15 min) (Amps)	25.0							
S2 Power (15 min) (Watts)	355							
S1 Torque (Continuous) (Nm)	10.02	9.16	8.40	7.72	6.68	6.11	5.60	5.15

Kollmorgen Motor Drawing/Spec Sheet



F-Arduino Code

```
/*****************************************************
 * Code for Hamilton Caster Senior Design Project
 *
 * DateCreated: April 7th 2021
 *
 *
 * PURPOSE:
 * This code performs the necessary safety checks and
 * operations for the caster cart to function
 *
 *REVISION NOTES:
 *Revision three introduces dual joystick control as well as general housekeeping
 *in order for the code to be more easily understandable.
 *
 *Added Turn power limiting to 25% throttle when one joystick is at 0 and the other is at some
value greater than 25%
 *
 *Added the option to toggle left stick input only
 *
 *GUIDE TO BASIC OPERATION:
 *1. Disengage the ESTOP. This will power on the motor control unit and the arduino circuit
 *2. To move forward, press and hold the brake button until light turns off then use thumbstick
throttles.
 *3. To move in reverse, the brake must be on. press and hold the brake button until the light
turns on.

*/


//*************Required Libraries*************
 #include "CytronMotorDriver.h"

//*************Define I/O*************
//Digital I/O
const int spare0 = 0;       //RESERVED serial comms
const int spare1 = 1;       //RESERVED serial comms
const int spare2 = 2;
const int PWM1 = 3;         //Motor Driver PWM 1 Input
const int DIR1 = 4;        //Motor Driver DIR 1 Input
const int revReqPin = 5;         //Input pin that reads if the reverse button is pressed.
const int brakeRelayPin = 6;      //Output pin for signal to coil on brake relay.
const int brakeReqPin = 7;        //Input pin that reads if the brake button is pressed.
```

```
  const int spare8 = 8;
  const int  PWM2 = 9;             //Motor Driver PWM 2 Input
  const int  DIR2 = 10;            //Motor Driver DIR 2 Input
  const int brakeLightPin = 11;     //Output pin for light when brake is engaged
  const int reverseLightPin = 12;   //Output pin for light when reverse mode is active
  const int spare13 = 13;

  //Analog I/O
  const int joystick0Pin = A0;        //Joystick for left Motor as viewed from the pushing position
  const int joystick1Pin = A1;        //Joystick for right motor as viewed from the pushing position
  const int spareA2 = 2;
  const int spareA3 = 3;
  const int spareA4 = 4;
  const int spareA5 = 5;


  /*************Functional Parameter Variables********
   * These are variables that can be configured by the user
  */
  const bool debugMode = false;          //Boolean that enables various values to print when
connected to serial monitor. WILL SLOW DOWN SCRIPT SPEED!
  const int delayTime = 0;              //sets the delay in milliseconds at the end of each iteration of
the main loop.
  const int brakeTimer = 1000;          //Defines how long the brake request button must be
pressed before action occurs
  const int reverseTimer = 1000;         //Defines how long the reverse request button must be
pressed before action occurs
  const int setRampDuration = 1750;      //Defines the duration for which the ramp down to a
value other than zero will occur.
  const int rampToZeroDuration = 1000;   //Defines the duration for which the ramp to zero
occurs.
  const bool leftStickOnly = false;      //False will allow input from both thumbstick inputs, True will
allow only the left thumbstick to control both inputs.
  const bool rightStickOnly = false;

    //RUN THE CALIBRATION CODE WITH SERIAL MONITOR ON TO DETERMINE THE
CORRECT MINs AND MAXs
  const float scaled_min[2] = {0,0};     //Defines the minimum value sent to motor controller 0 is
0% throttle.
  const float scaled_max[2] = {255,238};   //Defines the maximum value sent to motor controller
255 is 100% throttle.

  const float pot0_min = 740;     //Defines the minimum Value on potentiometer reading
  const float pot0_max = 265;    //Defines the maximum Value on potentiometer reading
```

```
  const float pot1_min = 253;     //Defines the minimum Value on potentiometer reading
  const float pot1_max = 750;      //Defines the maximum Value on potentiometer reading


  //*************Define Variables*************

  int brakeReq = 0;                       //1 when brake toggle has been requested.
  bool brakeRequestLatch = false;           //True when a brake request is in progress
  unsigned long brakeReqStartTime = 0;    //Time at which the brake request began.
  bool brakeRelay = false;               // false = BRAKE RELAY OFF, true = BRAKE RELAY ON

  int reverseReq = 0;                    //1 when brake toggle has been requested.
  bool reverseRequestLatch = false;       //True when a reverse request is in progress
  unsigned long reverseReqStartTime = 0;  //
  bool reverseMode = false;              //True when cart is in reverse. used for turning on reverse
button light

  //For these arrays, 0th element is for motor0 and 1st element is for motor 1
  int scaledValue[2] = {0,0};                //Array for analog input scaled values that are to be sent to
the motor controller function. 0 for motor0, 1 for motor1
  float rampStart[2] = {0,0};               //This is the value of the scaledValue1 at the time the initial
analog input is read and converted.
  float rampEnd[2] = {0,0};                 //This is the value of the scaledValue1 at the time it is
written to the motor controller.
  float newValue[2] = {0,0};                //set to equal scaledValue as it gets read from analog input
and is condition to usable scale
  float oldValue[2] = {0,0};               //set equal to scaledValue just as it is sent to the motor
controller after all calculations are performed.
  bool rampReqLatch[2] = {false,false};       //True when ramp is requested, false when not in
ramp
  bool rampComplete[2] = {false,false};       //True when ramp is completed, false when not
completed
  unsigned long rampReqStartTime[2] = {0,0};  //The time at which the millis() timer was started
  unsigned long deltaTime[2] = {0,0};         //Time passed since the timer was started
  int rampDuration[2] = {0,0};              //Duration for which the ramp will occur over

  // Configure the motor driver.
  CytronMD motor0(PWM_DIR, PWM1, DIR1);  // LEFT MOTOR: PWM 1 = Pin 3, DIR 1 = Pin 4.
  CytronMD motor1(PWM_DIR, PWM2, DIR2); // RIGHT MOTOR: PWM 2 = Pin 9, DIR 2 = Pin
10.


void setup() {
```

```
  //Setup I/O
  pinMode(reverseLightPin,OUTPUT);
  pinMode(revReqPin,INPUT);
  pinMode(brakeRelayPin,OUTPUT);
  pinMode(brakeLightPin,OUTPUT);
  pinMode(brakeReqPin,INPUT);
  pinMode(joystick0Pin,INPUT);
  pinMode(joystick1Pin,INPUT);

  Serial.begin(9600);
  Serial.println();
  if(debugMode == true){
    Serial.println("Program Begin...");
  }

}

void loop() {

  if(debugMode == true){
    Serial.println("XXXXXXXXXXXXXXXXXXVoid Loop StartXXXXXXXXXXXXXXXXXX");
  }

  readInputs();

  //*************REVERSE MODE CODE*******************
  //IF reverse toggle request is pressed and timer has not started, start timing.
  if(reverseReq == HIGH && reverseRequestLatch == false && brakeRelay == false) {
    reverseReqStartTime = millis();
    reverseRequestLatch = true;
    if(debugMode == true){
      Serial.println("Reverse Toggle Requested");
    }
  }
  //IF reverse toggle has been released before reverseTimer is done, reset timer.
  else if(reverseReq == LOW && reverseRequestLatch == true) {
    reverseReqStartTime = 0;
    reverseRequestLatch = false;
    if(debugMode == true){
      Serial.println("Reverse Toggle Request Denied");
    }
  }
  //IF brake toggle is pressed and timer has started, check timer is done.
  else if (reverseReq == HIGH && reverseRequestLatch == true){
```

```
    //IF current time minus timer start is greater than reverseTimer, toggle reverse mode bool and
reset timer
    if(millis() - reverseReqStartTime >= reverseTimer){
      reverseMode = toggleBool(reverseMode);
      reverseRequestLatch = false;
      if(debugMode == true){
        Serial.println("Reverse Mode Toggled, Request Completed");
      }
    }
  }
  //*************END OF REVERSE MODE CODE*******************


  //*************BRAKE RELAY CODE*******************
  //IF brake toggle request is pressed and timer has not started, start timing.
  if(brakeReq == HIGH && brakeRequestLatch == false) {
    brakeReqStartTime = millis();
    brakeRequestLatch = true;
    if(debugMode == true){
      Serial.println("Brake Toggle Requested");
    }
  }
  //IF brake toggle has been released before brakeTimer is done, reset timer.
  else if(brakeReq == LOW && brakeRequestLatch == true) {
    brakeReqStartTime = 0;
    brakeRequestLatch = false;
    if(debugMode == true){
      Serial.println("Brake Toggle Request Denied");
    }
  }
  //IF brake toogle is pressed and timer has started, check timer is done.
  else if (brakeReq == HIGH && brakeRequestLatch == true){
    //IF current time minus timer start is greater than brakeTimer, toggle break relay and reset
timer
    if(millis() - brakeReqStartTime >= brakeTimer){
      brakeRelay = toggleBool(brakeRelay);
      brakeRequestLatch = false;
      if(debugMode == true){
        Serial.println("Brake Toggled, Request Completed");
      }
    }
  }
  //*************END OF BRAKE RELAY CODE*******************
```

```
  rampDown(0);
  rampDown(1);

  writeOutputs();

  delay(delayTime);
}


//********** DEFINE FUNCTIONS HERE **********


//This function Writes all Outputs
void writeOutputs(){

  //Set oldValues equal to the post operation scaledValues
  oldValue[0] = scaledValue[0];
  oldValue[1] = scaledValue[1];

  if(brakeRelay == false){
    //Brakes Engaged because Relay is OFF
    digitalWrite(brakeRelayPin,LOW);
    digitalWrite(brakeLightPin,HIGH);

    //Write the scaledValues to the motors if the brakes are off meaning that the breakRealy is
true
    scaledValue[0] = 0;
    scaledValue[1] = 0;
  }
  else if(brakeRelay == true){
    //Brakes Disnegaged becasue Relay is ON
    digitalWrite(brakeRelayPin,HIGH);
    digitalWrite(brakeLightPin,LOW);
  }

  //IF reverseMode is false, reverseMode is OFF
  if(reverseMode == false){
    digitalWrite(reverseLightPin,LOW);
  }
  //IF reverseMode is true, reverseMode is ON
  else if(reverseMode == true){
    scaledValue[0] = -1 * scaledValue[0];
    scaledValue[1] = -1 * scaledValue[1];
```

```
    digitalWrite(reverseLightPin,HIGH);
  }

    motor0.setSpeed(scaledValue[0]);
  motor1.setSpeed(scaledValue[1]);

  //Print serial monitor messages if debugMode has been enabled.
  if(debugMode == true){

    Serial.print("brakeRelay: ");
    Serial.println(brakeRelay);

    Serial.print("reverseMode");
    Serial.println(reverseMode);

    Serial.println("**Values to Motor Controller**");
    Serial.print("Left Motor: ");
    Serial.println(scaledValue[0]);
    Serial.print("Right Motor: ");
    Serial.println(scaledValue[1]);
    Serial.println("******************************");

  }
}

//This function Reads all Inputs
void readInputs(){

  brakeReq = digitalRead(brakeReqPin);
  reverseReq = digitalRead(revReqPin);

  float sensorValue0 = analogRead(joystick0Pin);
  float sensorValue1 = analogRead(joystick1Pin);

  float tempValue0 = 0;
  float tempValue1 = 0;

  //Use linear scaling to map analog inuputs to digital output
  if(leftStickOnly == true){
    //Use only the input from the left thumbstick
    tempValue0 = (((scaled_max[0] - scaled_min[0])/(pot0_max - pot0_min))*(sensorValue0 -
pot0_min)) + scaled_min[0];
    tempValue1 = (((scaled_max[1] - scaled_min[1])/(pot0_max - pot0_min))*(sensorValue0 -
pot0_min)) + scaled_min[1];
```

```
  }
  else if(rightStickOnly == true){
    //Use only the input from the left thumbstick
    tempValue0 = (((scaled_max[0] - scaled_min[0])/(pot1_max - pot1_min))*(sensorValue1 -
pot1_min)) + scaled_min[0];
    tempValue1 = (((scaled_max[1] - scaled_min[1])/(pot1_max - pot1_min))*(sensorValue1 -
pot1_min)) + scaled_min[1];
  }
  else{
    //Use the input from each respective thumbstick
    tempValue0 = (((scaled_max[0] - scaled_min[0])/(pot0_max - pot0_min))*(sensorValue0 -
pot0_min)) + scaled_min[0];
    tempValue1 = (((scaled_max[1] - scaled_min[1])/(pot1_max - pot1_min))*(sensorValue1 -
pot1_min)) + scaled_min[1];
  }

  //Type cast the tempValues to integers for use with Motor Controller function
  scaledValue[0] = (int) tempValue0;
  scaledValue[1] = (int) tempValue1;

  //Make sure that we are getting positive values within output scale range because negative is
reverse and that could be bad if not anticipated.
  if(scaledValue[0] < 0){
    scaledValue[0] = 0;
  }
  if(scaledValue[0] > 255){
    scaledValue[0] = 255;
  }

  if(scaledValue[1] < 0){
    scaledValue[1] = 0;
  }
  if(scaledValue[1] > 255){
    scaledValue[1] = 255;
  }

  //Makes the maximum percent input 40% throttle if only one thumbstick is being pressed.
  //This allows the user to use the full range of input mechanical motion while limiting the actual
output or manipulating the ramping
  //This is intended to reduce the jerking of the cart when trying to turn.
  if((float) scaledValue[0] <= 10 && (float) scaledValue[1] >= 102){
    scaledValue[1] = 102;
  }
  if((float) scaledValue[1] <= 10 && (float) scaledValue[0] >= 102){
```

```
    scaledValue[0] = 102;
  }

  //Set the most recent scaled analog read to new current value
  newValue[0] = scaledValue[0];
  newValue[1] = scaledValue[1];

  if(debugMode == true){
    Serial.println("**Values from Input**");
    Serial.print("scaledValue[0]: ");
    Serial.println(scaledValue[0]);
    Serial.print("scaledValue[1]: ");
    Serial.println(scaledValue[1]);
    Serial.println("********************");
  }
}

//This function takes in one boolean type and flips it opposite of its current value. I.E. in true , out false.
int toggleBool(bool x){
  if(x == true){
    x = false;
  }
  else if(x == false){
    x = true;
  }
  return x;
}




/*this function handles the ramping down of a given motor
 * You must specify one parameter, 0 or 1 for either motor0 or motor1 respectively.
*/
void rampDown(const int x){

  if(debugMode == true){
  Serial.print("****Ramp for motor*****");
  Serial.println(x);
  Serial.print("newValue: ");
  Serial.println(newValue[x]);
  Serial.print("oldValue: ");
  Serial.println(oldValue[x]);
```

```
 }

 if(rampReqLatch[x] == false && newValue[x] < oldValue[x]){

   rampReqLatch[x] = true;
   rampReqStartTime[x] = millis();        //time ramp starts
   rampEnd[x] = newValue[x];
   rampStart[x] = oldValue[x];
   rampDuration[x] = setRampDuration;

   if(debugMode == true){
     Serial.print("Ramp Requested Target Ramp To: ");
     Serial.println(rampEnd[x]);
   }

 }
 else if(rampReqLatch[x] == true && newValue[x] > oldValue[x]){

   //this should end any ramp and prevent ramping if the user input wants to accelerate while a
ramp down is in progress
   rampReqLatch[x] = false;

   if(debugMode == true){
     Serial.println("Ramp Canceled");
   }

 }
 else if(rampReqLatch[x] == true){

     //If the current input is lower than the rampEnd, then reset the ramp target to new low value
starting from previous value
   if(newValue[x] < rampEnd[x]){

     rampEnd[x] = newValue[x];
     //rampStart = oldValue;
     //rampTime = millis();

     if(debugMode == true){
       Serial.print("Ramp Target Adjusted to: ");
       Serial.println(rampEnd[x]);
     }

   }
```

```
    if(rampEnd[x] == 0){
      rampDuration[x] = rampToZeroDuration;
    }

    deltaTime[x] = (millis() - rampReqStartTime[x]);

    if(deltaTime[x] <= rampDuration[x]){

      scaledValue[x] = (int) (((((rampEnd[x]) - rampStart[x]) / rampDuration[x])* deltaTime[x]) +
rampStart[x]);

      if(debugMode == true){
        Serial.println("**Values From Ramp**");
        Serial.print("scaledValue: ");
        Serial.println(scaledValue[x]);
        Serial.print("deltaTime: ");
        Serial.println(deltaTime[x]);
        Serial.println("*******************");
      }

      //If ramp is completed exit ramp
      if(scaledValue[x] <= rampEnd[x]){
        rampComplete[x] = true;
      }
    }

    if(rampComplete[x] == true){

      rampReqLatch[x] = false;
      rampComplete[x] = false;

      if(debugMode == true){
        Serial.println("Ramp Complete");
      }
    }
  }
}
```

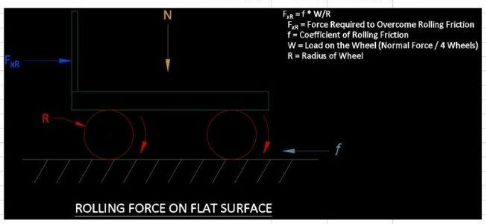
G-Calculations

Gearmotor Specifications Calculated for Given Criteria

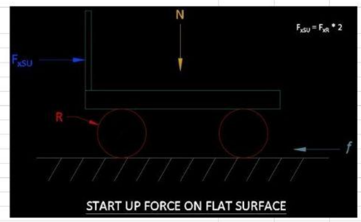
Force and Torque Calculations for Powered Cart Gearmotors		
Calculate Total Weight of Powered Cart		
Known Information		
Weight to Transport (Load) =	4000.00	Pounds (lb)
Weight of Cart (from Inventor software: Cart Body, Two Swivel Casters, Handle) =	213.55	Pounds (lb)
Weight of Swivel Caster S-SPWH-8TRB-2 (per Caster) =	18.00	Pounds (lb)
Weight of Drive Caster (per Caster) =	24.00	Pounds (lb)
Radius of Wheel (R) =	4.000	Inches (in)
Coefficient of Rolling Friction (f) =	0.057	Wheel Radius
Number of Swivel Casters =	2.000	
Number of Rigid Casters =	2.000	
Number of Gearmotors =	2.000	
Maximum Speed =	3.000	mph
Angle of Incline (θ) =	3.000	Degrees (°)
Assumed Information		
Weight of Battery/Battery Pack =	464.00	Pounds (lb)
Weight of Electric Gearmotor (per Gearmotor) =	8.00	Pounds (lb)
Weight of Electrical Components, Brakes, Control Panel, Hardware, etc. =	35.00	Pounds (lb)
Total Weight of Powered Cart =	4812.55	Pounds (lb)
Total Weight of Powered Cart Rounded for Calculations (W_{TC}) =	4800	Pounds (lb)

Calculate Force to Overcome Rolling Friction and Start Up of Cart on Flat Surface

Calculate Rolling Force for Flat Surface			
Load on the Wheel (W) =	1200.000	Pounds (lb)	$W = W_{TC} / 4$
Force Required to Overcome the Rolling Friction per Caster (F) =	17.100	Pounds (lb)	$F = f \times W / R$
Total Force Required to Overcome the Rolling Friction of all Four Casters (F_{xR}) =	68.400	Pounds (lb)	$F_{xR} = F \times 4$



Calculate Start Up Force for Flat Surface			
Total Force Required to Overcome the Start Up Friction of all Four Casters (F_{xSU}) =	136.800	Pounds (lb)	$F_{xSU} = F_{xR} \times 2$

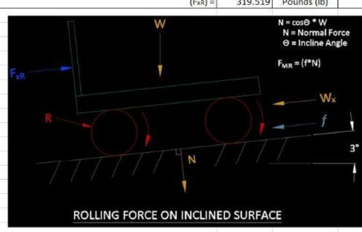


Calculate Torque for each Gearmotor for Rolling Friction on Flat Surface			
Total Force Required for each Motor (F_{MfsR}) =	34.200	Pounds (lb)	$F_{MfsR} = F_{xR} / 2$
Gearmotor Torque (T_{MfsR}) =	136.800	lb in	$T_{MfsR} = F_{MfsR} \times R$
Total Gearmotor Torque using a Design Factor of 2			
Total Gearmotor Torque for Start Up on Flat Surface (T_{MTfsR}) =	273.600	lb in	$T_{MTfsR} = T_{MfsR} \times 2$
Total Torque of Gearmotor Rounded to Whole Number (T_{MTfsR}) =	274	lb in	

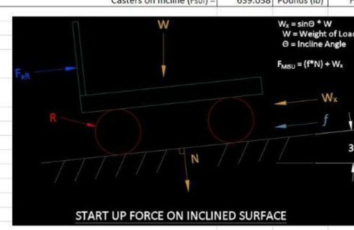
Calculate Torque for each Gearmotor for Start Up on Flat Surface ($T_{MfsSU} = F_{MfsSU} \times R$)			
Total Force Required for each Motor (F_{MfsSU}) =	68.400	Pounds (lb)	$F_{MfsSU} = F_{xSU} / 2$
Gearmotor Torque (T_{MfsSU}) =	273.600	lb in	$T_{MfsSU} = F_{MfsSU} \times R$
Total Gearmotor Torque using a Design Factor of 2			
Total Gearmotor Torque for Start Up on Flat Surface (T_{MTfsSU}) =	547.200	lb in	$T_{MTfsSU} = T_{MfsSU} \times 2$
Total Torque of Gearmotor Rounded to Whole Number (T_{MTfsSU}) =	547	lb in	

Calculate Force to Overcome Rolling Friction and Start Up of Cart on Inclined Surface

Calculate Rolling Force for Inclined Surface			
Normal Force (N)=	4793.422	Pounds (lb)	$N = \cos\theta * W_{TC}$
Force of Cart in X Direction of Inclined Surface (W_x)=	251.213	Pounds (lb)	$W_x = \sin\theta * W_{TC}$
Weight on Each Wheel (W_w)=	1198.355	Pounds (lb)	$W_w = N / 4$
Force Required to Overcome the Rolling Friction per Caster (F) =	17.077	Pounds (lb)	$F = f \times W_w / R$
Total Force Required to Overcome the Rolling Friction of all Four Casters (F_x) =	68.306	Pounds (lb)	$F_x = F \times 4$
Total Force Required to Overcome the Rolling Friction on Incline (F_{xR}) =	319.519	Pounds (lb)	$F_{xR} = F_x + W_x$



Calculate Start Up Rolling Force for Inclined Surface			
Total Force Required to Overcome the Start Up Friction of all Four Casters on Incline (F_{SUI}) =	639.038	Pounds (lb)	$F_{xSUI} = F_{xR} \times 2$



Calculate Torque for each Gearmotor for Continuous Motion of Cart			
Total Force Required for each Motor (F_{MIR}) =	159.759	Pounds (lb)	$F_{MIR} = F_{xR} / 2$
Gearmotor Torque (T_{MIR}) =	639.038	lb in	$T_{MIR} = F_{MIR} \times R$
Total Gearmotor Torque using a Design Factor of 2			
Total Continuous Gearmotor Torque (T_{MTIR}) =	1278.075	lb in	$T_{MTIR} = T_{MIR} \times 2$
Total Torque of Gearmotor Rounded to Whole Number (T_{MTIR}) =	1278	lb in	

Calculate Torque for each Gearmotor for Start Up Motion of Cart			
Total Force Required for each Motor (F_{MISU}) =	319.519	Pounds (lb)	$F_{MISU} = F_{xSUI} / 2$
Gearmotor Torque (T_{MISU}) =	1278.075	lb in	$T_{MISU} = F_{MISU} \times R$
Total Gearmotor Torque using a Design Factor of 2			
Total Start Up Gearmotor Torque for Inclined Surface (T_{MTISU}) =	2556.151	lb in	$T_{MTISU} = T_{MISU} \times 2$
Total Torque of Gearmotor Rounded to Whole Number (T_{MTISU}) =	2557	lb in	

Specifications for Gearmotors for Powered Cart - Flat Surface		
Torque for Continuous Motion (T_{MTC}) =	274	lb in
Peak Torque for Start-Up (T_{MTsu}) =	547	lb in
RPM of Motor @ 3 mph =	126	rpm

Specifications for Gearmotors for Powered Cart - Inclined Surface		
Torque for Continuous Motion (T_{MTC}) =	1278	lb in
Peak Torque for Start-Up (T_{MTsu}) =	2557	lb in
RPM of Motor @ 3 mph =	126	rpm

Specifications for Gearmotors for Powered Cart		
Torque for Continuous Motion (T_{MTC}) =	1278	lb in
Peak Torque for Start-Up (T_{MTsu}) =	2557	lb in
RPM of Motor @ 3 mph =	126	rpm

Calculate Required Horsepower for each Gearmotor			
Power Required to Move Cart Continuously on 3° Incline	2.6	HP	$P_{hp} = T_{lb\,in} \times n / 63025$
Power Required for Start Up Motion of Cart on 3° Incline	5.1	HP	$P_{hp} = T_{lb\,in} \times n / 63025$

These horsepower values are an estimate and would need to be verified by motor vendor

Calculations for Drive Caster Key

Key Length for Gearmotor/Caster Shaft

Key Size		
Height =	0.250	in
Width =	0.250	in
Gearmotor Information		
Shaft Diameer (Θ) =	1.000	in
Max Torque (T) =	2557	lb in

Key Material Type

Cold Rolled C1018				Cold Rolled C1045			
Tensile Strength (s_u) =	64000	psi		Tensile Strength (s_u) =	82000	psi	
Yield Strength (s_y) =	54000	psi		Yield Strength (s_y) =	45000	psi	
Ultimate Strength in Shear (s_{us}) =	48000	psi	$s_{us} = 0.75*s_u$	Ultimate Strength in Shear (s_{us}) =	61500	psi	$s_{us} = 0.75*s_u$
Yield Strength in Shear (s_{ys}) =	27000	psi	$s_{ys} = 0.5*s_y$	Yield Strength in Shear (s_{ys}) =	22500	psi	$s_{ys} = 0.5*s_y$
Design Factor (N) =	3						
Design Stress in Shear (τ_d) =	9000.00	psi	$\tau_d = s_{ys}/N$	Design Stress in Shear (τ_d) =	7500.00	psi	$\tau_d = s_{ys}/N$
Minimum Required Key Length in Shear (L_{min}) =	2.273	in	$L_{min} = (2*T)/(\tau_d*D*W)$	Minimum Required Key Length in Shear (L_{min}) =	2.727	in	$L_{min} = (2*T)/(\tau_d*D*W)$
Design Stress in Compression (σ_d) =	18000.00	psi	$\sigma_d = s_y/N$	Design Stress in Compression (σ_d) =	15000.00	psi	$\sigma_d = s_y/N$
Minimum Required Key Length in Cimpression (L_{min}) =	2.273	in	$L_{min} = (4*T)/(\sigma_d*D*H)$	Minimum Required Key Length in Compression (L_{min}) =	2.727	in	$L_{min} = (4*T)/(\sigma_d*D*H)$

Caster Wheel Material			Gearmotor Shaft Material		
Class 30 Gray Iron					
Tensile Strength (s_u) =	31000	psi	Tensile Strength (s_u) =	108000	psi
Yield Strength (s_y) =		psi	Yield Strength (s_y) =	89900	psi

**Key material is not the weakest material.
**Use Equation 11-4 if hub or shaft have a lower yield strength than the key for bearing stress.

**Caster wheel material is the weekest material. Equation below should be used with caster wheel material properties used. Used N=2 for this equation.

Design Stress in Compression (σ_d) =	15500.00	psi	$\sigma_d = s_y/N$
Minimum Required Key Length in Cimpression (L_{min}) =	2.639	in	$L_{min} = (4*T)/(\sigma_d*D*H)$

Material Specifications used for Calculations

Steel	Tensile Strength (Ultimate)	Tensile Strength (Yield)	Modulus of Elasticity	Poissons Ratio	Shear Modulus	
ASTM A36	58,000 psi	36,300 psi	29,000 ksi	0.26	11,500 ksi	https://www.azom.com/article.aspx?ArticleId=6117
C1018 (AISI 1018)	63,800 psi	53,700 psi	29,700 ksi	0.29	11,600 ksi	https://www.azom.com/article.aspx?ArticleID=6115
AST A311 (AISI 1144)	108,000 psi	89,900 psi	27,557-30,458 ksi	0.27-0.30	11,600 ksi	https://www.azom.com/article.aspx?ArticleID=6595

Hardware	Tensile Strength	Hardness
1/4-20 x 3/4" Hex Drive Flat Head Screw	120,000 psi	Rockwell C32
1/4-20 x 3/4" Hex Head Screw (Grade 5)	120,000 psi	Rockwell C25
10-32 x 1" Socket Head Cap Screw	170,000 psi	Rockwell C37

H-Operation Guide

Forward Operation

1. Pull out the emergency stop button to power the cart.
2. Press and hold the right push button with the red LED until you hear a click. The red light will now turn off and the brakes will disengage.
3. Use thumb paddles to operate the cart.

Reverse Operation

1. Bring the cart to a complete stop
2. Press and hold the right push button with the red LED until you hear a click. The red light will now turn on and the brakes will engage.
3. Press and hold the left push button until the blue LED illuminates. This indicates the cart is reverse drive mode.
4. Press and hold the right push button with the red LED until you hear a click. The red light will now turn off and the brakes will disengage.
5. Use thumb paddles to operate the cart.
6. To switch back to forward operation, repeat steps 1 thru 5.

J-Certification of Powered Cart Operation with 4,000 lb Load

DESHAZO
CRANES / SERVICE / AUTOMATION

LOAD TEST CERTIFICATION

CUSTOMER: Miami University
CUSTOMER CONTACT: Senior Design Team
WORK ORDER #: Hamilton Caster Project

BRIDGE

MANUFACTURER: Hamilton Caster - Motorized Cart Prototype
MODEL #: NA
SERIAL #: NA
CAPACITY: 4000 LBS

HOIST

MANUFACTURER:
MODEL #:
SERIAL #:
CAPACITY:

TROLLEY

MANUFACTURER:
MODEL #:
SERIAL #:
CAPACITY:

The above listed crane has satisfactorily performed the indicated load test. Yes

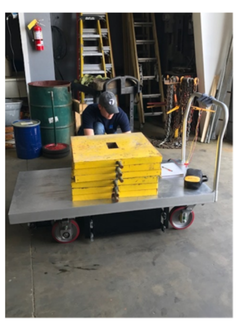
TEST WEIGHT: 100% *NOT TO EXCEED 125% OF RATED CAPACITY.

4000 LBS

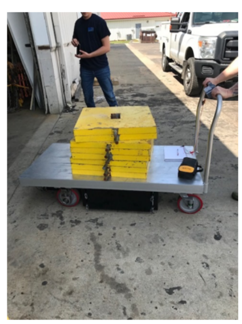
DeShazo Technician: **Date** 04/07/2021

Customer Witness: Drew & Purdy **Date** 04/07/2021

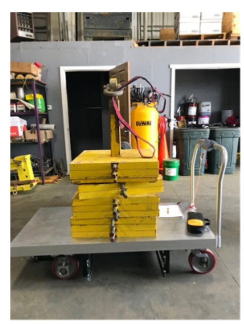
1st pick (3) 360 lb plates
1080 lbs total.



2nd pick (6) 360 lb plates
2160 lbs total.



3rd pick (8) 360 lb plates
2880 lbs total.



4th pick (10) 360 lb plates
& 400 lb stand = 4000 lbs total

Miami University
Senior Design Team
Hamilton Caster Project